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ROSS VALLEY FIRE DEPARTMENT
LABOR-MANAGEMENT SUBCOMMITTEE
Thursday, October 5, 2023
San Anselmo Town Council Chambers, at 525 San Anselmo Ave. San Anselmo, CA 94960, and via Zoom.

https://us06web.zoom.us/j/86005899261
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For callers *9 to raise your hand *6 to mute/unmute

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8:00 am RVFD Labor-Management Subcommittee Meeting

1. **Call to order – 8:00 am**.

2. Introduction of Members

3. Consent Agenda: Items on the consent agenda may be removed and discussed separately. Discussion may take place at the end of the agenda. Otherwise, all items may be approved with one action.

   a) Approve Minutes of the April 20, 2022, Labor-Management Subcommittee Meeting

   Item 3a – Minutes April 20, 2022

4. Staff Recommends the Labor-Management Subcommittee Appoints One Committee Member to Serve as the Subcommittee Co-Chair. – Interim Fire Chief Mahoney

Item 4 – Staff Report for Appointment of Co-Chair to Labor-Management Subcommittee
Item 4 – 2022 Side Letter Staffing/Deployment - Attachment #1

5. Review Purpose of the Subcommittee and Establish Subcommittee's Objectives – Interim Fire Chief Mahoney

6. Receive Update on SAFER Grant – Interim Fire Chief Mahoney

7. Review Recommendations in The "2022 Staffing/Deployment " Side Letter and Determine a Funding Plan to Increase Staffing. – Interim Fire Chief Mahoney

Item 7 – Staff Report for Increasing Staffing to Three Personnel
Item 7 – 2022 Side Letter Staffing/Deployment – Attachment #1
Item 7 – 2020 Side Letter of Agreement – Attachment #2
Item 7 – 2019 Standards of Coverage Assessment – Attachment #3
Item 7 – NIST Fireground Field Experiments – Attachment #4
Item 7 – NIST EMS Field Experiments – Attachment #5
Item 7 – 2020 National Fire Protection Association 1710 – Link #1

8. Subcommittee requests for future agenda items, questions, and comments to staff, staff miscellaneous items.

9. Open time for public expression. The public is welcome to address the Subcommittee at this time on matters, not on the agenda. However, please be advised that pursuant to Government Code Section 54954.2, the Subcommittee is not permitted to take action on any matter not on the agenda unless it determines that an emergency exists or that the need to take action arose following the posting of the agenda.

10. Select the Next Meeting Date.

11. Adjourn

s/Samantha Stettler, Administrative Assistant

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ROSS VALLEY FIRE DEPARTMENT

Minutes of the Ross Valley Subcommittee Meeting of April 20, 2022

Note: These are summary action minutes only. The zoom recording can be accessed by clicking here

1. 6:36 pm Call to order.

Fire Board: Kuhl, Finn, Burdo, Hellman
FF's: Jamotte, Standfield, Arenas
BC's: Grasser
Executive Officer: Donery
Staff Present: Weber, Yeager
Town Managers Present: Abrams, Donery, Johnson

Agenda – April 20, 2022

2. Introduction of Members

Subcommittee members, Town Managers and Staff introduced themselves.

No public comment concerning this item.

3. Open time for Public Expression: The public is welcome to address the Board on matters not on the agenda. Please be advised that pursuant to Government Code Section 54954.2, the Board is not permitted to take action on any matter not on the agenda unless it determines that an emergency exists and that the need to take action arose following the posting of the agenda.

None

4. Subcommittee requests for future agenda items, questions, and comments to Staff, staff miscellaneous items.

None

No public comment concerning this item.

5. Appoint Chairperson and Co-Chairperson to the Subcommittee for 2022 – Chief Weber

Chief Weber summarized the staff report, and opened the floor for the committee to nominate the Chair and Co-chair.

Dir. Burdo volunteered to serve in either position and Dir. Finn second his motion.

M/S Burdo/Finn – roll call vote, all ayes. – for Burdo to serve in either position.

Captain Standfield nominated Captain Arenas to serve in either position.

Dir. Burdo and Captain Arenas had a brief discussion regarding the roles and they decided the appointments.

- Chair: Dir. Burdo
- Co-Chair: Captain Arenas

Amendment to the first motion to appoint Dir. Burdo as the Chair and Captain Arenas as the Co-Chair

M/S Jamotte/Grasser – roll call vote, all ayes.

No public comment concerning this item

6. Review Purpose of the Subcommittee and Establish Subcommittee's Objectives – Chief Weber

Chief Weber provided background related to why the Subcommittee was formed and he mentioned that previously the committee only had three of the four JPA Member agencies and in discussions, it was decided to make the committee Brown Act compliant, therefore, all four JPA members are now included. Further, he also mentioned that contract negotiations should not happen here.

For instance, the committee should discuss service and staffing levels. As well as sharing fiscal challenges the member agencies might have so that the committee can collaborate to find solutions. Chief Weber mention that the committee is an extension of the strong and positive working relationship between Labor and Management.

San Anselmo Town Manager Donery agreed with everything Chief Weber said.

Engineer Jamotte thanked the Committee on behalf of the Firefighters. They all appreciate the efforts to move forward with all the staffing issues they have faced for a long time.

Captain Standfield also agreed with what Chief Weber said and added that they understand that staffing is expensive and he mentioned the SAFER Grant and the CityGate study for the Standards of Coverage, and that the study determined that the coverage is light or less of what it should be.

Dir. Burdo also mentioned the great working relationship between management and labor and that it seems like they are all in the same page and appreciates the committee's objectives.

No public comment concerning this item.

7. Receive Update on SAFER Grant – Chief Weber

Chief Weber reported that we have not gotten an update from FEMA. He added that this Grant would fund three Firefighter positions which would fill one engine position. While the grant is a great opportunity, there should be a discuss from a policy level and affordability since it would be very hard to accept the grant knowing there would be layoffs on the 37th month. Additionally, he shared a cost estimate of $600k to fund one (1) position.

Burdo asked if the committee would have to convene should we receive the grant before the item goes to the Fire Board.

Finn agreed with Burdo regarding the committee meeting before the item goes to the Board.

Arenas agreed as well and asked if the cost to fund the positions after the grant is done has been shared with the Board, so that each member agency understands their fiscal impacts and commitment. Burdo responded that the information has not been provided yet. Donery gave some funding assumptions and said that San Anselmo Finance could put an estimate together.

Finn asked if the SAFER Grant is all or nothing. Chief Weber said historically it is all or nothing.

Burdo asked if the committee would like to meet at a special meeting. Chief Grasser said that an estimate should be provided while we wait for a SAFER Grant award response instead of waiting for an answer and the Board would have 30 days to decide. Hellman, Jamotte, Kuhl, and Arenas agreed with Grasser. Chief Weber mentioned what Dir. Greene brought to the Town's Council to identify the future need. Burdo agrees that the committee should meet at a special meeting in the event we are granted the award to provide a recommendation to the Fire Board.

Stanfield said something to consider is the stations and the facility changes needed to fully staff them as well as what the real impacts are and the tools we already have. Chief Weber responded that there is already preliminary discussions and cost analysis to upgrade the stations.

Action items:
- The committee will meet before the Fire Board meeting should the grant be awarded
- San Anselmo Finance to provide a cost analysis for the three positions

This item will be covered during the regular RVFD Board Meeting in June.

No public comment concerning this item.

8. Receive Update Regarding Governance and Leadership Study (RFP) – Chief Weber

Chief Weber mentioned the RFP preview that was presented to the RFVD fire board and the MCFD shared services agreement expiring on August 2023. He also mentioned what the RFP will entail and its goals so that the Board understands the options for long term sustainability and to improve service levels. Chief Weber added the item to this meeting to see if there were any questions before the item is presented to the Fire Board at their next regular meeting.

Executive Officer Dave Donery said that when the draft was presented to the Board, Sleepy Hollow expressed their desire to participate in the process.

Dir. Hellman asked what the role of LAFCO is during an RFP. Chief Weber responded that LAFCO approach the Department to look at District models and while LAFCO cannot mandate or decide what the Department does, we are required to inform LAFCO of JPA changes that have a governance or taxing authority impact so they are involved and it is important to work with them early on in the process.

Chief Grasser mentioned that the last study was done all in house with the Fire Chief and we did not have assistance from anyone who could suggest what the best alternatives were and only had two options. Therefore, having this RFP will benefit all stakeholders because we will have the opportunity to look at all the available options.

No public comment concerning this item.

9. Select the Date for the Next Quarterly Subcommittee Meeting – Chief Weber

Dir. Burdo asked if there were any dates suggested. Chief Weber said that the Board set up quarterly meetings and the committee can call for special meetings.

The committee discussed the scheduling and the next quarterly meeting will be in July, date and time to be determined.

No public comment concerning this item.

10. Adjourn

The next meeting is scheduled for July, via zoom video conferencing.

Respectfully submitted,

s/Mariana Gonzalez
Administrative Assistant

ROSS VALLEY FIRE DEPARTMENT
STAFF REPORT

For the Meeting on October 5, 2023

To: Labor-Management Subcommittee

From: Dan Mahoney, Interim Fire Chief

Subject: Staff Recommends the Labor-Management Subcommittee Appoints One Committee Member to Serve as the Subcommittee Co-Chair.

RECOMMENDATION:

Staff Recommends the Labor-Management Subcommittee Appoints One Committee Member to Serve as the Subcommittee Co-Chair.

BACKGROUND/DISCUSSION:

The Department created a Labor-Management Subcommittee on January 8, 2020. At the January 12, 2022 Board Meeting a "Staffing/Deployment" side letter presented by the labor group was approved. Part of the side letter agreement was to expand membership of the Labor-Management Subcommittee to include at least one Association Member representing labor, one Board Member from each member agency and the Management Committee. This Subcommittee would meet at least quarterly, and discuss how to increase staffing.

On April 20, 2022 the Subcommittee held a meeting appointing Director Steve Burdo as the Board Chair and Labor Representative Oscar Arenas as the Co-Chair.

At the September 13, 2023 Board Meeting, the Fire Board appointed one Board Member, Director Elizabeth Robbins, from Ross to fill the Town of Ross's vacancy on the Labor-Management Subcommittee.

The current Labor-Management Subcommittee Members are:

- Ross: Director Elizabeth Robbins
- San Anselmo: Director Steve Burdo
- Sleepy Hollow FPD: Director Thomas Finn
- Fairfax: Director Stephanie Hellman
- Labor Representative: Sid Jamotte
- Labor Representative: Tomas Pastalka
- Labor Representative: Tim Grasser
- Management Committee: Dave Donery (Executive Officer)

- Management Committee: Dan Mahoney (Interim Fire Chief)
- Management Committee: Christa Johnson (Ross Town Manager)
- Management Committee: Heather Abrams (Fairfax Town Manager)

The Co-Chair position is currently vacant as Labor Representative Oscar Arenas is no longer on the Subcommittee. The Co-Chair seat will need to be filled by the subcommittee.

FISCAL IMPACT:

There is no fiscal impact associated with this item.

Encl.: 2022 Side Letter Staffing/Deployment - **Attachment #1**

SIDE LETTER

STAFFING / DEPLOYMENT
BETWEEN

ROSS VALLEY FIRE DEPARTMENT
AND
ROSS VALLEY FIREFIGHTERS' ASSOCIATION LOCAL 1775

The Ross Valley Fire Department (hereinafter Department) and the Ross Valley Firefighters' Association (hereinafter Association) have mutually agreed to the following:

- Upon the closure of Fire Station 18 located in Ross, California, scheduled for July 1, 2025, the six assigned personnel (three Fire Captains and three Firefighter Engineers) shall be moved West to increase staffing from two to three personnel at Fire Stations 19 and 21;
- The parties further agree the third person on each engine will be converted to a Firefighter Paramedic Position through attrition.
- Nothing in this letter agreement shall affect the minimum number of personnel required for daily staffing under the parties' MOU.
- The parties agree that the labor-management sub-committee will meet at minimum quarterly, beginning the first quarter of 2022, with the goal of determining how to also increase the staffing to three personnel at Fire Station 20 in Sleepy Hollow. This sub-committee will include at least one Association member representing labor, a Board member from each member agency, and the management committee.

If the foregoing is in accordance with your understanding, please sign below:

For the Department	For the Association
______________________	______________________
Date: 24-Jan-22	Date: 01/10/2022

Item 5f
Attachment #1
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ROSS VALLEY FIRE DEPARTMENT
STAFF REPORT

For the Meeting of October 5, 2023

To: Labor-Management Subcommittee

From: Dan Mahoney, Interim Fire Chief

Subject: Review Recommendations in The "2022 Staffing/Deployment " Side Letter and Determine a Funding Plan to Increase Staffing.

RECOMMENDATION:

Staff recommends that the Labor-Management Subcommittee review recommendations in the "2022 Staffing/Deployment " side letter and determine a funding plan to increase staffing.

BACKGROUND:

Since the creation of the Joint Powers Authority (JPA) in 1982, the Ross Valley Fire Department's (Department) response model formerly relied on and was augmented by a large group of local volunteer firefighters who responded to incidents, such as structure or vegetation fires, to provide assistance to the Department's two-person engine company deployment model. Additionally, many of our full-time personnel lived in the communities our department serves and they too would respond to incidents off-duty. The ability to use off-duty personnel and volunteer firefighters provided some operational relief to the Department's two-person engine companies. This model was less than ideal, creating a delayed and inconsistent response force. The Department's Volunteer Program no longer exists due to lack of interest and most full-time personnel have moved away from the community we serve primarily due to high housing costs

Community expectations of the Department have increased, and external factors have created challenges and demands that have put our Department at the forefront of mitigating complex and challenging emergency responses of all kinds. Examples include flooding; swift water rescue; violent encounters / active shooter response; a "new normal" of intensely destructive Wildland Urban Interface fires; and extension of wildland fire season from a few months (formerly) to potentially almost year round. These realities, particularly from the fire prevention and risk reduction standpoints, have led the Department to enhance our fire hazard and life safety inspections of businesses and residential apartment buildings. The Department, with the help of funding through Measure C, has also increased our neighborhood defensible space efforts, working with communities to reduce fuels, improve emergency access and egress, and plan for potential evacuations. Since the Departments JPA was formed 41 years ago, the

Department has hired two Fire Inspectors (JPA Funds) to increase service demands relating to fire prevention, one Emergency Preparedness Coordinator (Measure C funds) and one Defensible Space Coordinator (Measure C funds). No additional firefighters have been hired to meet these increased operational demands of the Department's engine company, as the minimum fire engine company staffing still remains at two-personnel.

In 2001, the National Fire Protection Association (NFPA), a leader in the development of industry standards for the fire service, issued its first edition of the "Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments" known as NFPA 1710. The document identifies minimum staffing for fire engines along with identifying the number of personnel that shall be deployed to a structure fire.

In 2019, Citygate Associates conducted a comprehensive Standards of Coverage Assessment of the Department to provide a foundation for future fire service planning. The goal of this assessment was to identify both current services and desired service levels, and to assess the Department's ability to provide them. This data-driven report strongly suggests that the RVFD should staff three-person engine companies.

At the January 2020 Board meeting, a "Staffing/Deployment" side letter was approved to enhance the current "Labor Management Subcommittee" (subcommittee) with additional members. The sub committee's goal was " how to increase staffing".

The subcommittee held its first meeting on April 20, 2022. Discussion was held regarding the need to identify future funding if the Department was awarded its grant application for the 2021 "Staffing for Adequate Fire and Emergency Response" (SAFER) Grant. It was explained that the grant would provide funding for the first 36 months of the proposed Firefighter position (three Firefighters in total), however, on month 37, the member agencies would need to begin funding the position. Staff was given direction to provide an ongoing cost estimate after the first 36 months and present it to the Board for discussion at the June 2022 Board meeting. Staff presented the cost estimate at the June 2022 Board meeting. No direction to Staff or action was taken other than for Staff to keep the Board informed on the SAFER grant application. Ultimately the SAFER Grant was not awarded to the Department. The Subcommittee has not met since, and there has been no further formal discussions at the Board level.

At the September 2023 Board Meeting, Staff recommended filling a vacancy in the Subcommittee and holding another Subcommittee meeting before the October 2023 Board meeting. The Subcommittee is scheduled to meet on October 5, 2023.

DISCUSSION:

When evaluating the need to increase staffing, this staff report will refer to the industry standard set forth by the National Fire Protection Association 1710. The Departments 2019 Standards Of Coverage Assessment will also be a guiding document as to how the Department compares to the standard. Below is a brief background of these documents and key points within them relating to the Department's current staffing.

National Fire Protection Association 1710 (NFPA 1710) - A U.S.-based international nonprofit organization devoted to eliminating death, injury, property, and economic loss due to fire. In 2001, the first edition of NFPA 1710 was issued. The development of that benchmark standard was the result of a considerable amount of hard work and tenacity by the technical committee members and the organizations they represented. This standard was the first organized approach to defining levels of service, deployment capabilities, and staffing levels for career fire departments. Research work and empirical studies in North America were used by the committee as a basis for developing response times and resource capabilities for those services, as identified by the fire department.

The following two NFPA 1710 industry standards will be referred to within this staff report:

NFPA 1710 ENGINE COMPANY STANDARDS
5.2.3.1.1 These companies shall be staffed with a minimum of four on-duty members (NFPA 1710 p.11)
NFPA 1710 INITIAL ALARM ASSIGNMENT STANDARDS
5.2.4.1.1 (9) Single family Dwelling Initial Alarm Assignment Capability - Total effective response force with a minimum of 16 firefighters. (NFPA 1710 p.12) **Initial Alarm Assignment = number of firefighters initially deployed to a structure fire*

2019 Standards Of Coverage Assessment (2019 SOC) - In 2019, Citygate Associates conducted a comprehensive Standards of Coverage Assessment of the Department to provide a foundation for future fire service planning. The goal of this assessment was to identify both current services and desired service levels, and to assess the Department's ability to provide them. Citygate utilized various NFPA and Insurance Services Office publications as best practice guidelines, along with the self-assessment criteria of the Commission on Fire Accreditation International.

The following are recommendations, opinions and excerpts from the 2019 SOC that correlate with how the Department meets the NFPA 1710 industry standards:

Recommendation #3: Consider providing a third firefighter per day on the three engines other than Engine 18. (2019 SOC p.7)

Citygates Overall Opinion: "Citygate is, however, concerned about the overall limited Department staffing per day and its ability to respond with more "weight of attack*" to keep emerging serious emergencies controlled. Even Countywide mutual aid resources are not quickly available in this part of Marin County, as they would be in an urban area with flat terrain and interconnected roads." (2019 SOC p.4)

2.5.1 Critical Firefighting Tasks: "Table 8 illustrates the critical tasks required to control a typical single-family dwelling fire with six response units (engines/chief), for a total Effective Response Force* of 16 personnel, where the Ross Valley Fire Department initially sends 12. A confirmed serious fire additionally receives a second Battalion Chief and a fourth engine raising this to 15 personnel. However, in many locations these additional units come from much farther away. These tasks are taken from typical fire departments' operational procedures, which are consistent with the customary findings of other agencies using the Standards of Coverage process. No conditions exist to override the Occupational Safety and Health Administration two-in/two-out safety policy, which requires that firefighters enter Immediately Dangerous to Life and Health atmospheres, such as building fires, in teams of two, while two more firefighters are outside and immediately ready to rescue them should trouble arise." (2019 SOC p.26)

2.5.3 Critical Task Analysis and Effective Response Force Size - A question one might ask is, "If fewer firefighters arrive, such as does occur in the Ross Valley Department, what from the list of tasks mentioned would not be completed?" This is also critical given the two firefighter staffing. The initial force is a smaller count as it takes the third and fourth-due units much longer to arrive. Most likely, the search team would be delayed, as would ventilation. The attack lines would only consist of two firefighters, which does not allow for rapid movement of the hose line above the first floor in a multiple-story building. Rescue is conducted with at least two person teams. Thus, when rescue is essential, other tasks are not completed in a simultaneous, timely manner. Effective deployment is about the **speed** (travel time) and the **weight*** (number of firefighters) of the response. (2019 SOC p.30)

This staff report will also reference various field studies.

**Weight of attack - refers to multiple-unit responses (Effective Response Force, or ERF, commonly also called a First Alarm) for more serious emergencies such as building fires, multiple-patient medical emergencies, vehicle collisions with extrication required, or technical rescue incidents.*

The Department's current response model relies on a two-person engine company consisting of a Captain and Engineer for emergency (including Emergency Medical Services EMS) and non-emergency response, for fire prevention efforts, to provide public education, and to perform every other task that is required for the Department to function at the highest level and meet the needs of the community. Unlike other Fire Departments, and the NFPA 1710 industry standard (5.2.3.1.1), the Department does not have a Firefighter position within our ranks. Rather, the roles and assignments that typically fall on a person in this position at the scene of an incident instead fall to the Engineer or Captain. Below are the typical duties of a Captain, Engineer and Firefighter at a structure fire incident:

TYPICAL DUTIES AT A STRUCTURE FIRE		
CAPTAIN	**ENGINEER**	**FIREFIGHTER**
Engine Company Supervisor *Crew Safety Office* *In charge of crew accountability* *Makes decisions quickly/accurately to limit loss of life* *Command's emergency situations until relieved* *COORDINATES fire control/search and rescue/ventilation/salvage/ overhaul/ventilation operations,* *Provides EMS care*	*Operates and pumps fire engine at fire* *Responsible for maintaining and driving apparatus to emergency incidents* *Functions as a Firefighter when assigned to other functions on the fire when not the pumping Engine* *CONDUCTS fire control/search and rescue/ventilation/salvage/ overhaul/ventilation operations* *Provides EMS care*	*Responsible for stretching hose lines* *Operating all tools and equipment on the Engine used for various types of emergency fire and rescue operations* *CONDUCTS fire control/search and rescue/ventilation/salvage/ overhaul/ventilation operations* *Provides EMS care*

All of the above are critical life saving tasks that need to be accomplished on the fire ground. You will notice the compaction of responsibilities that our Engineers and Captains experience at every incident due to no Firefighter position. Functioning with a two-person engine company negatively impacts our safety, capacity, and operational effectiveness as noted in the 2019 SOC "Critical Task Analysis" mentioned above.

The following section identifies common engine company workloads and quantifies the difference between a two-person and three-person engine company through National Institute of Standards and Technology (NIST) field experiments. Even an increase in staffing on one of our four fire engines will have an immediate impact as seen below:

Structure Fire Fighting Impacts - As mentioned in the Departments 2019 SOC, one of the two contributing factors to an effective deployment model is *weight* (number of firefighters) of the response. The Department currently has 15 firefighters on its Initial Alarm Response, one less Firefighter than the industry standard. Increasing staffing on one fire engine per the "Staffing/Deployment" agreement will allow the Department to comply with the following NFPA 1710 standard:

NFPA 1710 5.2.4.1.1: (9) Single family Dwelling Initial Alarm Assignment Capability Total effective response force with a minimum of 16 firefighters. (NFPA 1710 p.12)

Fire extinguishment and search/rescue operations are time critical and can be a matter of life or death. The following "National Institute of Standards and Technology Fireground

Field Experiments" (NIST Fire) quantifies the time differences between two and three person engine companies. You will notice a faster "Hose Stretch" that equates to a more rapid fire extinguishment and a faster "Search/Rescue Start Time." All that equates to an increased survivability rate for fire victims.

NIST FIREGROUND FIELD EXPERIMENTS	
Hose Stretch	A two-person crew took 57 seconds longer than a three-person crew to stretch a line. (NIST Fire p.38)
Search/Rescue Start Time	The three-person crew started a primary search/rescue more than 25 % faster than the two-person crew. (NIST Fire p.41)

Emergency Medical Care Impacts - Engine companies are usually the first on scene during Emergency Medical Service (EMS) calls. The following "National Institute of Standards and Technology EMS Field Experiments" (NIST EMS) quantifies the time differences between two and three person engine companies. Notice a three-person engine company provides faster "Patient Access" and a "Patient Removal " start time. All that equates to improved medical care on routine EMS incidents.

PATIENT ACCESS
Two-person crews finished the patient access tasks approximately half a minute later than larger first responder crews.(NIST EMS p.33) *(*Note: Our two-person engine companies are sometimes tasked with carrying 94.6 lbs of medical equipment while gaining "patient access".)*
PATIENT REMOVAL
Two-person first responder crews completed patient removal between (1.2 – 1.5) minutes slower than larger crews, depending on crew size. This is largely the result of work load in carrying equipment, supplies and the patient with fewer crew members. (NIST EMS p.33)

One of the most challenging EMS calls a firefighter responds too is a cardiac arrest (not breathing/no pulse). Providing efficient CPR is vital to reversing the effects of cardiac arrest and saving a life. Providing chest compressions, rescue breathing and operating a defibrillator are three core tasks that must take place simultaneously. A two-person engine company cannot perform these three tasks simultaneously. Additional fire engines from further away subsidize our two-person engine company, thus delaying efficient CPR by minutes, when seconds count.

The "Chain Of Survival" identifies four factors that will increase the survivability rate of someone in cardiac arrest. Increasing to a three-person engine company will improve speed of patient access/patient removal, and allow the first engine company on scene to provide immediate CPR (chest compressions/rescue breathing) and defibrillation, resulting in an improved survivability rate within the community.

CHAIN OF SURVIVAL		
1.	Early Access	Patient Access
2.	Early CPR	Chest Compressions and rescue breathing are core CPR tasks
3.	Early Defibrillation	Core CPR task
4.	Early Advanced Medical Care	Part of Patient Removal

Physiological Effects - Reports on firefighter fatalities consistently document overexertion/overstrain as the leading cause of line-of-duty fatalities. There is strong epidemiological evidence that heavy physical exertion can trigger sudden cardiac events. Therefore, information about the effect of crew size on physiological strain is very valuable.

Danger is increased for small crews because the stress of fire fighting keeps heart rates elevated beyond the maximum heart rate for the duration of a fire response. (NIST Fire pg 50)
Average Heart Rates
• Higher for members of small crews.   ○ Particularly two-person crews. • Higher heart rates were maintained for sustained time intervals.

CONCLUSION

The Department needs a paradigm shift to maintain effective operational readiness in this modern world. In order to meet all of these new demands, we need to increase our engine company staffing as soon as possible. The Department is currently the only department in Marin County that has two-person engine companies. Marin County fire agencies have a combined 31 staffed fire engines, 26 of which are staffed with three personnel. Of the remaining five engines not staffed with three personnel, four of those engines are the Departments.

It has been a long term goal of the Fire Board to make the transition to a three-person engine company. The “2022 Staffing/Deployment” Side Letter provides an opportunity for the Department to begin staffing its engines with one three-person engine company prior to July 1, 2025 if the Board so chooses. The remaining two engine companies will be staffed with three personnel after the closure of Station 18 on July 1. 2025.

MEMBER AGENCY COSTS

The chart below represents a fully-burdened cost of three Firefighter Paramedic positions, taking into consideration the following: monthly salary/benefits were calculated using the Boards agreed (on 1/8/22) amounts from the Firefighter Paramedic "Side Letter Of Agreement" and salary schedule/benefits were adjusted to match the negotiated increase/benefit changes since 2020, overtime costs are based on the negotiated leave days (sick/vacation), and one time equipment costs are based on outfitting a Firefighter with protective clothing (one time equipment costs only included in 24/25 and 25/26).

Cost by Member Agency				
FY	Fairfax	Ross	San Anselmo	Sleepy Hollow FPD
Percent. Share	23.30%	23.37%	40.53%	12.80%
24/25	$147,262	$147,705	$256,161	$80,900
25/26	$156,034	$156,503	$271,420	$85,719
26/27	$164,114	$164,607	$285,473	$90,157

FUNDING OPTIONS

Option 1: Each Member agency will begin paying their respective "percentage share" from the position date of hire.

Option 2: Authorize one-time use from undesignated reserves to fund the first year from the position date of hire. Each Member agency will begin paying their respective "percentage share" after year one.

Option 3: Authorize one-time use from undesignated reserves to fund a phased approach using a combination of undesignated reserves and member agency respective "percentage share" for the first two years of the position. The Department would use undesignated reserves to pay the difference of the actual cost and the amount being billed to the member agencies. Member agencies would be charged 50% in year one, 75% in year 2, and 100% in year 3.(See chart below).

Option 3: Cost by Member Agency (Phased Approach)					
FY	Fairfax	Ross	San Anselmo	Sleepy Hollow FPD	Reserve Funds
Percent. Share	23.30%	23.37%	40.53%	12.80%	
24/25 (50%)	$73,631	$73,852	$128,080	$40,450	$316,014
25/26 (75%)	$117,026	$117,377	$203,565	$64,289	$167,419
26/27 (100%)	$164,114	$164,607	$285,473	$90,157	$0

FISCAL IMPACT:

There is no immediate financial impact as a recommendation will need to be brought forth to the Fire Board.

ENCLOSED REFERENCES/ATTACHMENTS:

Ross Valley Fire Department 2022 Side Letter Staffing/Deployment Between Ross Valley Fire Department And Ross Valley Firefighters' Association Local 1775.

Ross Valley Fire Department 2020 Side Letter of Agreement between the Ross Valley Fire Department and the Ross Valley Professional Firefighters' IAFF Local 1775.

(2019 SOC): Citygate Associates, LLC. 2019. Ross Valley Fire Department Standards of Coverage Assessment Volume 1 of 2: Technical Report.

(NIST Fireground): National Institute of Standards and Technology. 2010. Report on Residential Fireground Field Experiments. 56.

(NIST EMS): National Institute of Standards and Technology. 2010. Report on EMS Field Experiments. 60.

(NFPA1710): National Fire Protection Association. 2020. NFPA 1710 Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments.

SIDE LETTER

STAFFING / DEPLOYMENT
BETWEEN

ROSS VALLEY FIRE DEPARTMENT
AND
ROSS VALLEY FIREFIGHTERS' ASSOCIATION LOCAL 1775

The Ross Valley Fire Department (hereinafter Department) and the Ross Valley Firefighters' Association (hereinafter Association) have mutually agreed to the following:

- Upon the closure of Fire Station 18 located in Ross, California, scheduled for July 1, 2025, the six assigned personnel (three Fire Captains and three Firefighter Engineers) shall be moved West to increase staffing from two to three personnel at Fire Stations 19 and 21;
- The parties further agree the third person on each engine will be converted to a Firefighter Paramedic Position through attrition.
- Nothing in this letter agreement shall affect the minimum number of personnel required for daily staffing under the parties' MOU.
- The parties agree that the labor-management sub-committee will meet at minimum quarterly, beginning the first quarter of 2022, with the goal of determining how to also increase the staffing to three personnel at Fire Station 20 in Sleepy Hollow. This sub-committee will include at least one Association member representing labor, a Board member from each member agency, and the management committee.

If the foregoing is in accordance with your understanding, please sign below:

For the Department	For the Association
______________________	______________________
Date: 24-Jan 22	Date: 01/10/2022

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Item 7
Attachment #1
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Side letter of Agreement between the Ross Valley Fire Department and the Ross Valley Professional Firefighters' IAFF Local 1775

Whereas the Ross Valley Fire Department is in the process of analyzing facilities and staffing, the parties agree to the following:

1. The parties agree on the importance of maintaining filled positions to allow necessary time for entry level training prior to being placed on emergency apparatus. Additionally, parties agree on the importance of long-term planning for facilities and staffing that must be done in a collaborative and thoughtful way to ensure quality, sustainable services.

2. The parties agree to move forward with the creation of a Firefighter Paramedic position. Additionally, the parties agree to place on hold the Firefighter/Engineer Paramedic recruitment to allow a reasonable timeframe to work collaboratively on staffing options.

3. The parties agree that the Firefighter Paramedic position will be dissolved and incumbents holding those positions will be automatically transferred into the existing Firefighter/Engineer Paramedic position after successfully passing a probationary period or 12mos whichever is first if parties do not reach mutually agreeable terms related to position restructuring.

4. This agreement shall hereby be incorporated by this reference into the parties' MOU.

5. The Firefighter Paramedic position will be entitled to the same benefits and provisions as others in the Ross Valley Firefighters' Association according to the current MOU.

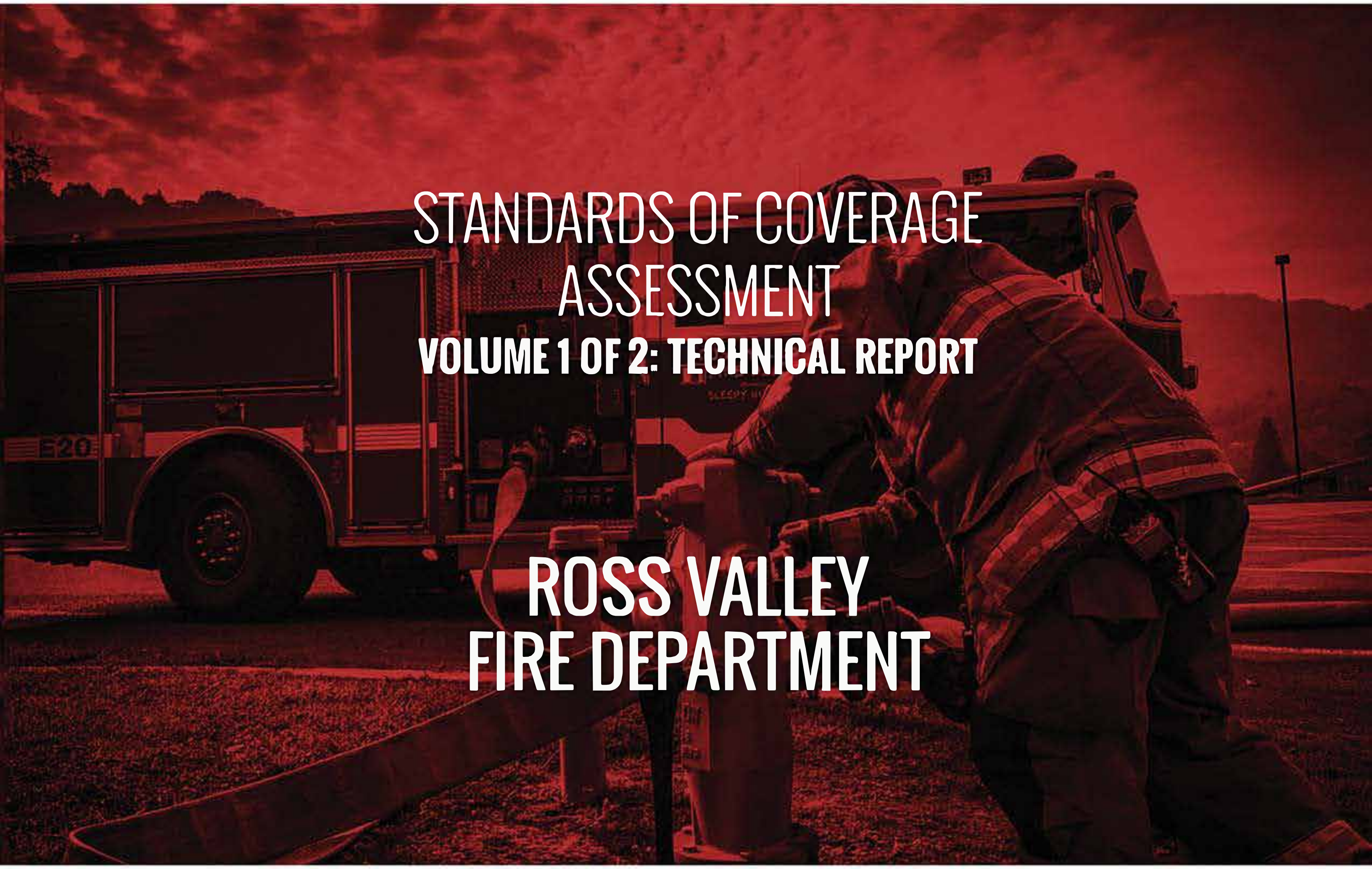
6. The monthly Salary for the Firefighter Paramedic position shall be:

Step A	$7,986
Step B	$8,385
Step C	$8,805

Ross Valley Fire Department	**Ross Valley Fire Firefighters' Association IAFF Local 1775**
By: ______________________	By: ______________________
Name: ______________________	Name: ______________________
Title: ______________________	Title: ______________________
Date ______________________	Date ______________________

By: ______________________	Ratified: IAFF Local 1775
Name: ______________________	By: ______________________
Title: ______________________	Name: ______________________
Date ______________________	Title: ______________________
	Date ______________________

CITYGATE ASSOCIATES, LLC
PUBLIC SAFETY SERVICES



STANDARDS OF COVERAGE ASSESSMENT

VOLUME 1 OF 2: TECHNICAL REPORT

ROSS VALLEY FIRE DEPARTMENT

SEPTEMBER 2019

CITYGATE ASSOCIATES, LLC
WWW.CITYGATEASSOCIATES.COM
600 COOLIDGE DR., STE. 150
FOLSOM, CA 95630
PHONE: (916) 458-5100
FAX: (916) 983-2090

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EXECUTIVE SUMMARY

The Ross Valley Fire Department (Department) is a consolidated department protecting lives, property, and the environments of Ross, San Anselmo, Sleepy Hollow, and Fairfax. The Department retained Citygate Associates, LLC (Citygate) to conduct a comprehensive Standards of Coverage (SOC) assessment to provide a foundation for future fire service planning. The goal of this assessment is to identify both current services and desired service levels, and then to assess the Department's ability to provide them. As part of this study, the Town of Ross (Town) requested an analysis of the impact on the current level of services if the fire engine in the Town was relocated, and alternatively, the fire engine and ambulance were relocated from their present location in the Town. After understanding any possible gaps in operations and resources, Citygate has provided recommendations to improve Department operations and services over time.

This assessment is presented in several parts, including this Executive Summary outlining the most significant findings and recommendations; the fire station/crew deployment analysis supported by maps and response statistics; and an assessment of specific fire crew deployment choices for the Town of Ross. A separate Map Atlas (**Volume 2**) contains all the maps referenced throughout this report. Overall, there are 18 findings and 3 specific action recommendations.

POLICY CHOICES FRAMEWORK

There are no mandatory federal or state regulations directing the level of fire service staffing, response times, or outcomes. Thus, the level of fire protection services provided are a *local policy decision* and communities have the level of fire services that they can afford, which may not always be the level desired. However, if services are provided at all, local, state, and federal regulations relating to firefighter and citizen safety must be followed.

OVERALL SUMMARY OF CURRENT ROSS VALLEY FIRE CREW DEPLOYMENT

Citygate finds that that the Department is well organized being a partnership of several agencies to accomplish its mission to serve a suburban population in a municipal land-use pattern although in hilly terrain with few cross-connecting roads aside from the main roads on the valley floor. The Department serves mostly residential and small downtown populations with a mixed land-use pattern typical of Marin County communities. The small towns and the road to West Marin attract a high number of visitors that also must be protected. However, the hilly geography and the limited road network, which is dependent on one main connector road, makes the area very difficult to serve efficiently from a small number of fire stations.

Fire service deployment, simply stated, is about the *speed* and *weight* of the response. *Speed* refers to initial response (first-due) of all-risk intervention resources (engines, trucks, and/or ambulances) strategically deployed across a jurisdiction for response to emergencies within a time interval to achieve desired outcomes. *Weight* refers to multiple-unit responses (Effective Response Force, or ERF, commonly also called a First Alarm) for more serious emergencies such as building fires, multiple-patient medical emergencies, vehicle collisions with extrication required, or technical rescue incidents. In these situations, a sufficient number of firefighters must be assembled within a reasonable time interval to safely control the emergency and prevent it from escalating into a more serious event.

Most suburban communities desire outcomes to include limiting building fire damage to only part of the inside of an affected building and/or minimizing permanent impairment resulting from a medical emergency. To do so, the initial units should arrive within 7:30 minutes from 9-1-1 notification and a multiple-unit ERF should arrive within 11:30 minutes of 9-1-1 notification at the Marin County Sheriff's Dispatch Center (Comm Center), all at 90 percent or better reliability. Total response time to emergency incidents includes three distinct components: (1) 9-1-1 call processing/dispatch time; (2) crew turnout time; and (3) travel time. Recommended best practices for these response components are 1:30 minutes, 2:00 minutes, and 4:00/8:00 minutes respectively for first-due and multiple-unit ERF responses in urban/suburban areas.

In the Department, the current fire station system provides the following first-due unit response time performance across a variety of population density/risk areas for emergency medical and fire incident types. As Table 1 shows, *all* station areas receive service *longer* than a best practices goal point of 7:30 minutes.

Table 1—Call to Arrival Performance to 90 Percent of Fire and EMS Incidents (Taken from Table 16)

Station Area	2018
Department-Wide	08:45
Station 18	07:55
Station 19	07:45
Station 20	08:47
Station 21	09:07

The Department's dispatch times are *excellent*. Crew turnout times need modest improvement. The times in Table 1 do, however, reflect a longer *travel* time slower than an urban/suburban preferred 4:00 minutes for 90 percent of the incidents, as Table 2 displays.

Table 2—Travel Time Performance to 90 Percent of Fire and EMS Incidents (Taken from Table 15)

Station Area	2018
Department-Wide	06:09
Station 18	04:40
Station 19	05:38
Station 20	06:24
Station 21	06:30

The overall longer-than-desired first-due unit travel times are *not* the result of a lack of fire stations. They are the result of the non-grid street network design, simultaneous incidents at peak hours of the day, and traffic congestion—particularly rush hour and tourism on weekends.

CITYGATE'S OVERALL OPINIONS

The Department is very difficult to serve efficiently from a small number of fire stations due to the hilly geography and the limited road network, which is dependent on one main connector road. Over time, each population cluster opened a fire station for a minimum single first unit response and knew they were co-dependent on each other for multiple-unit serious emergencies. The geography cannot be changed and improving the road network is not politically feasible or cost-effective. Thus, reducing coverage by removing any one or more fire engines or the paramedic ambulance will increase response times to the local community receiving reduced coverage.

While the state fire code now requires fire sprinklers even in residential dwellings, it will be many more years before the vast majority of homes are replaced or remodeled with automatic fire sprinklers. If the communities' desired outcomes include limiting building fire damage to only part of the inside of an affected building, minimizing permanent impairment resulting from a medical emergency, and keeping wildland fires small to a few acres at the ignition point, then the communities served by the Ross Valley Fire Department will need first-due unit coverage in all neighborhoods.

However, even with maintaining the current four-station spacing, given the topography, not all hillside areas can receive response time coverage consistent with suburban best practice incident outcomes and a Citygate performance recommendation of a first-due arrival within 7:30 minutes from 9-1-1 dispatch notification and a multiple-unit Effective Response Force (ERF) arrival occurring within 11:30 minutes of 9-1-1 notification, all at 90 percent or better reliability.

The Department's call processing performance is excellent. The crew turnout time needs modest improvement but even such attainable improvement cannot substantially lower the fire unit travel times which are longer than desired. Department resources and equipment are appropriate to protect against the hazards likely to impact the Department's service area, but the daily staffing of eight firefighters on four engines, plus a two-firefighter/paramedic ambulance from the Ross Valley Paramedic Authority (RVPA) and a Duty Chief Officer only provides a *minimum* total response force sufficient to begin controlling a single emerging to serious fire incident, or to provide care at an EMS incident with one to five patients.

In terms of emergency incident workload per unit, no single fire unit or station area is approaching workload saturation. The level of simultaneous incidents is not high enough to warrant another unit at peak hours of the day. Citygate is, however, concerned about the overall limited Department staffing per day and its ability to respond with more "weight of attack" to keep emerging serious emergencies controlled. Even Countywide mutual aid resources are not quickly available in this part of Marin County, as they would be in an urban area with flat terrain and interconnected roads.

The quantity of calls in the Town of Ross (or any other single historic population cluster in the joint Department's service area) is too small and too volatile from which to use historical incidents as the only criteria to maintain the fire station. Providing fire services is akin to purchasing fire insurance, and it is important to consider the desired level of protection. The public policy issue is whether to have access to a fire station nearby or farther away, knowing that a station farther away, even with its unit(s) available for response, cannot offer more than edge suburban or emerging rural area response times to much of the Town of Ross.

DEPLOYMENT KEY FINDINGS AND RECOMMENDATIONS

The following are findings and recommendations presented throughout the report.

Finding #1: The Department has legacy response performance objectives partially consistent with best practice recommendations as published by the Commission on Fire Accreditation International. However, they should be updated to reflect current risks and desired outcomes for all types of emergency risk outcomes.

Finding #2: The Department has a standard response plan that considers risk and establishes an appropriate initial response for each incident type. Each type of call for service receives the combination of engines, specialty units, and command officers customarily needed to begin to control that type of incident based on Department experience.

Finding #3: The mapping analysis shows the need for neighborhood-based first response units for fire and EMS incidents.

Finding #4: The risk assessment maps show there are risks to be protected from fire besides just single-family homes, and some areas have lower fire flow capacity for serious or conflagration size fires.

Finding #5: The Department's service demand is consistent, indicating the need for a 24-hours-per-day, seven-days-per-week fire and EMS emergency response system.

Finding #6: The number of simultaneous incidents is volatile. However, in a four-station department, it is very rare that more than two incidents occur at once.

Finding #7: Call processing performance at 1:04 minutes is *better than* a best practice recommendation of 1:30 minutes.

Finding #8: Crew turnout performance at 2:41 minutes is *slower* than a Citygate-recommended goal of 2:00 minutes or less.

Finding #9: First-due unit travel time performance to 90 percent of the incidents Department-wide at 6:09 minutes is well past the Department's likely goal of 4:00 minutes, a goal consistent with best practices.

Finding #10: The Department's call to arrival time to 90 percent of the incidents at 8:45 is slower than a Citygate's recommended goal of 7:30 minutes in developed suburban areas. The principal reason is the longer travel times, reflective of the topography and road network in the Department's service area.

Finding #11: The Effective Response Force (First Alarm) *travel* times are only modestly longer than a best practices goal of 8:00 minutes and are reflective of the good, central placement of the four fire stations.

Finding #12: In the Town of Ross, on EMS emergencies, Engine 18 responded 214 times and Medic 18 responded 169 times in a two-year period.

Finding #13: In the Town of Ross, adjoining Engines 17 (Kentfield) and Engine 19 each arrived first over a two-year period 19 and 20 times, totaling 39. Thus, the outside units only arrived/were needed first 12.6 percent of the time.

Finding #14: In a two-year period, Engines 18 and 17 (Kentfield) were assigned to incidents at the same time 78 times or 16 percent of Engine 18's total responses. Stated this way, if Engine 18 was closed, there are approximately 1.5 incidents per week to which Engine 17 will not be available to respond.

Finding #15: Closing Station 18 will add about 2:00 minutes *minimum* of travel time into that station area.

Finding #16: In the Ross Valley Fire Department, Station 18 has the best travel time of any of the four station areas at 4:40 minutes, only 40 seconds longer than an urban/suburban best practice recommendation of 4:00 minutes. Adding 2:00 minutes travel, plus dispatch and turnout time of at least 3:00 minutes, moves a Town of Ross total response time from 7:40 to 9:40 which would be more like an edge suburban area or emerging rural area. First unit response times of 10:00 minutes-plus means small fires will become larger and critical EMS patients may not receive lifesaving care.

Finding #17: If the Engine 18 daily firefighter count of two were transferred to Engine 19, or reduced to one being transferred, they would be joining an engine that serves a much larger area and is more exposed to simultaneous incident demand. Due the dynamic nature of 9-1-1 emergencies, there is no way to predict if all of the Town of Ross Engine 18 and Medic 18 first arrivals would be covered by just Engines 19 and 17 (Kentfield) or by other units even farther away.

Finding #18: Covering the Town of Ross from either Station 19 or 17 (Kentfield) depends on essentially one road being open and not congested with traffic. Any one accident or natural emergency could close the road, effectively making the Town of Ross a cul-de-sac served from one direction and, in a sub-regional emergency, either Engine 19 or 17 would be shared with a larger service area.

Recommendation #1: **<u>Adopt Updated Deployment Policies:</u>** The Ross Valley Fire Department governing Board should adopt *updated*, complete performance measures to aid deployment planning and to monitor performance. The measures of time should be designed to deliver outcomes that will save patients medically salvageable upon arrival and to keep small but serious fires from becoming more serious. With this is mind, Citygate recommends the following measures:

1.1 <u>Distribution of Fire Stations:</u> To treat pre-hospital medical emergencies and control small fires, the first-due unit should arrive within 8:30 minutes, 90 percent of the time from the receipt of the 9-1-1 call at dispatch; this equates to a 90-second dispatch time, a 2:00-minute company turnout time, and a 5:00-minute travel time.

1.2 Multiple-Unit Effective Response Force for Serious Emergencies: To confine building fires near the room of origin, keep vegetation fires under one acre in size, and treat multiple medical patients at a single incident, a multiple-unit ERF of at least 12 personnel, including at least one Duty Chief Officer, should arrive within 12:30 minutes from the time of 9-1-1 call receipt in dispatch, 90 percent of the time; this equates to a 90-second dispatch time, 2:00-minute company turnout time, and 9:00-minute travel time.

1.3 Hazardous Materials Response: Provide hazardous materials response designed to protect the Department's service areas from the hazards associated with uncontrolled release of hazardous and toxic materials. The fundamental mission of the Fire Department's response is to isolate the hazard, deny entry into the hazard zone, and notify appropriate officials/resources to minimize impacts on the community. This can be achieved with a first-due total response time of 8:30 minutes or less to provide initial hazard evaluation and/or mitigation actions. After the initial evaluation is completed, a determination can be made whether to request additional resources from the regional hazardous materials team.

1.4 Technical Rescue: Respond to technical rescue emergencies as efficiently and effectively as possible with enough trained personnel to facilitate a successful rescue with a first-due total response time of 8:30 minutes or less to evaluate the situation and/or initiate rescue actions. Following the initial evaluation, assemble additional resources as needed within a total response time of 12:30 minutes to safely complete rescue/extrication and delivery of the victim to the appropriate emergency medical care facility.

Recommendation #2: Consider maintaining the current location of all four engines and keeping Medic 18 in the Town of Ross to balance its coverage area to the west and east.

Recommendation #3: Consider providing a third firefighter per day on the three engines other than Engine 18. Doing so would raise the daily weight of attack from 12 to 15 and, with Kentfield's three personnel, to 18. This force would be sufficient to provide the weight of attack and simultaneous incident redundancy for suburban positive outcomes. Especially on serious building and wildland fire ignitions, there is no second chance to stop the fire. This is a local policy decision to be made by the affected communities to determine the level of fire service that they can afford.

NEXT STEPS

- Review and absorb the content, findings, and recommendations of this report.
- Adopt revised response performance goals as recommended.
- Request staff to return with a community engagement plan to discuss adding up to three more firefighters per day, one on each of the three engines other than Engine 18.

SECTION 1—INTRODUCTION AND BACKGROUND

The Ross Valley Fire Department (Department) retained Citygate Associates, LLC (Citygate) to conduct a comprehensive Standards of Coverage (SOC) assessment to provide a foundation for future fire service planning. The goal of this assessment is to identify both current services and desired service levels and then to assess the Department's ability to provide them. Citygate's scope of work and corresponding Work Plan were developed consistent with Citygate's Project Team members' experience in fire administration and deployment. Citygate utilizes various National Fire Protection Association (NFPA) and Insurance Services Office (ISO) publications as best practice guidelines, along with the self-assessment criteria of the Commission on Fire Accreditation International (CFAI).

1.1 REPORT ORGANIZATION

This report is organized into the following sections. **Volume 2** (Map Atlas) is separately bound.

	Executive Summary: Summary of current services and significant future challenges.
Section 1	Introduction and Background: An introduction to the study and background facts about the Department.
Section 2	Standards of Coverage Assessment: An overview of the SOC process and detailed analysis of existing deployment policies, outcome expectations, community risk, critical tasks, distribution and concentration effectiveness, reliability and historical response effectiveness, and overall deployment evaluation.
Section 3	Town of Ross Focused Study: An assessment of the effectiveness of locating one of the Department's engines and/or ambulances in the Town of Ross.
Section 4	Overall Evaluation: An overall deployment evaluation with concluding recommendations.
Appendix A	Risk Assessment

1.1.1 Goals of the Report

This report cites findings and provides recommendations, as appropriate, related to each finding. Findings and recommendations throughout this report are sequentially numbered. A complete list of all these same findings and recommendations is provided in the Executive Summary.

This document provides technical information about the way fire services are provided and legally regulated and the way the Department currently operates. This information is presented in the form of recommendations and policy choices for consideration by the Department's leadership.

The result is a solid technical foundation upon which to understand the advantages and disadvantages of the choices facing Department's partners regarding the best way to provide fire services and, more specifically, at what level of desired outcome and expense.

1.1.2 Limitations of Report

In the United States, there are no federal or state regulations requiring a specific minimum level of fire services. Each community, through the public policy process, is expected to understand the local fire and non-fire risks and its ability to pay, and then choose its level of fire services. *If* fire services are provided at all, federal and state regulations specify how to do so safely for the public and for the personnel providing the services.

While this report and technical explanation can provide a framework for the discussion of Department services, neither this report nor the Citygate team can make the final decisions, nor can they cost out every possible alternative in detail. Once final strategic choices receive policy approval, Department staff can conduct any final costing and fiscal analysis as typically completed in its normal operating and capital budget preparation cycle.

1.2 Project Approach and Scope of Work

1.2.1 Project Approach and Research Methods

Citygate utilized multiple sources to gather, understand, and model information about the Department. Citygate requested a large amount of background data and information to better understand current costs, service levels, history of service level decisions, and other prior studies.

In subsequent site visits, Citygate performed focused interviews of the Department's project team members and other project stakeholders. Citygate reviewed demographic information about the Department's service area and the potential for future growth and development. Citygate also obtained map and response data from which to model current and projected future fire service deployment, with the goal to identify the location(s) of stations and crew quantities required to best serve the Department as it currently exists and to facilitate future deployment planning.

Once Citygate gained an understanding of the Department's service area and its fire and non-fire risks, the Citygate team then developed a model of fire services that was tested against the travel time mapping and prior response data to ensure an appropriate fit. Citygate also evaluated future service area growth and service demand by risk types. This resulted in Citygate proposing an approach to both address current needs with effective and efficient use of existing resources and long-range needs. The result is a framework for enhancing Fire Department services while meeting reasonable community expectations and fiscal realities.

1.2.2 Project Scope of Work

Citygate's approach to this Standards of Coverage assessment involved:

- Reviewing information provided by the Department and the Town along with conducting stakeholder listening sessions with project stakeholders.
- Utilizing a geographic mapping software program to model fire station travel time coverage.
- Using an incident response time analysis program called StatsFD™ to review the statistics of prior incident performance, plotting the results on graphs and geographic mapping exhibits.
- Identifying and evaluating future Department population and related development growth.
- Projecting future service demand by risk type.
- Identifying and evaluating potential alternate service delivery models.
- Recommending appropriate risk-specific response performance goals.
- Identifying a long-term strategy, including incremental short- and mid-term goals to achieve desired response performance objectives.
- Utilizing the CFAI self-assessment criteria and other NFPA standards as the basis for evaluating the deployment services provided.

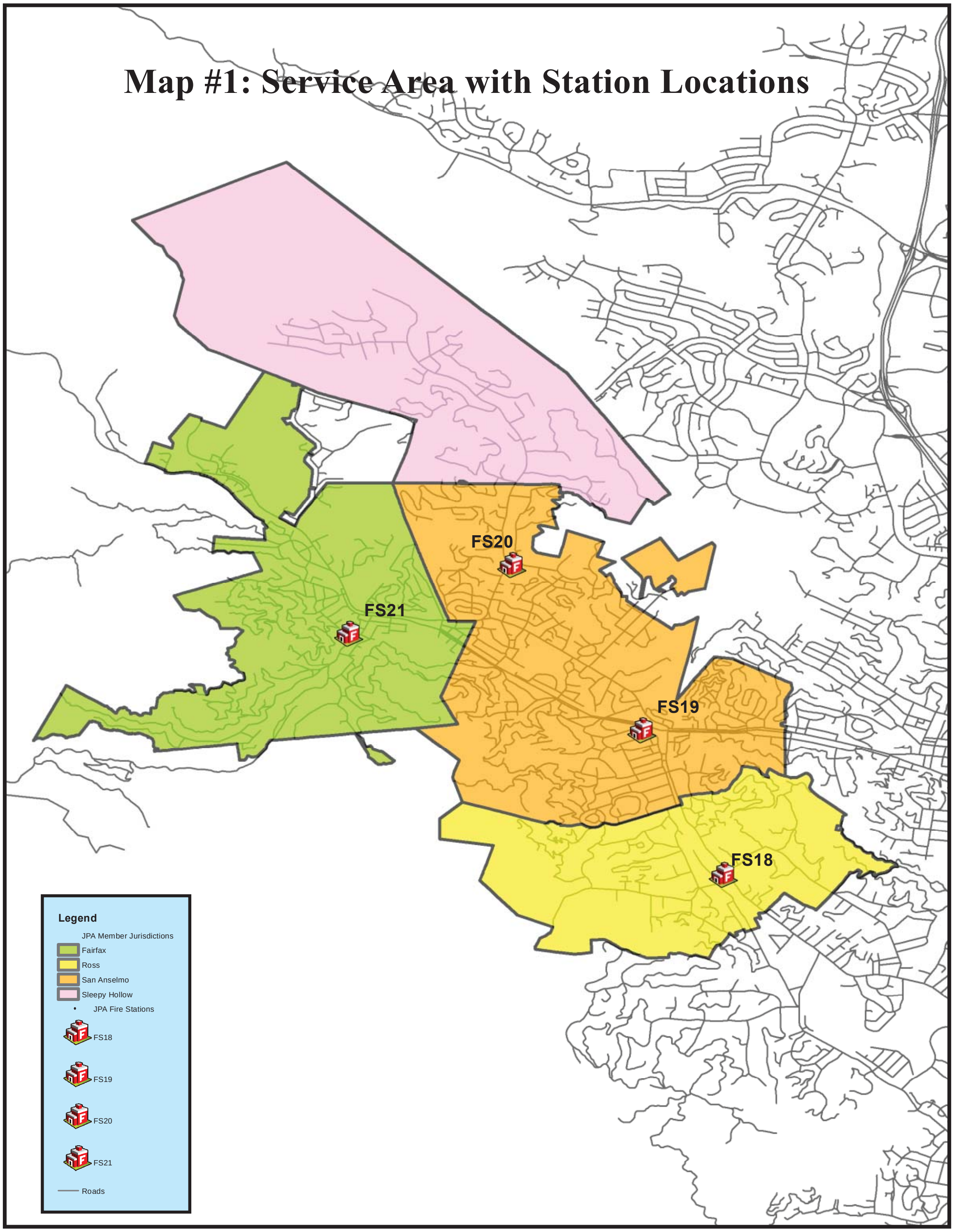
1.3 Communities Served Overview

The Department is a consolidated department protecting lives, property, and the environments of Ross, San Anselmo, Sleepy Hollow, and Fairfax. Ross Valley fire departments trace their history to the early 1900s, with the formation of small volunteer fire departments in the newly formed towns of Ross, San Anselmo, and Fairfax. Built near the wildfire prone slopes of Mount Tamalpais, these communities were and continue to be acutely aware of the risk of fire.

In 1982, the Fairfax Fire Department and the San Anselmo Fire Department joined forces and became known as the Ross Valley Fire Service. At the time Sleepy Hollow was receiving fire protection from the Town of San Anselmo through a contract for service and Sleepy Hollow chose not to become a member of the joint powers authority (JPA) while maintaining a non-voting seat on the Board. In 2010, the JPA was expanded to make Sleepy Hollow a full member of the JPA, ending its contract for service with the Town of San Anselmo. With the expansion of the JPA, the name was changed to the Ross Valley Fire Department. In 2012, Ross Valley Fire Department's Board of Directors voted to consolidate fire services with the Town of Ross, incorporating the

Town of Ross Fire Station 18 into the Ross Valley Fire Department. The current aggregate population of the Department's service area is estimated to be 24,785.

Figure 1—Fire Station Districts and General Geography



1.4 FIRE DEPARTMENT OVERVIEW

The Department's service capacity for building fire, wildland fire, medical emergency, hazardous materials, and technical rescue risk consists of eight personnel on duty daily staffing four Type-1 fire engines and one Duty Battalion Chief, operating from the Department's four fire stations. In addition, Medic 18 with two paramedic/firefighters from the Ross Valley Paramedic Authority (RVPA) is located at Station 18 in the Town of Ross.

All response personnel are trained to either the Emergency Medical Technician (EMT) level—capable of providing Basic Life Support (BLS) pre-hospital emergency medical care—or EMT-Paramedic (Paramedic) level—capable of providing Advanced Life Support (ALS) pre-hospital emergency medical care. Ground paramedic ambulance service is provided by the RVPA in the Department's service area.

Response personnel are also trained to the U.S. Department of Transportation Hazardous Material First Responder Operational (FRO) level to provide initial hazardous material incident assessment, hazard isolation, and for support for the Countywide hazardous material response team.

The Department also operates a cross-staffed Office of Emergency Services (OES) Type-1 (Structural Fire) engine from Station 20, a cross-staffed Type-3 (Wildland Fire) engine from Station 21, plus two reserve structure fire engines, one breathing air resupply unit, one hazardous materials response unit, and one utility truck. Technical rescue personnel and heavy rescue equipment would come from the County mutual aid system.

1.4.1 Facilities and Resources

The Department provides the aforementioned services from four fire stations as shown in Table 3.

Table 3—Fire Department Facilities and Assigned Resources

Station	Location	*Primary* Assigned Resources	*Minimum* Staffing
18	33 Sir Francis Drake Blvd., Ross	Engine	2
19	777 San Anselmo Ave., San Anselmo	Engine Battalion Chief	2 1
20	150 Butterfield Rd., San Anselmo	Engine	2
21	10 Park Road, Fairfax	Engine	2
Total *Per Day*			9

Source: Fire Department

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SECTION 2—STANDARDS OF COVERAGE ASSESSMENT

This section provides a detailed, in-depth analysis of the Department's current ability to deploy and mitigate emergency risks within its service area. The response analysis uses prior response statistics and geographic mapping to help the Department and the community to visualize what the current response system can and cannot deliver.

2.1 STANDARDS OF COVERAGE PROCESS OVERVIEW

The core methodology used by Citygate in the scope of its deployment analysis work is *Standards of Cover*, 5th and 6th editions, which is a systems-based approach to fire department deployment published by the Commission on Fire Accreditation International (CFAI). This approach uses local risk and demographics to determine the level of protection best fitting a community's needs.

The Standards of Coverage (SOC) method evaluates deployment as part of a fire agency's self-assessment process. This approach uses risk and community expectations on outcomes to help elected officials make informed decisions on fire and emergency medical services deployment levels. Citygate has adopted this multi-part systems approach as a comprehensive tool to evaluate fire station locations. Depending on the needs of the study, the depth of the components may vary.

Such a systems approach to deployment, rather than a one-size-fits-all prescriptive formula, allows for local determination. In this comprehensive approach, each agency can match local needs (risks and expectations) with the costs of various levels of service. In an informed public policy debate, a governing board "purchases" the fire and emergency medical service levels the community needs and can afford.

While working with multiple components to conduct a deployment analysis is admittedly more work, it yields a much better result than using only a singular component. For instance, if only travel time is considered, and frequency of multiple calls is not considered, the analysis could miss over-worked companies. If a risk assessment for deployment is not considered, and deployment is based only on travel time, a community could under-deploy to incidents.

Table 4 describes the eight elements of the Standards of Coverage process.

Table 4—Standards of Coverage Process Elements

SOC Element		Description
1	Existing Deployment Policies	Reviewing the deployment goals the agency has in place today.
2	Community Outcome Expectations	Reviewing the expectations of the community for response to emergencies.
3	Community Risk Assessment	Reviewing the assets at risk in the community. (For this report, see Appendix A—Risk Assessment.)
4	Critical Task Analysis	Reviewing the tasks that must be performed and the personnel required to deliver the stated outcome expectation for the ERF.
5	Distribution Analysis	Reviewing the spacing of first-due resources (typically engines) to control routine emergencies.
6	Concentration Analysis	Reviewing the spacing of fire stations so that more complex emergencies can receive sufficient resources in a timely manner (First Alarm Assignment or the ERF).
7	Reliability and Historical Response Effectiveness Analysis	Using prior response statistics to determine the percent of compliance the existing system delivers.
8	Overall Evaluation	Proposing Standard of Coverage statements by risk type as necessary.

Source: CFAI *Standards of Cover*, 5th Edition

Fire service deployment, simply summarized, is about the *speed* and *weight* of the response. *Speed* refers to initial response (first-due), all-risk intervention resources (engines, trucks, and/or ambulances) strategically deployed across a jurisdiction for response to emergencies within a specified time interval to control routine to moderate emergencies without the incident escalating to greater size or severity. *Weight* refers to multiple-unit responses for more serious emergencies such as building fires, multiple-patient medical emergencies, vehicle collisions with extrication required, or technical rescue incidents. In these situations, a sufficient number of firefighters must be assembled within a reasonable time interval to safely control the emergency and prevent it from escalating into a more serious event. Table 5 illustrates this deployment paradigm.

Table 5—Fire Service Deployment Paradigm

Element	Description	Purpose
Speed of Response	Travel time of initial response of all-risk intervention units strategically located across a jurisdiction.	Controlling routine to moderate emergencies without the incident escalating in size or complexity.
Weight of Response	Number of firefighters in a multiple-unit response for serious emergencies.	Assembling enough firefighters within a reasonable time frame to safely control a more complex emergency without escalation.

Thus, smaller fires and less complex emergencies require a single-unit or two-unit response (engine and/or specialty resource) within a relatively short response time. Larger or more complex incidents require more units and personnel to control. In either case, if the crews arrive too late or the total number of personnel is too few for the emergency, they are drawn into an escalating and more dangerous situation. The science of fire crew deployment is to spread crews out across a community or jurisdiction for quick response to keep emergencies small with positive outcomes, without spreading resources so far apart that they cannot assemble quickly enough to effectively control more serious emergencies.

2.2 CURRENT DEPLOYMENT

SOC ELEMENT 1 OF 8
EXISTING DEPLOYMENT POLICIES

Nationally recognized standards and best practices suggest using several incremental measurements to define response time. Ideally, the clock start time is when the 9-1-1 dispatcher receives the emergency call. In some cases, the call must then be transferred to a separate dispatch center. In this setting, the response time clock starts when the dispatch center receives the 9-1-1 call into its computer-aided dispatch (CAD) system. Response time increments include dispatch center call processing, crew alerting and response unit boarding (commonly called turnout time), and actual driving (travel) time.

The Department's response time goals are somewhat dated and not completely up to best practice recommendations. They were most recently discussed in a 2005 Standards of Cover (adopted March of 2005) done by staff as a companion to the 2005 Strategic Plan:

- First unit on-scene within total reflex time of 7-minutes to all areas served with a high potential for life loss, economic value or fire flow. Further 8-minutes for areas with a moderate or low potential for life loss, economic value or fire flow. Time was to be from the 911 call receipt to 90% of the incidents.

- Confine 90% of all structure fires within 30-minutes of arrival after 911 call receipt to the area of involvement as reported by the first arriving fire units, using an Effective Response Force of 14 firefighters with a fire flow stream(s) application of 1,500 gallons per minute (GPM).
- Maintain an emergency response capability, measured from 911 call receipt to arrival, that will ensure initiation of wildland structural fire protection with the first arriving unit within 8-minutes, and the first alarm companies within 12-minutes to 90% of all responses in all areas.
- Maintain an Emergency Medical Response of EMT-Ds,[1] measured from 911 call receipt to arrival, within 8-minutes to 90% of the incidents in all areas served.

Cities, towns, and counties in California have General Plans for land use regulation. One required chapter is a Safety Element. In reviewing the Ross Valley Fire Department's partners General Plans, none of them mention response times. As would be expected in the Marin County region, all of the General Plans contain significant goals and policies for the mitigation of wildfire, including vegetation management, structure resistance to fires, and road access.

The Department does not appear to regularly report measures of response time performance, per the 2005 criteria, to itself and its partner local governments. Internally, Service Level Objectives were reviewed on a regular basis until 2013.

Having adopted performance measures pertaining to all types of risks beside fire and EMS, such as hazardous materials and technical rescues, is considered a best practice today. The Department does have a service level history that can be documented in retrospective response times, number of response companies, and minimum staffing.

Currently, National Fire Protection Association (NFPA) Standard 1710,[2] a recommended deployment standard for career fire departments in urban/suburban areas, recommends initial (first-due) intervention unit arrival within 4:00 minutes *travel* time and recommends arrival of all the resources comprising the multiple-unit First Alarm within 8:00 minutes *travel* time, at 90 percent or better reliability.

As the Department's 2005 goals properly cited, response time begins with the receipt of the 9-1-1 call. The most recent published best practices by the NFPA for dispatching have increased the dispatch processing time up to 90 seconds and, if there are language barriers, 120 seconds. Further,

[1] Emergency Medical Technician – Defibrillator capable.

[2] NFPA 1710 – Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments (2016 Edition).

for crew turnout time, 60-80 seconds is recommended depending on the type of protective clothing that has to be donned.

If the travel time measures recommended by the NFPA (and Citygate) are added to dispatch processing and crew turnout times recommended by Citygate and best practices, then a realistic 90 percent first unit arrival goal is now 7:30 minutes from the time of the Marin County Sheriff's Dispatch Center (Comm Center) receiving the call. This is comprised of 90 seconds dispatch + 2:00 minutes crew turnout + 4:00 minutes travel.

Finding #1:	The Department has legacy response performance objectives partially consistent with best practice recommendations as published by the Commission on Fire Accreditation International. However, they should be updated to reflect current risks and desired outcomes for all types of emergency risk outcomes.

2.2.1 Current Deployment Model

Resources and Staffing

The Department's current deployment model consists of four engines staffed with a minimum of two personnel each and one Battalion Chief, for a total daily minimum year-round continuous staffing of at least 9 personnel operating from four fire stations, plus a two-firefighter/paramedic ambulance from the Ross Valley Paramedic Authority (RVPA). The Department has automatic and mutual aid agreements with all the fire agencies in Marin County and is also a signatory to the State of California Mutual Aid Agreements.

Response Plan

The Department is an all-risk fire agency providing the people it protects with services that include fire suppression, pre-hospital paramedic (ALS) EMS, hazardous material and technical rescue response, and other non-emergency services, including fire prevention, community safety education, and other related services.

Given these risks, the Department utilizes a tiered response plan calling for different types and numbers of resources depending on incident/risk type. The Sheriff's Dispatch Center (Comm Center) process selects and dispatches the closest and most appropriate resource types pursuant to the Department's response plan, as shown in Table 6.

Table 6—Response Plan by Incident Type

Incident Type	Resources Dispatched	Total Personnel*
Single-Patient EMS	1 Engine + 1 Paramedic Ambulance	**4**
Vehicle Fire	1 Engine	**2**
Building Fire, Initial Response**	3 Engines, 1 Ladder Truck, 1 Paramedic Ambulance, 1 Battalion Chief	**12**
Wildland Fire	4 Engines or Wildland Engines, 1 Paramedic Ambulance, 1 Battalion Chief	**12**
Rescue	3 Engines, 1 Ladder Truck, 1 Paramedic Ambulance, 1 Battalion Chief	**12**
Hazardous Material	4 Engines, 1 Paramedic Ambulance, 1 Battalion Chief	**12**

* Personnel were calculated as follows: engines = 2 personnel (except if Engine 17 (Kentfield) staffs 3 personnel); ladder truck = 3 personnel from outside the Department; paramedic ambulance = 2 personnel.
** Confirmed serious fires receive a second Battalion Chief and a fourth engine
Source: Fire Department

Finding #2:	The Department has a standard response plan that considers risk and establishes an appropriate initial response for each incident type. Each type of call for service receives the combination of engines, specialty units, and command officers customarily needed to begin to control that type of incident based on Department experience.

2.3 OUTCOME EXPECTATIONS

SOC ELEMENT 2 OF 8
COMMUNITY OUTCOME EXPECTATIONS

The Standards of Coverage process begins by reviewing existing emergency services outcome expectations. This includes determining for what purpose the response system exists and whether the governing body has adopted any response performance measures. If so, the time measures used must be understood and good data must be available.

Current national best practice is to measure percent completion of a goal (e.g., 90 percent of responses) instead of an average measure. Mathematically, this is called a fractile measure.[3] This is because measuring the average only identifies the central or middle point of response time

[3] A *fractile* is that point below which a stated fraction of the values lies. The fraction is often given in percent; the term percentile may then be used.

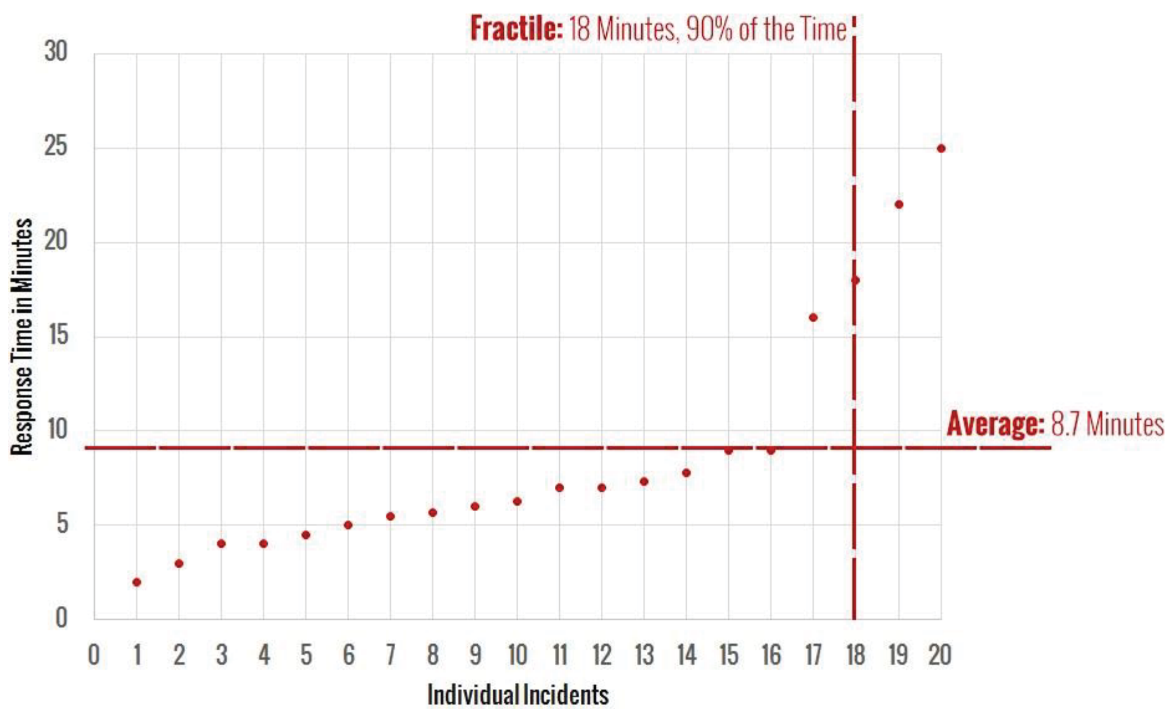
performance for all calls for service in the data set. Using an average makes it impossible to know how many incidents had response times that were way above the average or just above.

For example, Figure 2 shows response times for a fictitious fire department. This agency is small and receives 20 calls for service each month. Each response time has been plotted on the graph from shortest response time to longest response time.

Figure 2 shows that the average response time is 8.7 minutes. However, the average response time fails to properly account for four calls for service with response times far exceeding a threshold in which positive outcomes could be expected. In fact, it is evident in Figure 2 that 20 percent of responses are far too slow and that this jurisdiction has a potential life-threatening service delivery problem. Average response time as a measurement tool for fire services is simply not sufficient. This is a significant issue in larger cities if hundreds or thousands of calls are answered far beyond the average point.

By using the fractile measurement with 90 percent of responses in mind, this small jurisdiction has a response time of 18:00 minutes, 90 percent of the time. This fractile measurement is far more accurate at reflecting the service delivery situation of this small agency.

Figure 2—Fractile versus Average Response Time Measurements



More importantly, within the Standards of Coverage process, positive outcomes are the goal, and from that crew size and response time can be calculated to allow appropriate fire station spacing (distribution and concentration). Emergency medical incidents include situations with the most severe time constraints. The brain can only survive 4:00 to 6:00 minutes without oxygen. Cardiac arrest and other events can cause oxygen deprivation to the brain. Cardiac arrests make up a small percentage; drowning, choking, trauma constrictions, or other similar events have the same effect. In a building fire, a small incipient fire can grow to involve the entire room in a 6:00- to 8:00-minute time frame. If fire service response is to achieve positive outcomes in severe emergency medical situations and incipient fire situations, *all* responding crews must arrive, assess the situation, and deploy effective measures before brain death occurs or the fire spreads beyond the room of origin.

Thus, from the time of 9-1-1 receiving the call, an effective deployment system is *beginning* to manage the problem within a 7:00- to 8:00-minute total response time. This is right at the point that brain death is becoming irreversible and the fire has grown to the point of leaving the room of origin and becoming very serious. Thus, most urban/suburban population density communities desire a <u>first-due</u> response goal that is within a range to give the situation hope for a positive outcome. It is important to note the fire or medical emergency continues to deteriorate from the time of inception, not the time the fire engine starts to drive the response route. Ideally, the emergency is noticed immediately and the 9-1-1 system is activated promptly. This step of awareness—calling 9-1-1 and giving the dispatcher accurate information—takes, in the best of circumstances, 1:00 minute. Then crew notification and travel time take additional minutes. Upon arrival, the crew must approach the patient or emergency, assess the situation, and deploy its skills and tools appropriately. Even in easy-to-access situations, this step can take 2:00 minutes or more. This time frame may be increased considerably due to long driveways, apartment buildings with limited access, multiple-story apartments or office complexes, or shopping center buildings.

Unfortunately, there are times when the emergency has become too severe, even before the 9-1-1 notification and/or fire department response, for the responding crew to reverse; however, when an appropriate response time policy is combined with a well-designed deployment system, then only anomalies like bad weather, poor traffic conditions, or multiple emergencies slow the response system down. Consequently, a properly designed system will give citizens the hope of a positive outcome for their tax dollar expenditure.

For this report, total response time is the sum of Marin County Sheriff's Dispatch Center (Comm Center) dispatch processing plus crew turnout, and road travel time steps. This is consistent with CFAI and NFPA and Citygate best practice recommendations.

2.4 COMMUNITY RISK ASSESSMENT

SOC ELEMENT 3 OF 8
COMMUNITY RISK ASSESSMENT

The third element of the SOC process is a community risk assessment. Within the context of an SOC study, the objectives of a community risk assessment are to:

- Identify the values at risk to be protected within the community or service area.
- Identify the specific hazards with the potential to adversely impact the community or service area.
- Quantify the overall risk associated with each hazard.
- Establish a foundation for current/future deployment decisions and risk-reduction/hazard mitigation planning and evaluation.

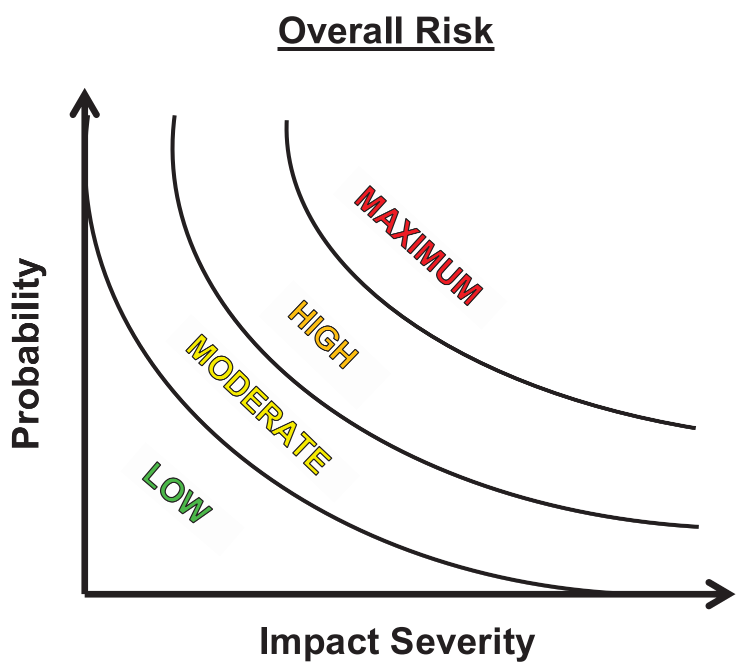
A *hazard* is broadly defined as a situation or condition that can cause or contribute to harm. Examples include fire, medical emergency, vehicle collision, earthquake, flood, etc. *Risk* is broadly defined as the *probability of hazard occurrence* in combination with the *likely severity of resultant impacts* to people, property, and the community as a whole.

2.4.1 Risk Assessment Methodology

The methodology employed by Citygate to assess community risks as an integral element of an SOC study incorporates the following elements:

- Identification of geographic planning sub-zones (risk zones) appropriate to the community or jurisdiction.
- Identification and quantification (to the extent data is available) of the specific values at risk to various hazards within the community or service area.
- Identification of the fire and non-fire hazards to be evaluated.
- Determination of the probability of occurrence for each hazard.
- Identification and evaluation of multiple relevant impact severity factors for each hazard by planning zone using agency/jurisdiction-specific data and information.
- Quantification of overall risk for each hazard based on probability of occurrence in combination with probable impact severity as shown in Figure 3.

Figure 3—Overall Risk



2.4.2 Risk Assessment Summary

Citygate's comprehensive risk assessment is contained in Appendix A of this study. Citygate's evaluation of the values at risk and hazards likely to impact the Ross Valley Fire Department service area yields the following:

1. The Department serves a diverse population, with densities ranging from less than 500 people per square mile to approximately 5,000 per square mile, over a varied land use pattern.
2. The Department's service area population is projected to grow by only 7.7 percent over the next 11 years to 2030, or an average annual growth of approximately 0.7 percent.
3. The service area includes nearly 11,000 housing units, as well as a large inventory of non-residential occupancies.
4. Marin County has a mass emergency notification system to effectively communicate emergency information to the public in a timely manner.
5. The Department's overall risk for five hazards related to emergency services provided range from **Low** to **High**, as summarized in Table 7.

The values in the summary table *do not* place a severity measure on any one risk type; they reflect a composite formula of the probability of occurrence in combination with probable impact severity. For example, while the Department's service area has significant wildland fire risks, the Department experienced only 19 vegetation fires over this study's two-year period, comprising 0.34 percent of total service demand. However, EMS is a daily occurrence, ranging from low- to high-risk individual medical events.

Table 7—Overall Risk by Hazard

Hazard	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Building Fire	*Low*	*Low*	*Moderate*	*Moderate*
Vegetation Fire	*Low*	*Low*	*Low*	*Low*
Medical Emergency	*High*	*High*	*High*	*High*
Hazardous Material	*Moderate*	*Moderate*	*Moderate*	*Moderate*
Technical Rescue	*Low*	*Low*	*Low*	*Low*

2.5 Critical Task Time Measures—What Must Be Done over What Time Frame to Achieve the Stated Outcome Expectation?

SOC Element 4 of 8
Critical Task Time Study

Standards of Coverage (SOC) studies use critical task information to determine the number of firefighters needed within a timeframe to achieve desired objectives on fire and emergency medical incidents. Table 8 and Table 9 illustrate critical tasks typical of building fire and medical emergency incidents, including the minimum number of personnel required to complete each task. These tables are composites from Citygate clients in urban/suburban departments similar to Ross Valley, *but with the more typical* unit staffing of three personnel per engine and two personnel per ambulance. It is important to understand the following relative to these tables:

- It can take a considerable amount of time after a task is ordered by command to complete the task and arrive at the desired outcome.
- Task completion time is usually a function of the number of personnel that are *simultaneously* available. The fewer firefighters available, the longer some tasks will take to complete. Conversely, with more firefighters available, some tasks are completed concurrently.

- Some tasks must be conducted by a minimum of two firefighters to comply with safety regulations. For example, two firefighters are required to search a smoke-filled room for a victim.
- Given the two-firefighter staffing on the Department units, the time to completion will be longer, at times significantly depending on task complexity or a hard to access patient or fire location.

2.5.1 Critical Firefighting Tasks

Table 8 illustrates the critical tasks required to control a typical single-family dwelling fire with six response units (engines/chief), for a total Effective Response Force of *16* personnel, where the Ross Valley Fire Department initially sends **12**. A confirmed serious fire additionally receives a second Battalion Chief and a fourth engine raising this to 15 personnel. However, in many locations these additional units come from much farther away. These tasks are taken from typical fire departments' operational procedures, which are consistent with the customary findings of other agencies using the Standards of Coverage process. No conditions exist to override the Occupational Safety and Health Administration two-in/two-out safety policy, which requires that firefighters enter Immediately Dangerous to Life and Health atmospheres, such as building fires, in teams of two, while two more firefighters are outside and immediately ready to rescue them should trouble arise.

Scenario: *Simulated approximately 2,000 square-foot, two-story residential fire with unknown rescue situation. Responding companies receive dispatch information typical for a witnessed fire. Upon arrival, they find approximately 50 percent of the second floor involved in fire.*

Table 8—First Alarm Residential Fire Critical Tasks – 16 Personnel

Critical Task Description		Personnel Required
1st-Due Engine (3 personnel)		
1	Conditions report	1
2	Establish supply line to hydrant	2
3	Deploy initial fire attack line to point of building access	1–2
4	Operate pump and charge attack line	1
5	Establish incident command	1
6	Conduct primary search	2
2nd-Due Engine (3 personnel)		
7	If necessary, establish supply line to hydrant	1–2
8	Deploy a backup attack line	1–2
9	Establish Initial Rapid Intervention Crew (IRIC)	2
1st-Due Truck (3 personnel)		
10	Conduct initial search and rescue if not already completed	2
11	Deploy ground ladders to roof	1–2
12	Establish horizontal or vertical building ventilation	1–2
13	Open concealed spaces as required	2
Chief Officer		
14	Transfer of incident command	2
15	Establish exterior command and scene safety	1
3rd Due Engine and Rescue Unit (3 personnel each)		
16	Establish Initial Rapid Intervention Crew (IRIC)	3
17	Secure utilities	2
18	Deploy second attack line as needed	2
19	Conduct secondary search	2

The duties in Table 8, grouped together, form an Effective Response Force (ERF) or First Alarm Assignment. These distinct tasks must be performed to effectively achieve the desired outcome; arriving on scene does not stop the emergency from escalating. While firefighters accomplish these tasks, the incident progression clock keeps running. These tasks are also consistent with nationally published research studies.[4]

Fire in a building can double in size during its free-burn period before fire suppression is initiated. Many studies have shown that a small fire can spread to engulf an entire room in less than 4:00 to 5:00 minutes after free burning has started. Once the room is completely superheated and involved in fire (known as flashover), the fire will spread quickly throughout the structure and into the attic and walls. For this reason, it is imperative that fire suppression and search/rescue operations commence before the flashover point occurs if the outcome goal is to keep the fire damage in or near the room of origin. In addition, flashover presents a life-threatening situation to both firefighters and any occupants of the building.

2.5.2 Critical Medical Emergency Tasks

The Department responds to more than 1,407 EMS incidents annually, including vehicle accidents, strokes, heart attacks, difficulty breathing, falls, childbirths, and other medical emergencies.

For comparison, Table 9 summarizes the critical tasks required for a cardiac arrest patient, typically with at least five personnel responding, where the Department sends four.

[4] Report on Residential Fireground Field Experiments, National Institute of Standards and Technology Technical Note 1661, April 2010. NFPA 1710, Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments, 2016 Edition.

Table 9—Cardiac Arrest Critical Tasks – Three Engine Personnel + Two Personnel ALS Ambulance

Critical Task		Personnel Required	Critical Task Description
1	Chest compressions	1–2	Compression of chest to circulate blood
2	Ventilate/oxygenate	1–2	Mouth-to-mouth, bag-valve-mask, apply O_2
3	Airway control	1–2	Manual techniques/intubation/cricothyroidomy
4	Defibrillate	1–2	Electrical defibrillation of dysrhythmia
5	Establish I.V.	1–2	Peripheral or central intravenous access
6	Control hemorrhage	1–2	Direct pressure, pressure bandage, tourniquet
7	Splint fractures	2–3	Manual, board splint, HARE traction, spine
8	Interpret ECG	2	Identify type and treat dysrhythmia
9	Administer drugs	2	Administer appropriate pharmacological agents
10	Spinal immobilization	2–5	Prevent or limit paralysis to extremities
11	Extricate patient	3–4	Remove patient from vehicle, entrapment
12	Patient charting	1–2	Record vitals, treatments administered, etc.
13	Hospital communication	1–2	Receive treatment orders from physician
14	Treat en route to hospital	2–3	Continue to treat/monitor/transport patient

2.5.3 Critical Task Analysis and Effective Response Force Size

What does a deployment study derive from a critical task analysis? The time required to complete the critical tasks necessary to stop the escalation of an emergency (as shown in Table 8 and Table 9) must be compared to outcomes. As shown in nationally published fire service time vs. temperature tables, after approximately 4:00 to 5:00 minutes of free burning a room fire will escalate to the point of flashover. At this point, the entire room is engulfed in fire, the entire building becomes threatened, and human survival near or in the room of fire origin becomes impossible. Additionally, brain death begins to occur within 4:00 to 6:00 minutes of the heart stopping. Thus, the ERF must arrive in time to prevent these emergency events from becoming worse.

The Department's daily staffing plus automatic aid is sufficient to deliver a single ERF of **12** personnel to a building fire—if they can arrive in time, which the statistical analysis of this report will discuss in depth. Mitigating an emergency event is a team effort once the units have arrived. This refers to the *weight* of response analogy; if too few personnel arrive too slowly, then the emergency will escalate instead of improving. The outcome times, of course, will be longer and yield less desirable results if the arriving force is later or smaller.

The quantity of staffing and the arrival timeframe can be critical in a serious fire. Fires in older and/or multiple-story buildings could well require the initial firefighters needing to rescue trapped or immobile occupants. If the ERF is too small, rescue and firefighting operations *cannot* be conducted simultaneously.

Fires and complex medical incidents require that additional units arrive in time to complete an effective intervention. Time is one factor that comes from *proper station placement*. Good performance also comes from *adequate staffing* and training. But where fire stations are spaced too far apart, and one unit must cover another unit's area or multiple units are needed, these units can be too far away and the emergency will escalate and/or result in less-than-desirable outcomes.

Previous critical task studies conducted by Citygate, the National Institute of Standards,[5] and NFPA Standard 1710 find that all units need to arrive with 15+ firefighters within 11:30 minutes (from the time of 9-1-1 call) at a building fire to be able to *simultaneously and effectively* perform the tasks of rescue, fire suppression, and ventilation.

A question one might ask is, "If fewer firefighters arrive, such as does occur in the Ross Valley Department, *what* from the list of tasks mentioned would not be completed?" This is also critical as given the two-firefighter staffing, the initial force is a smaller count as it takes the third- and fourth-due units much longer to arrive. Most likely, the search team would be delayed, as would ventilation. The attack lines would only consist of two firefighters, which does not allow for rapid movement of the hose line above the first floor in a multiple-story building. Rescue is conducted with at least two-person teams; thus, when rescue is essential, other tasks are not completed in a simultaneous, timely manner. Effective deployment is about the **speed** *(travel time)* and the **weight** *(number of firefighters)* of the response.

Sixteen initial personnel could handle a moderate-risk, confined residential fire; however, even an ERF of 16 personnel will be seriously slowed if the fire is above the first floor in a low-rise apartment building or commercial/industrial building. This is where the capability to add additional personnel and resources to the standard response becomes critical.

The Department has to initially dispatch extra units via mutual aid to deliver more personnel, given the two-firefighter per unit staffing, but doing so to deliver the "weight of attack" comes at two disadvantages—first, it takes longer (speed of attack) and second, more units are out of service should another simultaneous incident occur.

Given that the Department's ERF plan delivers **12** personnel to a moderate-risk building fire, it reflects a goal to confine serious building fires to the *building of origin*, *not* the room of origin or

[5] Report on Residential Fireground Field Experiments, National Institute of Standards and Technology Technical Note #1661, April 2010.

to prevent the spread of fire to adjoining buildings or wildland areas. This is a lesser desired outcome for urban/suburban areas, where the goal is to confine a building fire to or very near to the room of origin. That goal requires more firefighters more quickly.

The Department's current physical response to building fires is, in effect, its de-facto deployment measure to its populated areas—*if those areas are within a reasonable travel time from a fire station*. Thus, this becomes the baseline policy for the deployment of firefighters.

2.6 Distribution and Concentration Studies—How the Location of First-Due and First Alarm Resources Affects Emergency Incident Outcomes

SOC Element 5 of 8
Distribution Study

SOC Element 6 of 8
Concentration Study

The Department is served today by four fire stations deploying four engine companies and one Battalion Chief as the duty Incident Commander. It is appropriate to understand using geographic mapping tools what the existing stations do and do not cover for both risks to be protected and the geography that units must travel over.

In brief, there are two geographic perspectives to fire station deployment:

- **Distribution** – the spacing of first-due fire units to control routine emergencies before they escalate and require additional resources.
- **Concentration** – the spacing of fire stations sufficiently close to each other so that more complex emergency incidents can receive sufficient resources from multiple fire stations quickly. As indicated, this is known as the **Effective Response Force**, or, more commonly, the First Alarm Assignment—the collection of a sufficient number of firefighters on scene, delivered within the concentration time goal to stop the escalation of the problem.

To analyze first-due fire unit risks to be protected and coverage, Citygate used a geographic mapping tool to produce the maps described in the following subsection, which can be found in **Volume 2**.

2.6.1 Deployment Baselines

Map #1 – General Geography, Station Locations, and Response Resource Types

Map #1 shows the Department boundary, communities, and fire station service areas. This is a reference map for other maps that follow.

Map #2a – Risk Assessment: Planning Zones

Map #2a shows the four risk planning zones, as recommended by the CFAI, used for this study, which are the same as each station's initial (first-due) response area.

Map #2b – Risk Assessment: High Risk Occupancies

Map #2b displays the locations of the higher-risk building occupancies within the Department, as defined by the CFAI. These building occupancies typically require a larger initial ERF (staffing) due to the higher risks associated with these specific occupancies. It is apparent that there are high-risk occupancies in every planning zone.

Map #2c – Risk Assessment: Hazardous Materials Use/Storage Occupancies

Map #2c displays the locations of the higher-risk commercial building occupancies that use and/or store regulated Hazardous Materials. The regulations for these uses are enforced by the County Department of Public Works as the State-designated Certified Unified Program Agency (CUPA) for the County.

Map #2d – Risk Assessment: Wildland Fire Severity Zones

Map #2d displays the California Department of Forestry and Fire Protection (CAL FIRE) State Responsibility Areas for wildland fire protection, where the state has primary fiscal responsibility for wildfires through the Marin County Fire Department.

Map #2e – Risk Assessment: Lower Fire Flow (Water) Locations

Map #2e displays the locations of fire hydrants on older, smaller water mains that can only provide up to 500 or 1,000 gallons per minute of firefighting flow. Most newer communities can provide neighborhood fire flows substantially higher than this and most current fire department pumpers can easily pump 1,500-2,000 gallons per minute. Larger commercial building fires can require 2,000 to 5,000 gallons per minute, provided by several pumpers and hydrants.

Map #3 – Distribution: First-Due Travel Distance Coverage

This map displays the Insurance Service Office (ISO) recommendation that fire stations in developed areas cover a 1.5-mile *distance* response area. Depending on a jurisdiction's road network, the 1.5-mile measure usually equates to a 3:30- to 4:00-minute travel time. Thus the 1.5-mile measure is a reasonable indicator of station spacing and overlap. This map shows first-due unit coverage distance of 1.5 miles across the public road network from the Department's current fire station locations. The 1.5-mile coverage goes from very light meaning a single unit to very dark where three units overlap. The coverage also assumes all units are in station and available for response.

The purpose of response coverage modeling is to determine response time coverage across a jurisdiction's geography and station locations. This geo-mapping design is then validated against dispatch time data in the next section of this study to reflect actual response times. There should be some overlap between station areas so that a second-due unit can have a chance of an acceptable response time when it responds to a call in a different station's first-due response area. As can be seen, there is some overlap coverage in the more built-up areas of the Department.

Map #4 – Medic 18 Ambulance Coverage Areas

This map displays the service area assigned to Medic 18, where the goal is to cover the most populated areas within 8:00 minutes *travel* time. This map shows the importance for Medic 18 to be centrally located to cover from Greenbrae west to Sleep Hollow and Fairfax.

Map #5 – All Incident Locations

Map #5 shows the location of all incidents from 2017 through 2018. It is apparent that incidents occur in most all areas of the Department and to other areas for mutual aid.

Map #6 – Emergency Medical Services and Rescue Incident Locations

Map #9 illustrates only the emergency medical and rescue incident locations over the last two years. With the majority of the calls for service being medical emergencies, virtually all areas of the Department need pre-hospital emergency medical services. The greatest population density also incurs the highest EMS demand patterns. Medic 18 responses are <u>not</u> located on this map.

Map #7 – All Fire Locations

This map identifies the location of all fires within the Department over the last two years. All fires include <u>any</u> type of fire call, from vehicle to dumpster to building. There are obviously fewer fires than medical or rescue calls. Even given this, it is evident that fires occur in all fire station areas.

Map #8 – Structure Fire Locations

Map #8 displays the location of the structure fire incidents over the last two years. While the number of structure fires is a smaller subset of total fires, there are two meaningful findings from this map. First, there are structure fires in every fire station area, and second, there are a relatively small number of building fires in the Department overall, which in Citygate's experience is consistent with other similar smaller communities in the western United States.

Finding #3:	The mapping analysis shows the need for neighborhood-based first response units for fire and EMS incidents.

Finding #4:	The risk assessment maps show there are risks to be protected from fire besides just single-family homes, and some areas have lower fire flow capacity for serious or conflagration size fires.

2.7 Statistical Analysis

SOC Element 7 of 8
Reliability & Historical Response Effectiveness Studies

The map sets described in Section 2.6 above and presented in **Volume 2** show the ideal situation for response times and the response effectiveness given perfect conditions with no competing calls, traffic congestion, units out of place, or simultaneous calls for service. Examination of the actual response time data provides a picture of actual response performance with simultaneous calls, rush hour traffic congestion, units out of position, and delayed travel time for events such as periods of severe weather.

The following subsections provide summary statistical information regarding the Department and its services.

2.7.1 Demand for Service

The Department provided both federal National Fire Reporting System (NFIRS) version 5 incident and computer-aided dispatch (CAD) apparatus response data for two complete years from January 1, 2017 through December 31, 2018.

In 2018, the Department responded to 2,685 incidents, which is a daily demand of 7.36 incidents. During this same period, there were 7,503 individual apparatus responses. This means there was an average of 2.8 apparatus responses per incident, which is considered high and is likely due to the low staffing levels on each apparatus. The number of incidents has been calculated from NFIRS 5 records furnished for 2017 and 2018. According to these records, the Department experienced a decline in the number of incidents from 2017 through 2018.

Figure 4—Annual Service Demand by Year

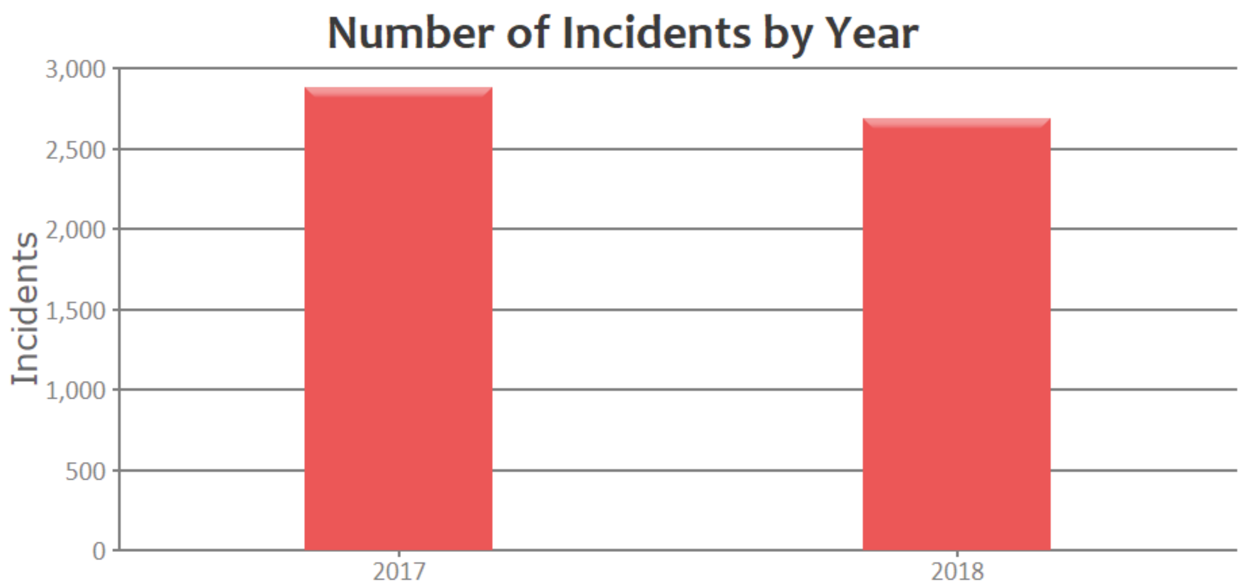


Figure 5 illustrates the number of incidents by incident type. While fire and EMS incidents remained relatively constant, there was a decrease in the number of other incident types. A reduction in the number of "other" incidents was most responsible for the decline in the total number of incidents.

Figure 5—Number of Incidents by Year – All Incident Types

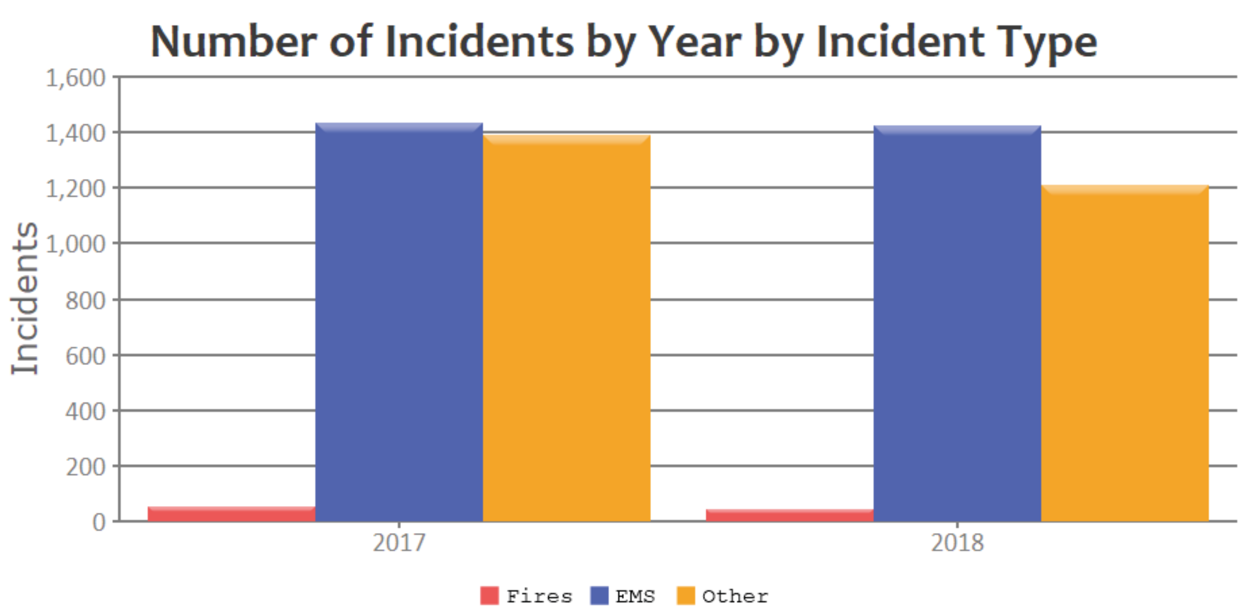
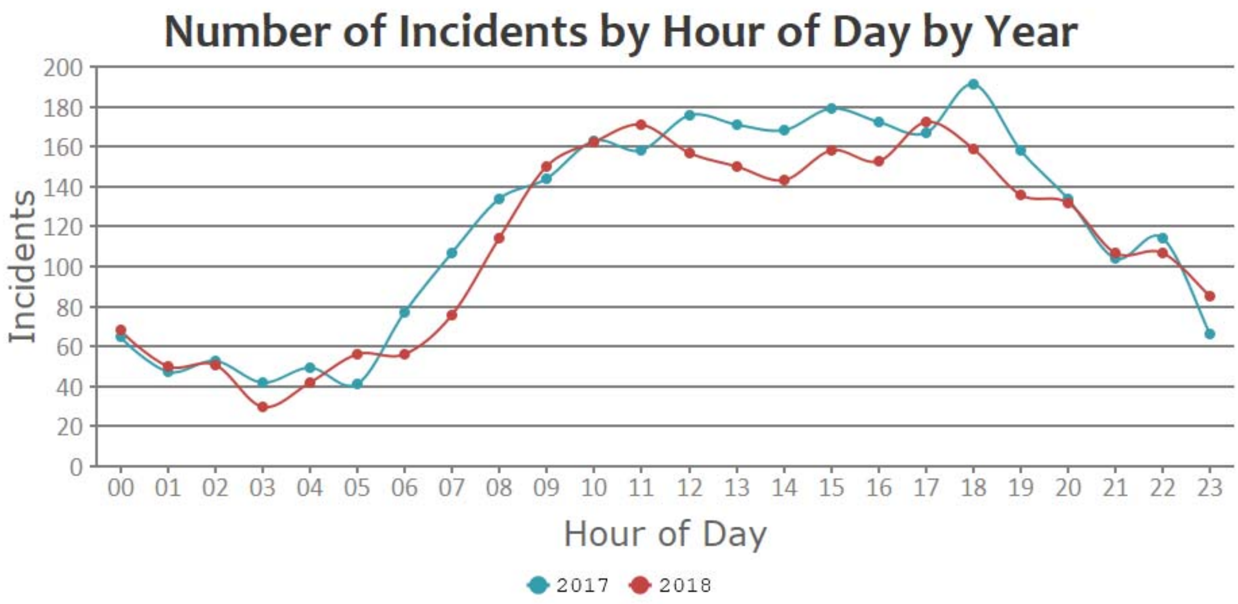


Figure 6 shows service demand by hour of day, illustrating that calls for service occur at every hour of the day and night, requiring fire and EMS response capability 24 hours per day, every day of the year. There was also a pattern of increased activity in 2017 during the morning, afternoon, and early evening hours.

Figure 6—Service Demand by Hour of Day and Year



Finding #5:	The Department's service demand is consistent, indicating the need for a 24-hours-per-day, seven-days-per-week fire and EMS emergency response system.

The next figure illustrates the number of incidents by station area in 2018. Station 21 had the highest volume of activity.

Figure 7—Number of Incidents by Station – 2018

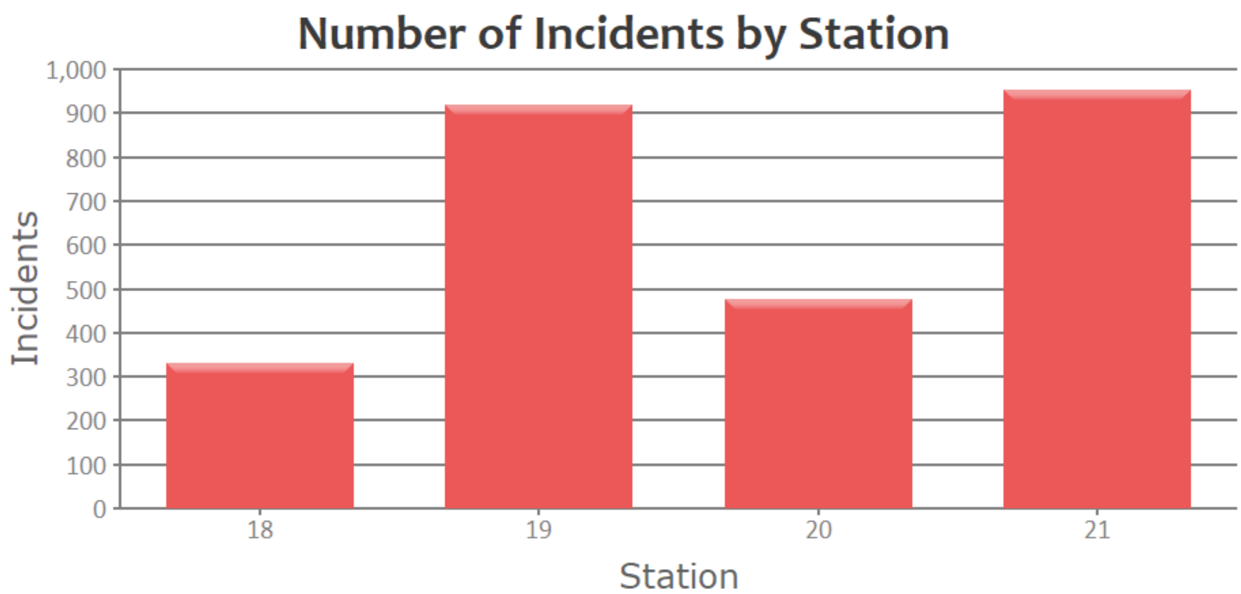


Table 10 lists the activity rankings of incidents by incident quantity, for more than 15 occurrences in a year. Note the strong ranking for EMS incidents.

Table 10—Incidents: Quantity by Incident Type – 2018

Incident Type	2018
321 EMS call, excluding vehicle accident with injury	1,343
611 Dispatched and canceled en route	232
553 Public service	197
554 Assist invalid	135
651 Smoke scare, odor of smoke	126
550 Public service assistance, other	75
322 Vehicle accident with injuries	51
743 Smoke detector activation, no fire – unintentional	49
700 False alarm or false call, other	41
745 Alarm system sounded, no fire – unintentional	35
412 Gas leak (natural gas or LPG)	32
444 Power line down	31

Incident Type	2018
600 Good intent call, other	30
622 No incident found on arrival of incident address	22
733 Smoke detector activation due to malfunction	20
740 Unintentional transmission of alarm, other	17
324 Motor vehicle accident no injuries	16
500 Service call, other	16
111 Building fire	16
735 Alarm system sounded due to malfunction	16
736 CO detector activation due to malfunction	15

Table 11 illustrates the ranking of incidents by property types. The highest rankings for incidents by property type are residential dwellings. Only those property types with 25 or more incidents are shown.

Table 11—Incidents: Quantity by Property Use – 2018

Property Use (NFIRS Code/Description)	2018
419 1 or 2 family dwelling	1,338
429 Multifamily dwellings	271
962 Residential street, road or residential driveway	218
960 Street, other	157
963 Street or road in commercial area	80
900 Outside or special property, other	72
311 24-hour care nursing homes, 4 or more persons	58
215 High school/junior high school/middle school	39
965 Vehicle parking area	34
161 Restaurant or cafeteria	29
888 Fire station	29
519 Food and beverage sales, grocery store	26
931 Open land or field	25

2.7.2 Simultaneous Emergency Incident Activity

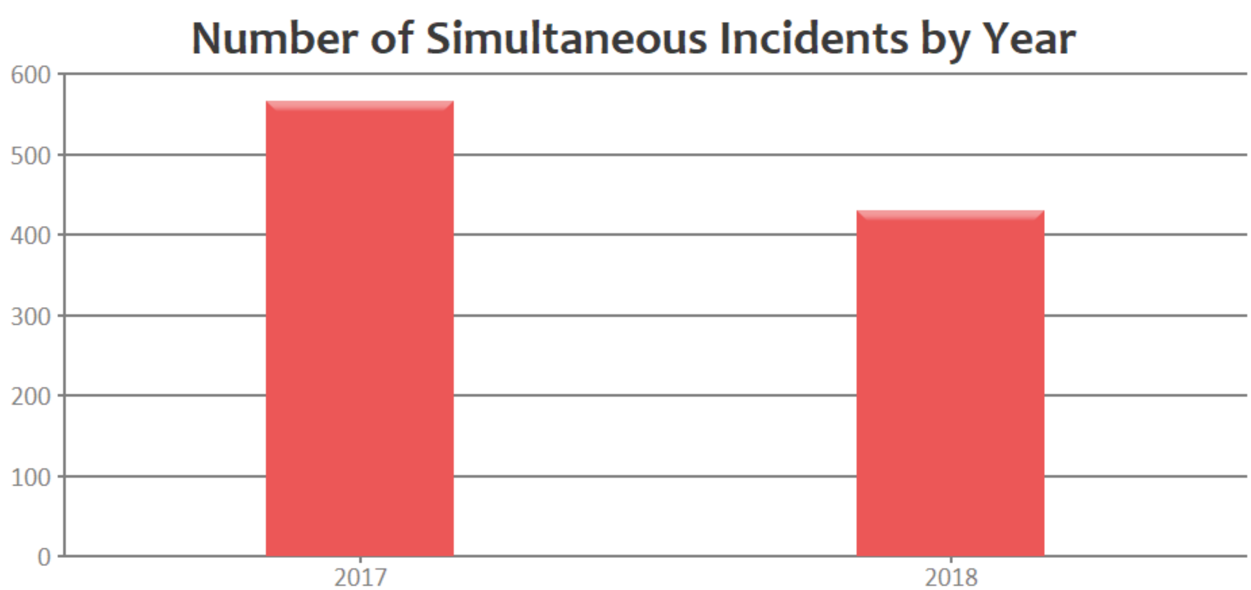
Simultaneous incidents occur when other incidents are underway at the time a new incident develops. In the Department's response area during 2018, 16.05 percent of incidents occurred while one or more other incidents were underway. The following is the percentage of simultaneous emergency incidents broken down by the number of simultaneous incidents. Non-emergency incidents are not included as a unit can be re-dispatched to a serious emergency.

Table 12—Percentage by Number of Simultaneous *Emergency* Incidents

Number of Simultaneous Incidents	Percentage
1 or more simultaneous incidents	16.05%
2 or more simultaneous incidents	01.30%
3 or more simultaneous incidents	00.01%

The following graph shows the number of simultaneous incidents can be volatile and recently decreased.

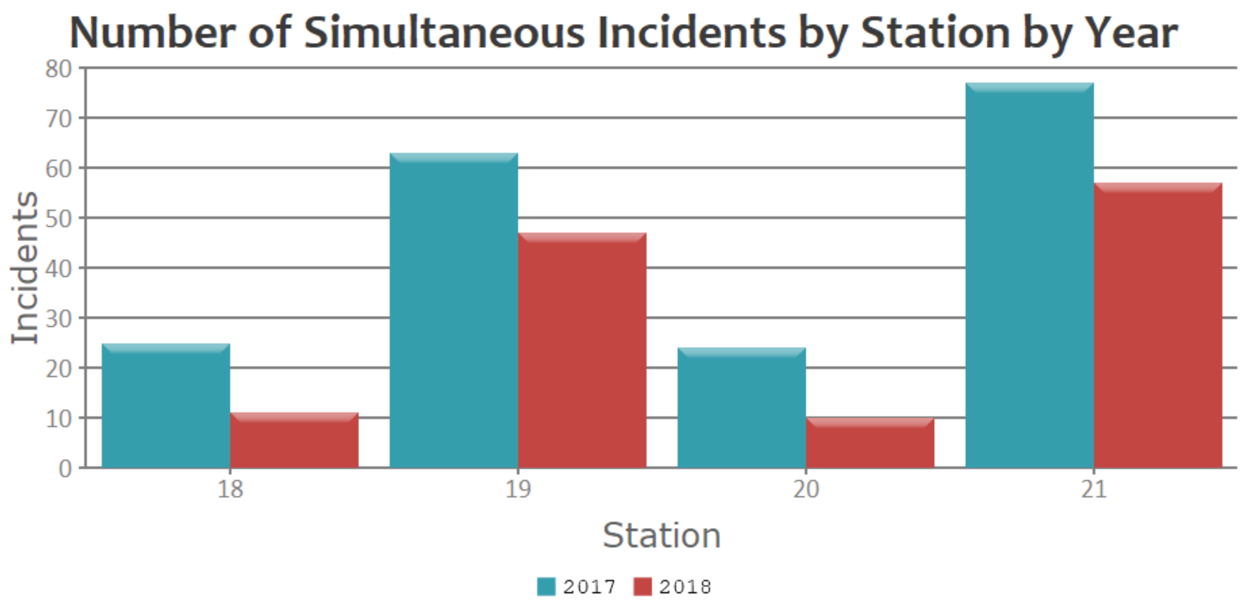
Figure 8—Number of Simultaneous Incidents by Year



In a larger region, simultaneous incidents in different station areas have very little operational consequence. However, when simultaneous incidents occur within a single station area, there can be significant delays in response times.

Figure 9 illustrates the number of single-station simultaneous incidents by station area by year. Station 21 has the highest number of in-station-area simultaneous incidents. Each station area experienced a significant drop in the number of simultaneous incidents from the previous year.

Figure 9—Number of Single-Station Simultaneous Incidents by Station by Year



Finding #6:	The number of simultaneous incidents is volatile. However, in a four-station department, it is very rare that more than two incidents occur at once.

2.7.3 Operational Performance

Measurements for the performance for the first apparatus to arrive on the scene of emergency incidents are the number of minutes and seconds necessary for 90 percent completion of the following components:

- Call processing
- Turnout
- Travel
- Dispatch to arrival
- Call to arrival

Each one of these components starts with a year-to-year comparison followed by a representation of performance over incremental time segments. Finally, each section includes a graph breaking down compliance with a stated goal by hour of day.

2.7.4 Call Processing

Call processing measures the time from the first incident time stamp in the Marin County Sheriff's Dispatch Center (Comm Center) until apparatus are notified of the request for assistance.

Table 13 shows call processing is 1:04 minutes for 90 percent compliance.

Table 13—Call Processing Performance to 90 Percent of Fire and EMS Incidents

Station	2018
Department-Wide	**01:04**
Station 18	01:12
Station 19	01:03
Station 20	01:01
Station 21	01:04

Finding #7:	Call processing performance at 1:04 minutes is *better than* a best practice recommendation of 1:30 minutes.

2.7.5 Turnout Time

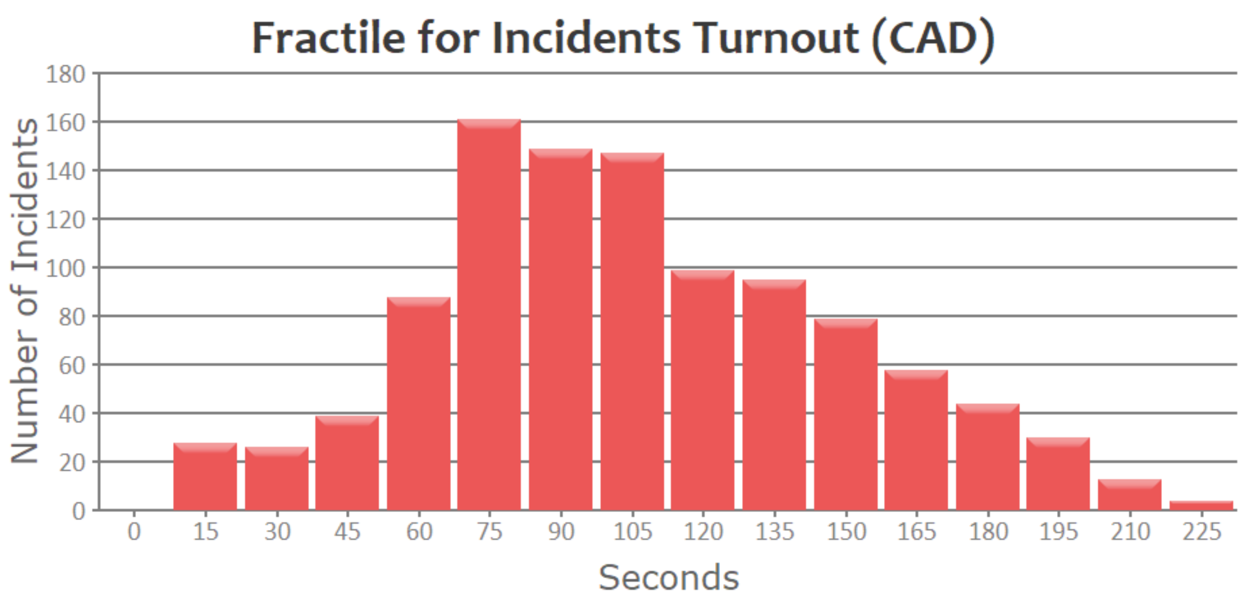
Turnout time measures the time from apparatus notification until apparatus starts traveling to the scene. In Table 14, a 2:00-minute Citygate recommended goal is used for measurement. Only one fire station is less than 30 seconds from a 2:00-minute turnout time.

Table 14—Turnout Time Performance to 90 Percent of Fire and EMS Incidents

Station	2018
Department-Wide	**02:41**
Station 18	02:19
Station 19	02:50
Station 20	02:38
Station 21	02:40

Figure 10 illustrates fractile turnout time performance. The peak segment for turnout performance is 75 seconds.

Figure 10—Fractile for Incidents Turnout (CAD)



Finding #8:	Crew turnout performance at 2:41 minutes is *slower* than a Citygate-recommended goal of 2:00 minutes or less.

2.7.6 Travel Time

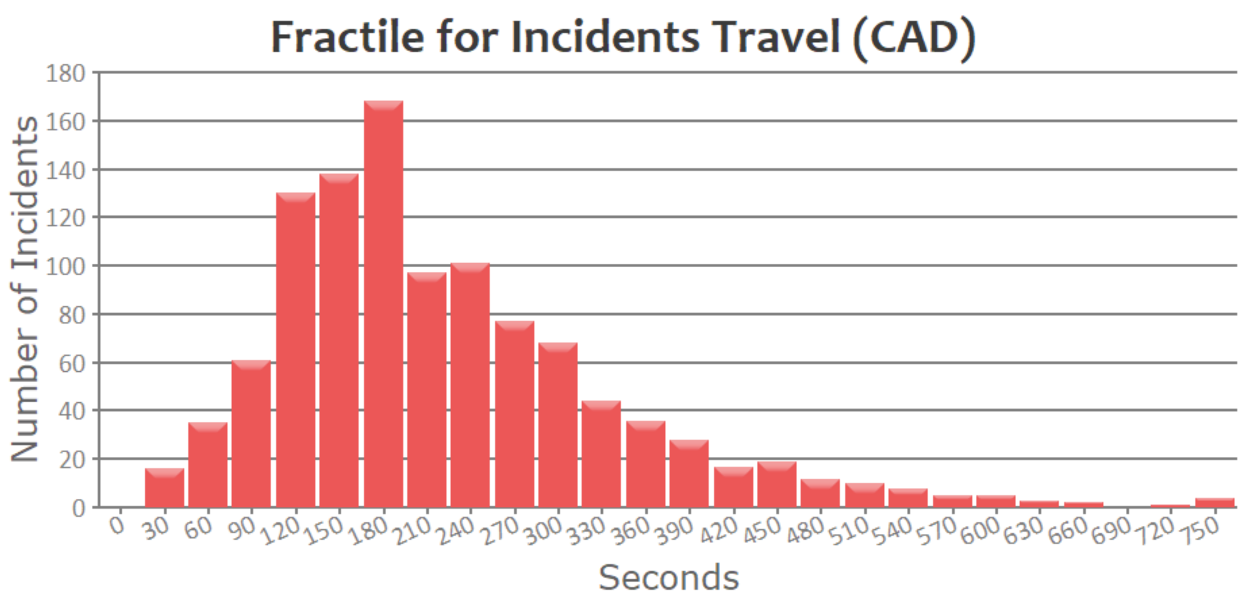
Travel time measures time to travel to the scene of the emergency. In most urban and suburban fire departments, a 4:00-minute travel time 90 percent of the time would be considered highly desirable. Table 15 shows that no stations achieve that goal.

Table 15—Travel Time Performance to 90 Percent of Fire and EMS Incidents

Station	2018
Department-Wide	**06:09**
Station 18	04:40
Station 19	05:38
Station 20	06:24
Station 21	06:30

The following graph illustrates fractile travel time performance. The peak segment for travel time performance is 180 seconds, or 3:00 minutes. There is a rapid drop-off in volume after the 180-second mark.

Figure 11—Fractile for Incidents Travel (CAD)



Finding #9:	First-due unit travel time performance to 90 percent of the incidents Department-wide at 6:09 minutes is well past the Department's likely goal of 4:00 minutes, a goal consistent with best practices.

2.7.7 Call to Arrival

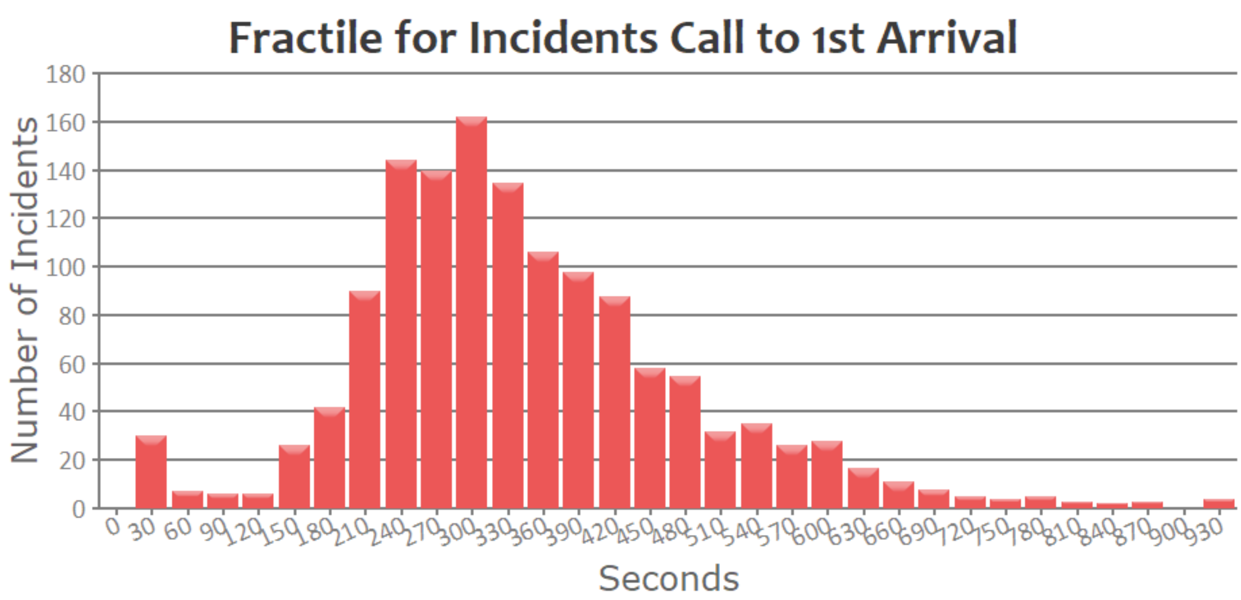
Call to arrival measures time from receipt of the request for assistance until the apparatus arrives on the scene. The existing Department total response time goal is 7:00 minutes to 90 percent of the emergency incidents.

Table 16—Call to Arrival Performance to 90 Percent of Fire and EMS Incidents

Station	2018
Department-Wide	**08:45**
Station 18	07:55
Station 19	07:45
Station 20	08:47
Station 21	09:07

The following graph illustrates fractile call to arrival performance. The peak segment is 300 seconds, or 5:00 minutes. The right-shifted graph indicates a number of incidents with longer travel times.

Figure 12—Fractile for Incidents Call to First Arrival



Finding #10:	The Department's call to arrival time to 90 percent of the incidents at 8:45 is slower than a Citygate's recommended goal of 7:30 minutes in developed suburban areas. The principal reason is the longer travel times, reflective of the topography and road network in the Department's service area.

2.7.8 Effective Response Force (First Alarm) Concentration Measurements

The minimum (not including the Chief Officer or ambulance) ERF for structure fires from the Department is three engines and one ladder truck. Additionally, an ambulance unit and one Chief Officer are sent. A best practices goal is for the last arriving unit's travel time to be less than 8:00 minutes in developed areas.

Table 17—Distribution – Structure Fire Initial Response – Fourth-Due Unit Travel Time Performance to 90 Percent of Fire and EMS Incidents

Station	2018
Station 18	08:50
Station 19	08:19
Station 20	10:20
Station 21	10:21

Finding #11:	The Effective Response Force (First Alarm) *travel* times are only modestly longer than a best practices goal of 8:00 minutes and are reflective of the good, central placement of the four fire stations.

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SECTION 3—TOWN OF ROSS FOCUSED STUDY

As part of the overall Standards of Cover assessment for the Ross Valley Fire Department partnership, the Town of Ross requested a focused study for the need to maintain the fire engine and/or Medic Ambulance 18 in the Town's fire station which dates to 1926. As all the partners know, replacing or relocating this station will be very difficult due to land use limitations. To evaluate the need for a station in the Town of Ross a series of questions must be considered. These questions are all answered in this section. After this section and Citygate's resultant findings, the last section of this study will provide a set of comprehensive recommendations.

The incident data range used in this section (except for items #1 and #2 below) is the same as the overall analysis in Section 2.7—January 1, 2017 through December 31, 2018.

3.1 QUESTIONS REGARDING STATION 18

1. How many fires have there been in the Town in each of the last six years? How many of them were structure versus non-structural?
   - One structure fire; 25 non-significant structure fires such as arcing wires or smell of smoke from equipment.
2. What is the fire loss estimate in the Town for the last six years?
   - $198,107
3. What is the breakdown of calls by year in the Town for two or three years?

Figure 13—Number of Incidents by Year by Incident Type – Station 18

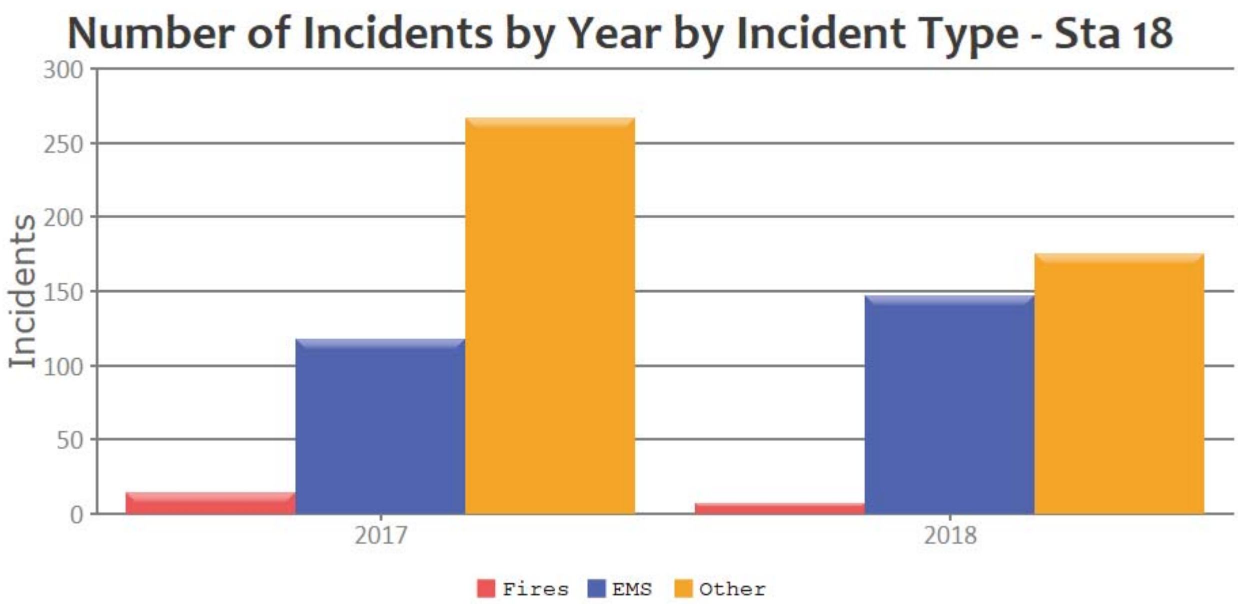


Table 18—Incidents: Quantity – Year by Incident Type for Station 18 – 2017 and 2018

Incident Type	2017	2018
321 EMS call, excluding vehicle accident with injury	114	133
611 Dispatched and canceled en route	71	38
553 Public service	28	20
554 Assist invalid	25	6
550 Public service assistance, other	11	15
651 Smoke scare, odor of smoke	10	11
412 Gas leak (natural gas or LPG)	11	9
571 Cover assignment, standby, move-up	8	11
743 Smoke detector activation, no fire – unintentional	8	10
745 Alarm system sounded, no fire – unintentional	10	7
400 Hazardous condition, other	13	2
444 Power line down	7	6
322 Vehicle accident with injuries	2	10
700 False alarm or false call, other	8	3
744 Detector activation, no fire – unintentional	5	5
622 No incident found on arrival of incident address	7	3

Incident Type	2017	2018
733 Smoke detector activation due to malfunction	6	3
735 Alarm system sounded due to malfunction	5	3
111 **Building fire**	**7**	
736 CO detector activation due to malfunction	3	3
740 Unintentional transmission of alarm, other	1	4
324 Motor vehicle accident no injuries	2	3
500 Service call, other	2	2
900 Special type of incident, other	1	2
730 System malfunction, other	2	1
650 Steam, other gas mistaken for smoke, other	1	2
600 Good intent call, other	1	2
531 Smoke or odor removal	1	2
440 Electrical wiring/equipment problem, other	3	
812 Flood assessment	2	
800 Severe weather or natural disaster, other	2	
746 Carbon monoxide detector activation, no CO	2	
734 Heat detector activation due to malfunction	2	
653 Barbecue, tar kettle	1	1
551 Assist police or other governmental agency	1	1
520 Water problem, other	1	1
463 Vehicle accident, general cleanup	1	1
131 Passenger vehicle fire	1	1
118 Trash or rubbish fire, contained	2	
100 Fire, other		2
813 Wind storm, tornado/hurricane assessment	1	
621 Wrong location	1	
552 Police matter	1	
522 Water or steam leak		1
521 Water evacuation	1	
462 Aircraft standby		1
461 Building or structure weakened or collapsed	1	
441 Heat from short circuit (wiring), defective/worn	1	
422 Chemical spill or leak	1	

Incident Type	2017	2018
354 Trench/below grade rescue		1
162 Outside equipment fire	1	
160 Special outside fire, other		1
151 Outside rubbish, trash or waste fire		1
142 Brush, or brush and grass mixture fire	1	
141 Forest, woods or wildland fire		1
140 Natural vegetation fire, other	1	
130 Mobile property (vehicle) fire, other	1	
116 Fuel burner/boiler malfunction, fire confined	1	
113 Cooking fire, confined to container		1
Total	**400**	**330**

4. What is the service call comparison between each of the four stations? Are there industry averages or norms with which that can be compared?

   ➢ There are no comparisons; all communities are different and "purchase" fire protection stand-by as "fire insurance" if they use it once a year or once a day.

   ➢ See Figure 7 on page 37 for volume by station.

5. In the Town, what is the 90 percent response time to fire calls, emergency calls, and all calls – <u>anywhere</u> Station 18 went?

   ➢ The following table shows the Station 18 response times to emergency incidents. The time listed is the time to completion, 90 percent of the time; the number in parenthesis is the number of records included in the calculation.

<u>Table 19—Station 18 Response Times to All Calls at 90 Percent Compliance</u>

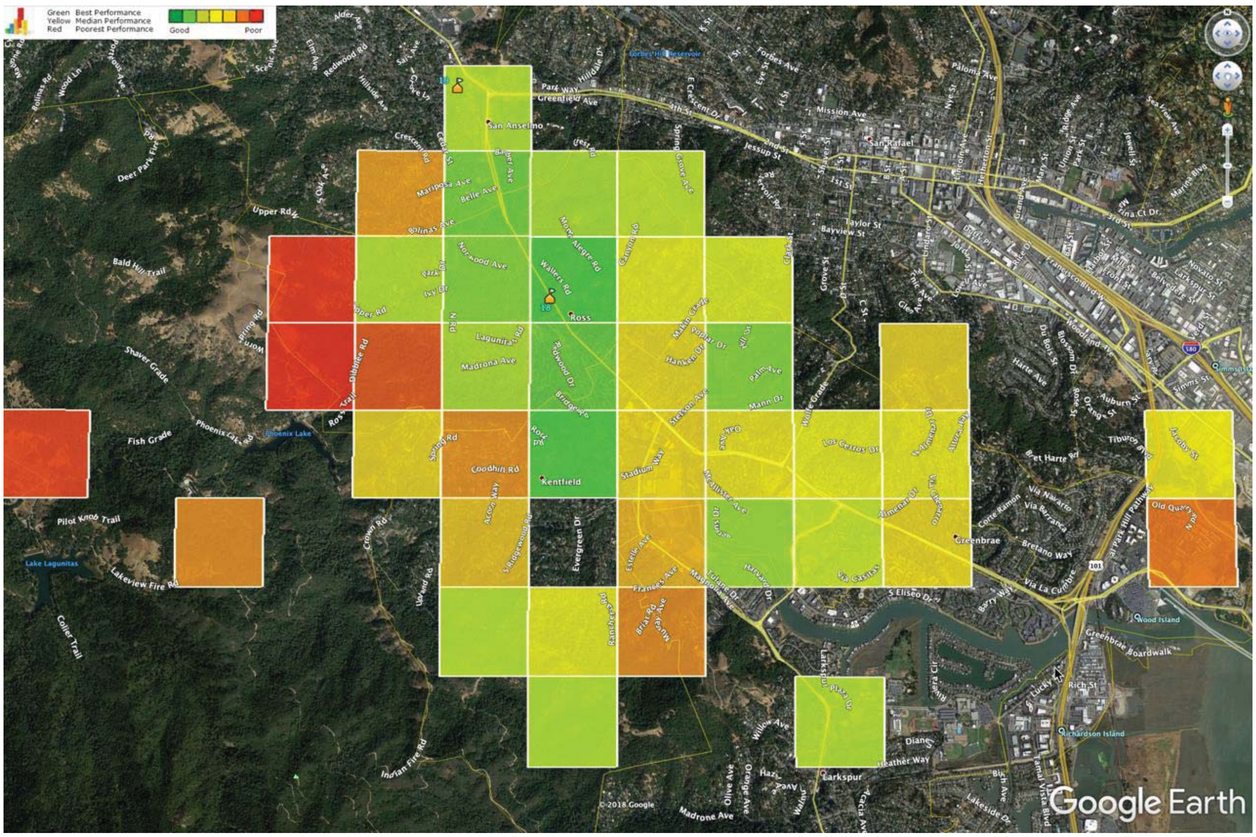
Response Element—Station 18	Overall	2017	2018
Dispatch Processing	01:12 (214)	00:52 (93)	01:12 (121)
Crew Turnout	02:32 (170)	02:38 (77)	02:19 (93)
Travel Time	05:05 (174)	05:14 (78)	04:40 (96)
Call to Arrival	08:28 (226)	08:40 (100)	07:55 (126)

6. What does the map that shows 90 percent response times by Station 18 look like?

   - As would be expected, the better response times tend to be closer to the stations and along the main road network. However, given the low quantity of incidents (small sample size math) and that some incidents are covered by units not in the station, or are responded to by a station farther away due to simultaneous incidents, the following map is <u>not</u> a static picture year over year.

     The following map shows in green where travel time is the fastest—at or near the desired goal point of 4:00 minutes. Orange to red indicates the longest travel times of 5:00 to 9:00 minutes.

<u>Figure 14—90 Percent Response Times by Distance for All Department Stations</u>



7. What is the number of events that Station 18 responded to in the response areas for Stations 19, 20, and 21?

   - The following table lists the responses by vehicle ID.

- ➢ The table also includes multiple-unit responses as some complex incidents require more staffing.

Table 20—Responses by Vehicle ID – 2017 and 2018

City	E18	E19	E20	E21	M14	M18
San Anselmo	133	1,550	761	117	188	1,012
Fairfax	12	29	213	1,733	22	707
Ross	**287**	15		3	38	187
Sleepy Hollow			95	11		42
Kentfield	**44**	3				804
Woodacre				7		
Fallon				4		2
Larkspur	2	1		2		131
Greenbrae	2					756
Forest Knolls				2		
San Rafael		1				
San Geronimo				1		
Point Reyes Station				1		
Corte Madera	1					151
Total	**481**	**1,599**	**1,069**	**1,881**	**248**	**3,792**

8. What is the number of medical emergencies the Ross Valley Paramedic Authority responds to in the Town per year?

- ➢ The following table shows the number of responses by apparatus by destination station area.

Table 21—EMS Responses by Station 18 Apparatus by Destination Station Area

Station	E18	M18	Total
18	214	169	383
19	60	862	922
20	12	192	204
21	12	707	719
Total	**298**	**1,930**	**2,228**

The previous table shows Medic 18's most frequent destination is Station 19, followed by Station 21. The station least likely to require a medic unit is Station 18. However, Medic 18 is a regional unit and, as such, is properly located in the middle of its response area east to west. This table also shows Engine 18 is more likely to remain inside Station 18's area but, if drawn outside, is most likely to travel into Station 19's area.

The following list shows which engine arrived first to EMS events in the Town of Ross. When both Station 18 units respond from inside the Town, arriving first is only a matter of seconds. The purpose of this table is to also show units other than those at Station 18 which arrive first:

- Engine 18 arrived first 165 times
- Engine 23 arrived first 40 times
- Engine 19 arrived first 6 times
- Engine 17 arrived first 3 times (Kentfield)
- Engine 21 arrived first 1 time
- Medic 18 arrived first 33 times
- Medic 14 arrived first 2 times

These numbers were calculated for all apparatus responding to EMS incidents and tend to mimic actual operational arrivals. If the search from the regional CAD data for the last two years is for where Station 18 EMS incidents involved both Engine 18 and Medic 18, there were 224 incidents.

9. How often was Station 17 (Kentfield) first on scene to a Town call? What is Station 17's response time to a Town call?

   - In 2017 and 2018, **Engine 17** arrived first in Station 18's area 19 times for *all* incident types. The 90 percent travel time was a little over 8:00 minutes, but this figure is highly volatile and ranges from 5:00 minutes to 21:00 minutes travel time across the various areas of the Town.

10. How often was Station 19 (San Anselmo) first on scene to a Town call?

   - In 2017 and 2018, **Engine 19** arrived first in Station 18's area 20 times to *all types* of incidents. The 90 percent travel time was about 9:45 minutes; again, this figure is highly volatile.

11. What is Station 19's average response time to a Town call?

- By national best practices, response times are not reported as averages, but as a fractile percent of a goal point. The following table lists anywhere Station 19 responded. The time listed is the time to completion 90 percent of the time; the number in parenthesis is the number of records included in the calculation.

Table 22—Station 19 Response Times to All Calls at 90 Percent Compliance

Response Element—Station 19	Overall	2017	2018
Dispatch Processing	01:02 (971)	01:01 (481)	01:03 (490)
Crew Turnout	02:44 (773)	02:40 (383)	02:50 (390)
Travel Time	05:50 (788)	06:00 (387)	05:38 (401)
Call to Arrival	08:03 (991)	08:23 (490)	07:45 (501)

3.2 Impact if Fire Station 18 Closes

12. Provide a current map of the first response for Stations 17, 18, 19, 20, and 21.

- Please refer to Map #3 in the Map Atlas of this report in **Volume 2**.

13. If Station 18 closed, what is the first response map for Stations 17, 19, 20, and 21? What is the zone of coverage map for the back-up initial response with closure of Station 18?

- Station 17 is outside of Citygate's historical statistical and geographic analysis. The Marin County Fire Chiefs Association would have to create a response matrix based on fire reporting districts to create a map. Based on existing station locations for 17 and 19, the Town of Ross would not receive the same coverage as from Station 18.

14. What is the impact to response times in Stations 19, 20, and 21 areas without Station 18?

- Simultaneous incidents occur when other incidents are underway at the time a new incident begins. In the entire Ross Valley Fire Department's response area during 2018, 16.05 percent of incidents occurred while one or more other incidents were underway.

  In 2017, Station 17 was on an incident *at the same time as Station 18* **45** times. In 2018, Engines 17 and 18 were on incidents at the same time **33** times.

In 2017 and 2018 combined, Engine 18 had 481 responses anywhere. Across two years, Engines 17 and 18 were active at the same time 78 times, or **16** percent of all of Engine 18's responses.

Stated this way, if Engine 18 was closed, there are approximately 1.5 incidents per week to which Engine 17 will not be available to respond.

Then for Engine 18 and Engine 19 from the other direction, based on year 2018 data, both units are committed together approximately 109 times, or two times per week. This is higher than the Engine 18/17 measure. Most occurrences average a joint co-commitment time of 38 minutes.

So, when Engine 18 is busy there is a small chance every week that either or both Engines 17 and 19 also will not be available. This makes sense as all units have more calls for service during peak daylight hours of the day, versus after midnight.

Table 23—Distribution Travel Time Analysis of Fire and EMS Responses from 01/01/17 to 12/31/18

Station Area	Apparatus Arrivals	Home Resources	Outside Resources	Outside Percent	Overall Travel	Home Travel	Outside Travel	Delta Home/Out
18	969	881	88	9.08%	07:03 (602)	06:43 (550)	08:44 (52)	2:01
19	2,586	1,859	727	28.11%	06:38 (1,913)	06:29 (1,385)	07:13 (528)	0:44
20	1,248	903	345	27.64%	07:05 (1,022)	06:33 (756)	08:28 (266)	1:55
21	2,627	1,992	635	24.17%	07:22 (1,629)	06:46 (1,303)	08:31 (326)	1:45

Closing Station 18 will add about 2:00 minutes of travel time into that station area. Overall medic travel times will be reduced to some incidents if Medic 18 were to be moved west, as the unit is located closer to a higher medic demand area.

15. What is the impact of having first response from Station 19 with a three-person engine and Station 17 with a four-person engine versus Station 18 as a two-person engine?

    ➢ Total staff (weight) is the same firefighter count of eight. But the Town firefighters are now located in and serving two other areas and are thus subject to simultaneous incident use in Stations 19 and 17's areas.

16. If RVPA stays in the Town, is there a response time change to medical emergencies?

- No, if the ambulance is available. Otherwise response time depends on Engine 19 or Engine 17 being available to respond.

- Other medic units needed in the Town of Ross when Medic 18 was not available were Medic 14 (53 times), Medic 95 (eight times), and one each for Medic 97, Medic 94, Medic 59, and Medic 13. This means other medic units needed to respond into Station 18's territory 65 times in two years.

17. If RVPA moves to Station 17 or Station 19, what is the average change in response time to a medical emergency?

    - Per Table 23, without a Station 18 resource, there are an additional 2:00 minutes of travel time, meaning total response time (dispatch processing, turnout, and travel time) is almost 12:00 minutes from 9-1-1, which is the same as a rural level of response.

    - Moving Medic 18 to Station 17 would also move it farther away from the highest incident densities that it serves.

Finding #12: In the Town of Ross, on EMS emergencies, Engine 18 responded 214 times and Medic 18 responded 169 times in a two-year period.

Finding #13: In the Town of Ross, adjoining Engines 17 (Kentfield) and Engine 19 each arrived first over a two-year period 19 and 20 times, totaling 39. Thus, the outside units only arrived/were needed first 12.6 percent of the time.

Finding #14: In a two-year period, Engines 18 and 17 (Kentfield) were assigned to incidents at the same time 78 times or 16 percent of Engine 18's total responses. Stated this way, if Engine 18 was closed, there are approximately 1.5 incidents per week to which Engine 17 will not be available to respond.

Finding #15: Closing Station 18 will add about 2:00 minutes *minimum* of travel time into that station area.

Finding #16: In the Ross Valley Fire Department, Station 18 has the best travel time of any of the four station areas at 4:40 minutes, only 40 seconds longer than an urban/suburban best practice recommendation of 4:00 minutes. Adding 2:00 minutes travel, plus dispatch and turnout time of at least 3:00 minutes, moves a Town of Ross total response time from 7:40 to 9:40 which would be more like an edge suburban area or emerging rural area. First unit response times of 10:00 minutes-plus means small fires will become larger and critical EMS patients may not receive lifesaving care.

Finding #17: If the Engine 18 daily firefighter count of two were transferred to Engine 19, or reduced to one being transferred, they would be joining an engine that serves a much larger area and is more exposed to simultaneous incident demand. Due the dynamic nature of 9-1-1 emergencies, there is no way to predict if all of the Town of Ross Engine 18 and Medic 18 first arrivals would be covered by just Engines 19 and 17 (Kentfield) or by other units even farther away.

Finding #18: Covering the Town of Ross from either Station 19 or 17 (Kentfield) depends on essentially one road being open and not congested with traffic. Any one accident or natural emergency could close the road, effectively making the Town of Ross a cul-de-sac served from one direction and, in a sub-regional emergency, either Engine 19 or 17 would be shared with a larger service area.

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SECTION 4—OVERALL EVALUATION

SOC ELEMENT 8 OF 8

OVERALL EVALUATION

The Department serves mostly residential and small downtown populations with a mixed land-use pattern typical of Marin County communities. However, the hilly geography and the limited road network dependent on one main connector road, is very difficult to serve efficiently from a small number of fire stations.

Over time, each population cluster opened a fire station for a minimum single first unit response and knew they were co-dependent on each other for multiple-unit serious emergencies. The geography cannot be changed and improving the road network is not politically feasible or cost-effective. Thus, reducing coverage by removing any one or more fire engines or the paramedic ambulance will increase response times to the local community receiving reduced coverage.

While the state fire code now requires fire sprinklers even in residential dwellings, it will be many more years before the vast majority of homes are replaced or remodeled with automatic fire sprinklers. If the communities' desired outcomes include limiting building fire damage to only part of the inside of an affected building, minimizing permanent impairment resulting from a medical emergency, and keeping wildland fires small to a few acres at the ignition point, then the communities served by the Ross Valley Fire Department will need first-due unit coverage in all neighborhoods.

However, even with maintaining the current four-station spacing, given the topography, not all hillside areas can receive response time coverage consistent with suburban best practice incident outcomes and a Citygate performance recommendation of a first-due arrival within 7:30 minutes from 9-1-1 dispatch notification and a multiple-unit Effective Response Force (ERF) arrival occurring within 11:30 minutes of 9-1-1 notification, all at 90 percent or better reliability.

The Department's call processing performance is excellent. The crew turnout time needs modest improvement but even such attainable improvement cannot substantially lower the fire unit travel times which are longer than desired over the challenging geography and road network.

Department resources and equipment are appropriate to protect against the hazards likely to impact the Department's service area, but the daily staffing of eight firefighters on four engines, plus a two-firefighter/paramedic ambulance from the Ross Valley Paramedic Authority (RVPA) and a Duty Chief Officer only provides a *minimum* total response force sufficient to begin controlling a single emerging to serious fire incident, or to provide care at an EMS incident with one to five patients.

In terms of emergency incident workload per unit, no single fire unit or station area is approaching workload saturation. The level of simultaneous incidents is not high enough to warrant another unit at peak hours of the day. Citygate is, however, concerned about the overall limited Department staffing per day and its ability to respond with more "weight of attack" to keep emerging serious emergencies controlled. Even Countywide mutual aid resources are not quickly available in this part of Marin County, as they would be in an urban area with flat terrain and interconnected roads.

In reviewing the Town of Ross questions about the utility of its fire station, while maintaining a fire crew in town is expensive, any alternative solution will raise response times beyond suburban best practice goals and come at the cost of sharing staffing with a larger service area. Relocating the crews out of the Town of Ross impacts more than just the Town. As an example, even if the Town paid Kentfield for fire coverage, Kentfield would be serving the entire Town of Ross in addition to its own community, which would mean the Kentfield fire unit would occasionally not be available to respond to an emergency call in its primary area.

The quantity of calls in the Town of Ross (or any other single historic population cluster in the joint Department's service area) is too small and too volatile from which to use historical incidents as the only criteria to maintain the fire station. Providing fire services is akin to purchasing fire insurance, and it is important to consider the desired level of protection. The public policy issue is whether to have access to a fire station nearby or farther away, knowing that a station farther away, even with its unit(s) available for response, cannot offer more than edge suburban or emerging rural area response times to much of the Town of Ross.

4.1 Deployment Recommendations

Based on the technical analysis and findings contained in this Standards of Coverage assessment, Citygate offers the following deployment recommendations:

Recommendation #1:	**Adopt Updated Deployment Policies:** The Ross Valley Fire Department governing Board should adopt *updated*, complete performance measures to aid deployment planning and to monitor performance. The measures of time should be designed to deliver outcomes that will save patients medically salvageable upon arrival and to keep small but serious fires from becoming more serious. With this is mind, Citygate recommends the following measures:

1.1 Distribution of Fire Stations: To treat pre-hospital medical emergencies and control small fires, the first-due unit should arrive within 8:30 minutes, 90 percent of the time from the receipt of the 9-1-1 call at dispatch; this equates to a 90-second dispatch time, a 2:00-minute company turnout time, and a 5:00-minute travel time.

1.2 Multiple-Unit Effective Response Force for Serious Emergencies: To confine building fires near the room of origin, keep vegetation fires under one acre in size, and treat multiple medical patients at a single incident, a multiple-unit ERF of at least 12 personnel, including at least one Duty Chief Officer, should arrive within 12:30 minutes from the time of 9-1-1 call receipt in dispatch, 90 percent of the time; this equates to a 90-second dispatch time, 2:00-minute company turnout time, and 9:00-minute travel time.

1.3 Hazardous Materials Response: Provide hazardous materials response designed to protect the Department's service areas from the hazards associated with uncontrolled release of hazardous and toxic materials. The fundamental mission of the Fire Department's response is to isolate the hazard, deny entry into the hazard zone, and notify appropriate officials/resources to minimize impacts on the community. This can be achieved with a first-due total response time of 8:30 minutes or less to provide initial hazard evaluation and/or mitigation actions. After the initial evaluation is completed, a determination can be made whether to request additional resources from the regional hazardous materials team.

1.4	Technical Rescue: Respond to technical rescue emergencies as efficiently and effectively as possible with enough trained personnel to facilitate a successful rescue with a first-due total response time of 8:30 minutes or less to evaluate the situation and/or initiate rescue actions. Following the initial evaluation, assemble additional resources as needed within a total response time of 12:30 minutes to safely complete rescue/extrication and delivery of the victim to the appropriate emergency medical care facility.
Recommendation #2:	Consider maintaining the current location of all four engines and keeping Medic 18 in the Town of Ross to balance its coverage area to the west and east.
Recommendation #3:	Consider providing a third firefighter per day on the three engines other than Engine 18. Doing so would raise the daily weight of attack from 12 to 15 and, with Kentfield's three personnel, to 18. This force would be sufficient to provide the weight of attack and simultaneous incident redundancy for suburban positive outcomes. Especially on serious building and wildland fire ignitions, there is no second chance to stop the fire. This is a local policy decision to be made by the affected communities to determine the level of fire service that they can afford.

Appendix A

Risk Assessment

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Appendix A—Risk Assessment

A.1 Community Risk Assessment

SOC Element 3 of 8
Community Risk Assessment

The third element of the Standards of Coverage (SOC) process is a community risk assessment. Within the context of an SOC study, the objectives of a community risk assessment are to:

- Identify the values at risk to be protected within the community or service area.
- Identify the specific hazards with the potential to adversely impact the community or service area.
- Quantify the overall risk associated with each hazard.
- Establish a foundation for current/future deployment decisions and risk-reduction/hazard-mitigation planning and evaluation.

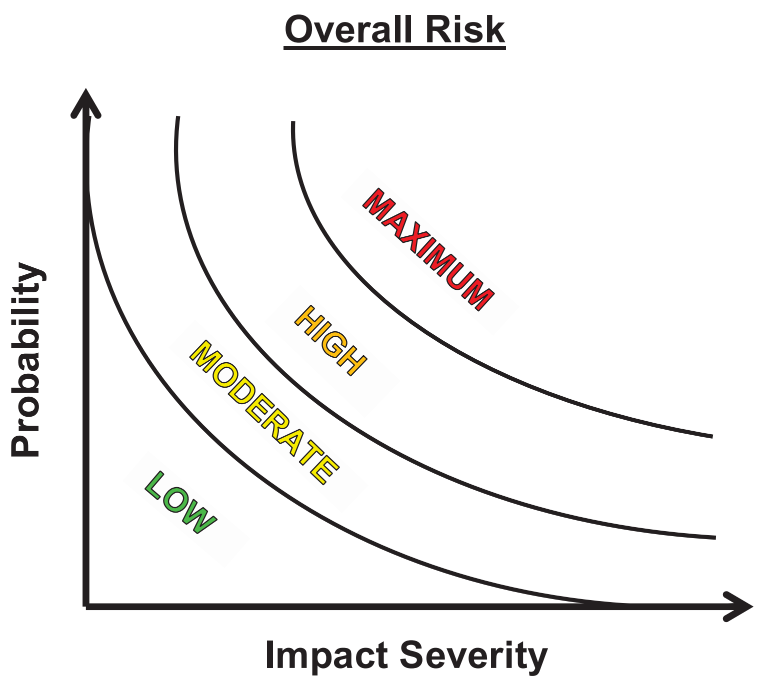
A hazard is broadly defined as a situation or condition that can cause or contribute to harm. Examples include fire, medical emergency, vehicle collision, earthquake, flood, etc. Risk is broadly defined as the *probability of hazard occurrence* in combination with the *likely severity of resultant impacts* to people, property, and the community as a whole.

A.1.1 Risk Assessment Methodology

The methodology employed by Citygate to assess community risks as an integral element of an SOC study incorporates the following elements:

- Identification of geographic planning sub-zones (risk zones) appropriate to the community or jurisdiction.
- Identification and quantification (to the extent data is available) of the specific values at risk to various hazards within the community or service area.
- Identification of the fire and non-fire hazards to be evaluated.
- Determination of the probability of occurrence for each hazard.
- Identification and evaluation of multiple relevant impact severity factors for each hazard by planning zone using agency/jurisdiction-specific data and information.
- Quantification of overall risk for each hazard based on probability of occurrence in combination with probable impact severity, as shown in Figure 15.

Figure 15—Overall Risk



Citygate used the following data sources for this study to understand the hazards and values to be protected in the District:

- U.S. Census Bureau population and demographic data
- District Geographical Information Systems (GIS) data
- Marin County General Plan and Zoning information
- Marin County Multi-Jurisdictional Local Hazard Mitigation Plan
- Fire Department data and information.

A.1.2 Risk Assessment Summary

Citygate's evaluation of the values at risk and hazards likely to impact the Ross Valley Fire Department service area yields the following:

1. The Department serves a diverse population, with densities ranging from less than 500 people per square mile to approximately 5,000 per square mile over a varied land use pattern.
2. The Department's service area population is projected to grow by only 7.7 percent over the next 11 years to 2030, or an average annual growth of approximately 0.7 percent.

3. The service area includes nearly 11,000 housing units as well as a large inventory of non-residential occupancies.

4. Marin County has a mass emergency notification system to effectively communicate emergency information to the public in a timely manner.

5. The Department's overall risk for five hazards related to emergency services provided range from **Low** to **High**, as summarized in Table 24.

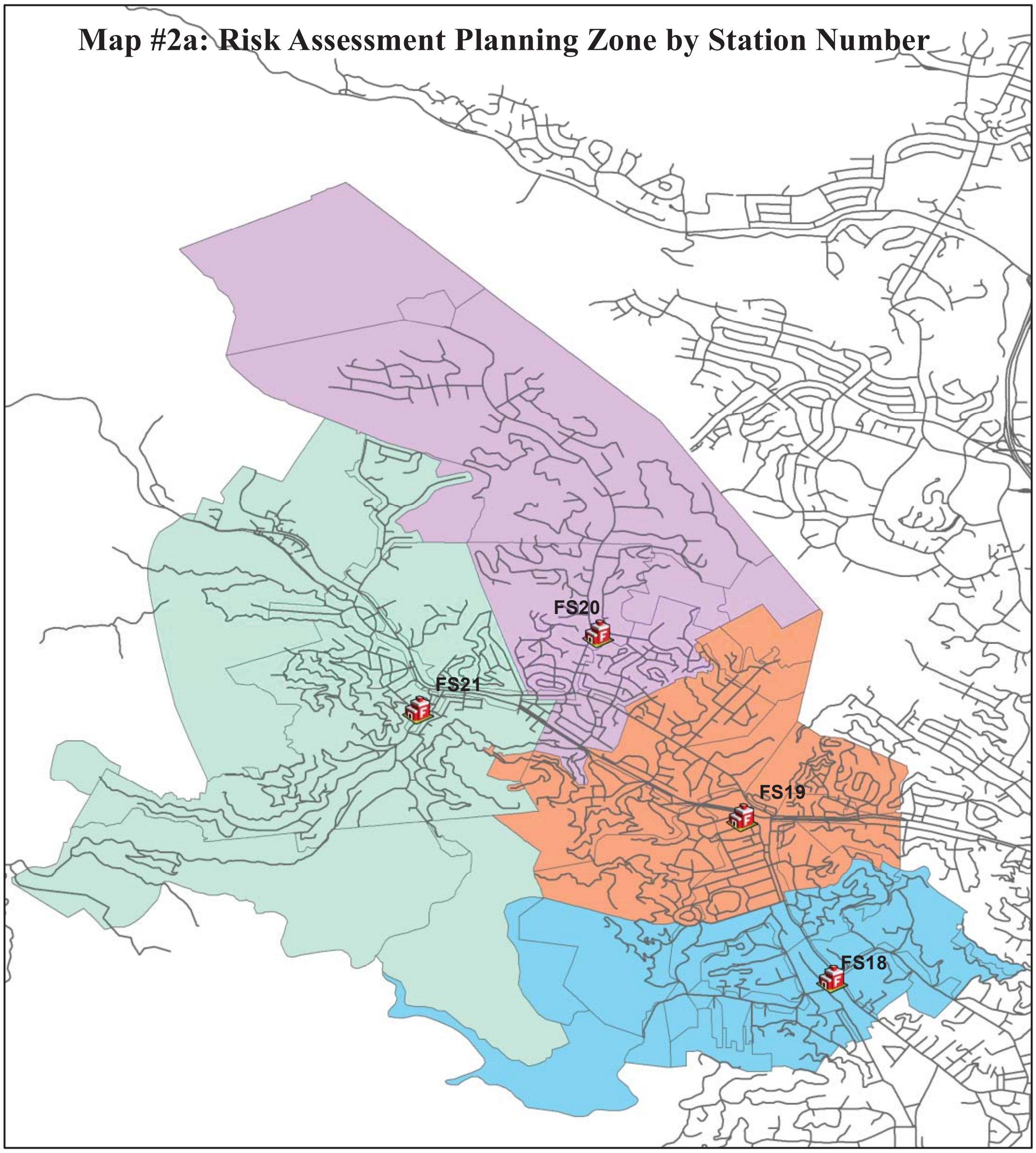
Table 24—Overall Risk by Hazard

Hazard	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Building Fire	*Low*	*Low*	*Moderate*	*Moderate*
Vegetation Fire	*Low*	*Low*	*Low*	*Low*
Medical Emergency	*High*	*High*	*High*	*High*
Hazardous Material	*Moderate*	*Moderate*	*Moderate*	*Moderate*
Technical Rescue	*Low*	*Low*	*Low*	*Low*

A.1.3 Planning Zones

The Commission on Fire Accreditation International (CFAI) recommends that jurisdictions establish geographic planning zones to better understand risk at a sub-jurisdictional level. For example, portions of a jurisdiction may contain predominantly moderate risk building occupancies, such as detached single-family residences, while other areas contain high- or maximum-risk occupancies, such as commercial and industrial buildings with a high hazard fire load. If risk were to be evaluated on a jurisdiction-wide basis, the predominant moderate risk could outweigh the high or maximum risk and may not be a significant factor in an overall assessment of risk. If, however, those high- or maximum-risk occupancies are a larger percentage of the risk in a smaller planning zone, then it becomes a more significant risk factor. Another consideration in establishing planning zones is that the jurisdiction's record management system must also track the specific zone for each incident to be able to appropriately evaluate service demand and response performance relative to each specific zone. For this assessment, Citygate utilized four planning zones, incorporating each fire station's first-due response area, as shown in Figure 16.

Figure 16—Risk Planning Zones



A.1.4 Values at Risk to Be Protected

Values at risk, broadly defined, are tangibles of significant importance or value to the community or jurisdiction potentially at risk of harm or damage from a hazard occurrence. Values at risk typically include people, critical facilities/infrastructure, buildings, and key economic, cultural, historic, and/or natural resources.

People

Residents, employees, visitors, and travelers in a community or jurisdiction are vulnerable to harm from a hazard occurrence. Particularly vulnerable are specific at-risk populations, including those unable to care for themselves or self-evacuate in the event of an emergency. At-risk populations typically include children less than 10 years of age, the elderly, and people housed in institutional settings. Table 25 summarizes key demographic data for the Ross Valley Fire Department's service area.

Table 25—Key Demographic Data – Ross Valley Fire Department

Demographic	2017	Percentage
Population	**24,785**	
Under 10 years	2,150	**8.67%**
10 – 19 years	3,483	**14.05%**
20 – 64 years	14,217	**57.36%**
65-74 years	3,111	**12.55%**
75 years and older	1,824	**7.36%**
Median age	**48.4**	**N/A**
Housing Units	**10,813**	
Owner-Occupied	7,683	**71.05%**
Renter-Occupied	2,534	**23.43%**
Average Household Size	**2.53**	**N/A**
Ethnicity		
Caucasian	22,492	**90.75%**
Asian	910	**3.67%**
Other	1,383	**5.58%**
Education (population over 24 yrs. of age)	**18,158**	**73.26%**
High School Graduate	17,546	**96.63%**
Undergraduate Degree	11,134	**61.32%**
Graduate/Professional Degree	5,309	**29.24%**
Employment (population over 15 yrs. of age)	**20,261**	**81.75%**
In Labor Force	13,816	**68.19%**
Unemployed	626	**4.53%**
Population Below Poverty Level	1,091	**4.40%**
Population without Health Insurance Coverage	487	**1.96%**

Source: U.S. Census Bureau (2017)

Of note from Table 25 is the following:

- More than 28.5 percent of the population is under 10 years or over 65 years of age.

- The Department's service area population is predominantly Caucasian (91 percent), followed by Asian (3 percent), and other ethnicities (6 percent).
- Of the population over 24 years of age, more than 96 percent has completed high school or equivalency.
- Of the population over 24 years of age, more than 61 percent have a college degree.
- Slightly more than 68 percent of the population 15 years of age or older is in the workforce; of those, 4.5 percent are unemployed.
- The population below the federal poverty level is 4.4 percent.
- Only two percent of the population does not have health insurance coverage.

The service area population is projected to increase by approximately 1,900 (7.7 percent) to nearly 27,000 over the next 11 years to 2030,[6] for an average annual growth of approximately 175 (0.7 percent).

Buildings

The service area includes nearly 11,000 housing units, as well as a large inventory of non-residential occupancies, including office, research, professional service, retail sales, restaurants/bar, motel, church, school, government facility, healthcare, and other non-residential uses.

Building Occupancy Risk Categories

The CFAI identifies the following four risk categories that relate to building occupancy:

Low Risk – includes detached garages, storage sheds, outbuildings, and similar building occupancies that pose a relatively low risk of harm to humans or the community if damaged or destroyed by fire.

Moderate Risk – includes detached single-family or two-family dwellings; mobile homes; commercial and industrial buildings less than 10,000 square feet without a high hazard fire load; aircraft; railroad facilities; and similar building occupancies where loss of life or property damage is limited to the single building.

High Risk – includes apartment/condominium buildings; commercial and industrial buildings more than 10,000 square feet without a high hazard fire load; low-occupant load buildings with high fuel loading or hazardous materials; and similar occupancies with potential for substantial loss of life or unusual property damage or financial impact.

[6] Reference: Marin County Housing Element 2015-2023, Figure II-2

Maximum Risk – includes buildings or facilities with unusually high risk requiring an Effective Response Force (ERF) involving a significant augmentation of resources and personnel and where a fire would pose the potential for a catastrophic event involving large loss of life and/or significant economic impact to the community.

Evaluation of the service area building inventory reveals 174 high risk building uses as they relate to the CFAI building fire risk categories as summarized in Table 26, Table 27, and Map #2B in **Volume 2** (Map Atlas).

Table 26—High Risk Building Occupancy Inventory by Risk Category

Building Occupancy Classification[2]		Number	Risk Category[1]
A-1	Assembly	5	***High***
H	Hazardous	0	***High***
I-4	Institutional	1	***High***
R-1	Hotel/Motel	2	***High***
R-2	Multi-Family Residential	148	***High***
R-2.1	Assisted Living Facilities	4	***High***
R-3.1	Residential Care Facilities	9	***High***
R-4	Care Facilities – Greater than 6 Persons	5	***High***
Total		**174**	

[1] CFAI *Standards of Cover* (5th Edition)
Source: Ross Valley Fire Department

Table 27—High Risk Occupancy Inventory by Planning Zone

Occupancy Classification	Planning Zone				Total
	Sta. 18	Sta. 19	Sta. 20	Sta. 21	
A-1	1	2	1	1	**5**
I-4		1			**1**
R-1		1	1		**2**
R-2	1	110	37		**148**
R-2.1	2	1	1		**4**
R-3.1	1	5	2	1	**9**
R-4		4	1		**5**
Total	**5**	**124**	**43**	**2**	**174**

Source: Ross Valley Fire Department

Critical Infrastructure / Key Resources

The U.S. Department of Homeland Security defines Critical Infrastructure / Key Resources (CIKR) as those physical assets essential to the public health and safety, economic vitality, and resilience of a community, such as lifeline utilities infrastructure, telecommunications infrastructure, essential government services facilities, public safety facilities, schools, hospitals, airports, etc. A hazard occurrence with significant impact severity affecting one or more of these facilities would likely adversely impact critical public or community services. No critical facilities or key resources were identified by the Department for this assessment.

Economic Resources

No economic resources were identified for this assessment.

Natural Resources

No natural resources were identified for this assessment.

A.1.5 Hazard Identification

Citygate utilizes prior risk studies where available, fire and non-fire hazards as identified by the CFAI, and agency/jurisdiction-specific data and information to identify the hazards to be evaluated for this study.

The 2018 Marin County Multi-Jurisdictional Local Hazard Mitigation Plan (LHMP) identifies the following 13 hazards for the County.

Table 28—Marin County Hazards

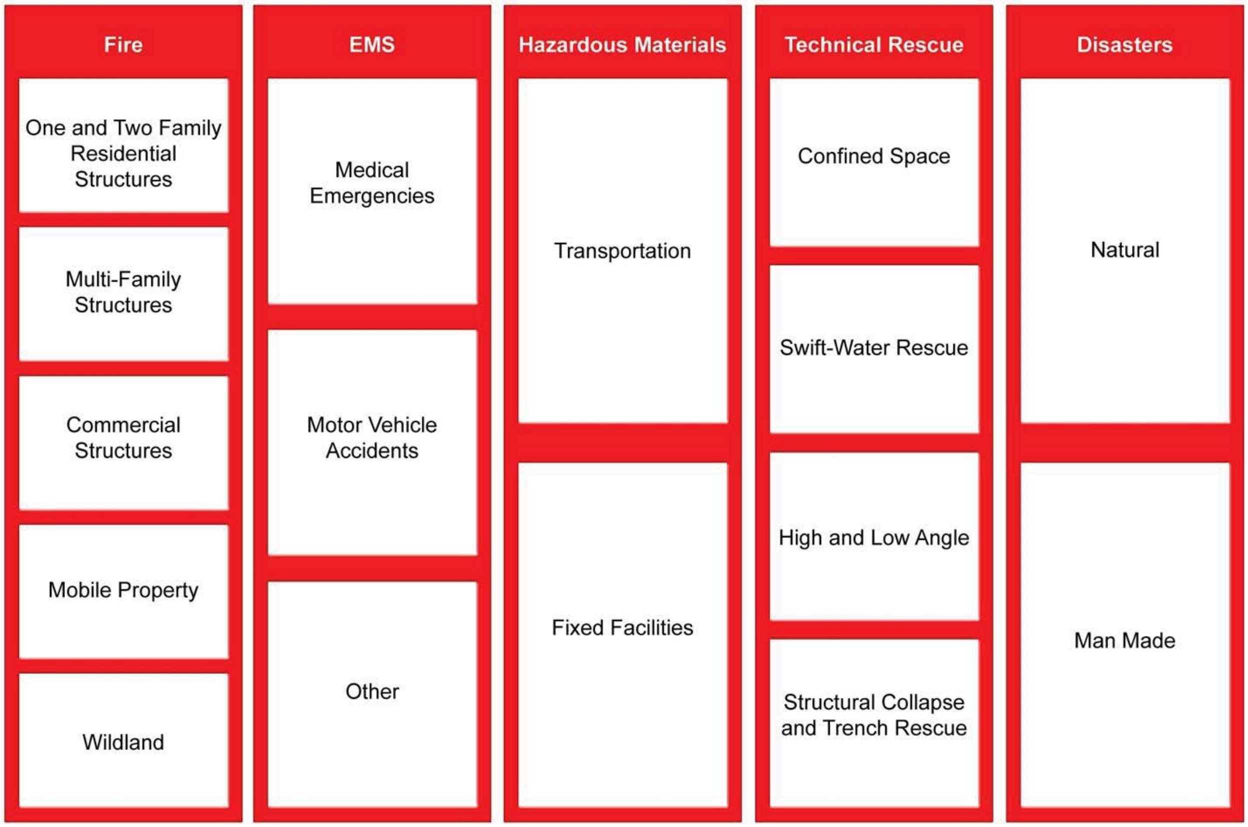
Hazard	
1	Coastal erosion
2	Dam failure
3	Drought
4	Earthquake
5	Flood
6	Heat
7	Landslide/mudslide/debris flow
8	Levee failure
9	Liquefaction
10	Severe wind/tornado
11	Severe storm
12	Tsunami/seiche
13	Wildfire

Reference: 2018 Marin County LHMP, Table 3-1

Although the Fire Department has no legal authority or responsibility to mitigate any of these hazards other than wildfire, it does provide services related to all these hazards, including fire suppression, emergency medical services, technical rescue, and hazardous materials response.

The CFAI groups hazards into fire and non-fire categories, as shown in Figure 17. Identification, qualification, and quantification of the various fire and non-fire hazards are important factors in evaluating how resources are or can be deployed to mitigate those risks.

<u>Figure 17—Commission on Fire Accreditation International Hazard Categories</u>



Source: CFAI *Standards of Cover* (5th Edition).

Subsequent to review and evaluation of the hazards identified in the 2018 Marin County Multi-Jurisdictional LHMP and the fire and non-fire hazards as identified by the CFAI as they relate to services provided by the Department, Citygate evaluated the following five hazards for this risk assessment:

- Building Fire
- Vegetation Fire
- Medical Emergency
- Hazardous Material Release/Spill
- Technical Rescue

A.1.6 Service Capacity

Service capacity refers to the Department's available response force; the size, types, and condition of its response fleet and any specialized equipment; core and specialized performance capabilities and competencies; resource distribution and concentration; availability of automatic and/or mutual aid; and any other agency-specific factors influencing its ability to meet current and prospective future service demand relative to the risks to be protected.

The Department's service capacity for building and vegetation fire, medical emergency, hazardous materials, and technical rescue risk consists of eight firefighters on four engines, plus a two-firefighter/paramedic ambulance from the Ross Valley Paramedic Authority (RVPA) and a Duty Chief Officer.

All response personnel are trained to either the Emergency Medical Technician (EMT) level, capable of providing Basic Life Support (BLS) pre-hospital emergency medical care, or EMT-Paramedic (Paramedic) level, capable of providing Advanced Life Support (ALS) pre-hospital emergency medical care. Ground paramedic ambulance service is provided by the Ross Valley Paramedic Authority (RVPA). Air ambulance services, when needed, are provided by Reach Air Medical Services (Concord, Santa Rosa, or Napa), LifeFlight (Palo Alto), the California Highway Patrol, or Sonoma County Sheriff. Three regional hospitals provide emergency medical services, including Marin General Hospital, Kaiser Permanente Medical Center San Rafael, and Novato Community Hospital. Marin General Hospital is also a Level-III trauma center.

Response personnel are also trained to the U.S. Department of Transportation Hazardous Material First Responder Operational (FRO) level to provide initial hazardous material incident assessment, hazard isolation, and support for a hazardous material response team. Additional hazardous materials response capacity is available from the Marin County Hazardous Materials Response Team. The Hazardous Materials Response Unit is housed at the Ross Valley Fire Department and is cross-staffed by Ross Valley personnel as needed for regional response.

Technical rescue services are provided by the Marin County Urban Search and Rescue (US&R) Regional Task Force, a multi-agency/discipline team with the tools, equipment, and training to conduct confined space, low/high-angle rope rescue, breaching, shoring, excavation, trench, and water rescue operations.

A.1.7 Probability of Occurrence

Probability of occurrence refers to the probability of a future hazard occurrence during a specific period. Because the CFAI agency accreditation process requires annual review of an agency's risk assessment and baseline performance measures, Citygate recommends using the 12 months following completion of an SOC study as an appropriate period for the probability of occurrence evaluation. Table 29 describes the five probability of occurrence categories and related scoring criteria used for this analysis.

Table 29—Probability of Occurrence Scoring Criteria

Score	Probable Occurrence	Description	General Criteria
0–1.0	***Very Low***	Improbable	Hazard occurrence is *unlikely*
1.25–2.0	***Low***	Rare	Hazard *could occur*
2.25–3.0	***Moderate***	Infrequent	Hazard *should occur* infrequently
3.25–4.0	***High***	Likely	Hazard *likely to occur* regularly
4.25–5.0	***Very High***	Frequent	Hazard is *expected to occur* frequently

Citygate's SOC assessments use recent multiple-year hazard response data to determine the probability of hazard occurrence for the ensuing 12-month period.

A.1.8 Impact Severity

Impact severity refers to the extent a hazard occurrence impacts people, buildings, lifeline services, the environment, and the community as a whole. Table 30 describes the five impact severity categories and related scoring criteria used for this analysis.

Table 30—Impact Severity Scoring Criteria

Score	Impact Severity	General Criteria
0 – 1.0	**Insignificant**	• No serious injuries or fatalities • Few persons displaced for only a short duration • None or inconsequential damage • None or very minimal disruption to community • No measurable environmental impacts • Little or no financial loss
1.25 – 2.0	**Minor**	• Some minor injuries; no fatalities expected • Some persons displaced for less than 24 hours • Some minor damage • Minor community disruption; no loss of lifeline services • Minimal environmental impacts with no lasting effects • Minor financial loss
2.25 – 3.0	**Moderate**	• Some hospitalizations; some fatalities expected • Localized displacement of persons for up to 24 hours • Localized damage • Normal community functioning with some inconvenience • Minor loss of critical lifeline services • Some environmental impacts with no lasting effects, or small environmental impact with long-term effect • Moderate financial loss
3.25 – 4.0	**Major**	• Extensive serious injuries; significant number of persons hospitalized • Many fatalities expected • Significant displacement of many people for more than 24 hours • Significant damage requiring external resources • Community services disrupted; some lifeline services potentially unavailable • Some environmental impacts with long-term effects • Major financial loss
4.25 – 5.0	**Catastrophic**	• Large number of severe injuries and fatalities • Local/regional hospitals impacted • Large number of persons displaced for an extended duration • Extensive damage • Widespread loss of critical lifeline services • Community unable to function without significant support • Significant environmental impacts and/or permanent environmental damage • Catastrophic financial loss

A.1.9 Overall Risk

Overall hazard risk is determined by multiplying the *probability of occurrence score* by the *impact severity score*. The resultant total determines the overall *risk rating* as shown in Table 31.

Table 31—Overall Risk Score and Rating

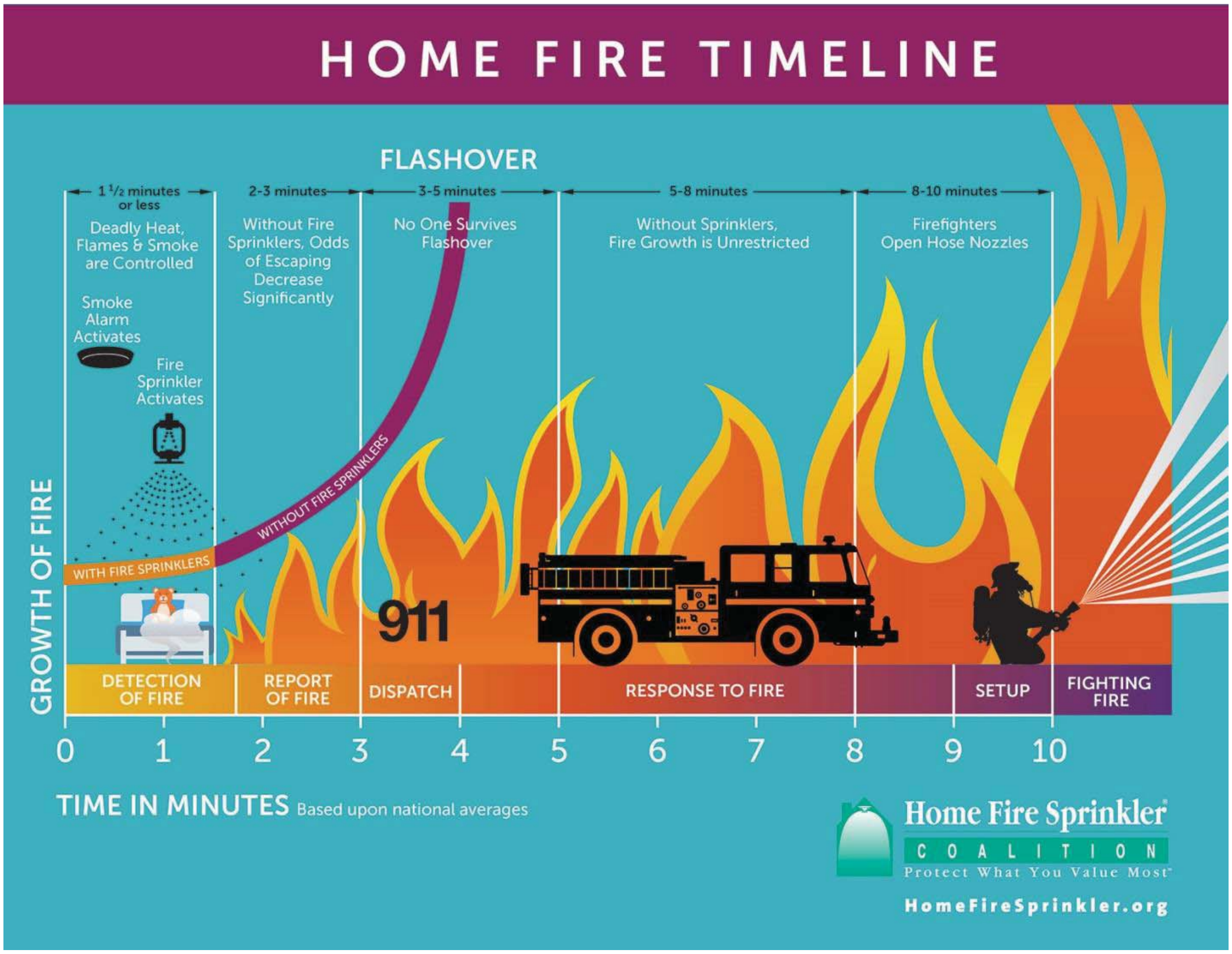
Overall Risk Score	Overall Risk Rating
0–5.99	*LOW*
6.0–11.99	*MODERATE*
12.0–19.99	*HIGH*
20.0–25.0	*MAXIMUM*

A.1.10 Building Fire Risk

One of the primary hazards in any community is building fire. Building fire risk factors include building size, age, construction type, density, occupancy, number of stories above ground level, required fire flow, proximity to other buildings, built-in fire protection/alarm systems, available fire suppression water supply, building fire service capacity, fire suppression resource deployment (distribution/concentration), staffing, and response time. Citygate used available data from the Department and the U.S. Census Bureau to assist in determining the Department's building fire risk.

Figure 18 illustrates the building fire progression timeline and shows that flashover, which is the point at which the entire room erupts into fire after all the combustible objects in that room reach their ignition temperature, can occur as early as 3:00 to 5:00 minutes from the initial ignition. Human survival in a room after flashover is extremely improbable.

Figure 18—Building Fire Progression Timeline



Source: http://www.firesprinklerassoc.org

Population Density

Population density within the service area ranges from less than 500 to approximately 5,000 people per square mile. Although risk analysis across a wide spectrum of other Citygate clients shows no direct correlation between population density and building fire *occurrence*, it is reasonable to conclude that building fire *risk* relative to potential impact on human life is greater as population density increases, particularly in areas with high density, multiple-story buildings.

Water Supply

A reliable public water system providing adequate volume, pressure, and flow duration in close proximity to all buildings is a critical factor in mitigating the potential impact severity of a community's building fire risk. Potable water is provided by the Marin Municipal Water District, and according to Fire Department staff, available fire flow is insufficient in several sections of the service area as shown in Map #2E in **Volume 2** (Map Atlas).

Building Fire Service Demand

For calendar years 2017 and 2018, the Department experienced 44 building fire incidents comprising 1 percent of total service demand over the same period, as summarized in Table 32.

Table 32—Building Fire Service Demand

Risk	Year	Planning Zone				Total	Percent Total Service Demand
		Sta. 18	Sta. 19	Sta. 20	Sta. 21		
Building Fire	2017	3	3	7	11	**24**	0.83%
	2018	0	5	7	8	**20**	0.75%
Total		**3**	**8**	**14**	**19**	**44**	**0.79%**
Percent of Total Service Demand		.79%	0.42%	1.46%	0.97%	**0.79**%	

Source: Ross Valley Fire Department incident data

As Table 32 illustrates, building fire service demand was consistent across the two-year study period, with the highest volume of incidents occurring at Station 21 and the lowest at Station 19. Overall, the Department's building fire service demand is very low, comprising less than one percent of all calls for service, which is consistent with other California jurisdictions of similar size and demographics.

Probability of Building Fire Occurrence

Table 33 summarizes Citygate's scoring of building fire probability by planning zone based on building fire service demand from Table 32.

Table 33—Building Fire Probability Scoring

Building Fire	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Probability Score	1.25	1.50	2.0	2.25

Building Fire Impact Severity

Table 34 summarizes Citygate's scoring of the Department's probable building fire impact severity by planning zone.

Table 34—Building Fire Impact Severity Scoring

Building Fire	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Impact Severity Score	3.0	3.0	3.0	3.0

Overall Building Fire Risk

Table 35 summarizes the Department's overall building fire risk scores and ratings by planning zone.

Table 35—Overall Building Fire Risk

Building Fire	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Total Risk Score	3.75	4.50	6.00	6.75
Risk Rating	***Low***	***Low***	***Moderate***	***Moderate***

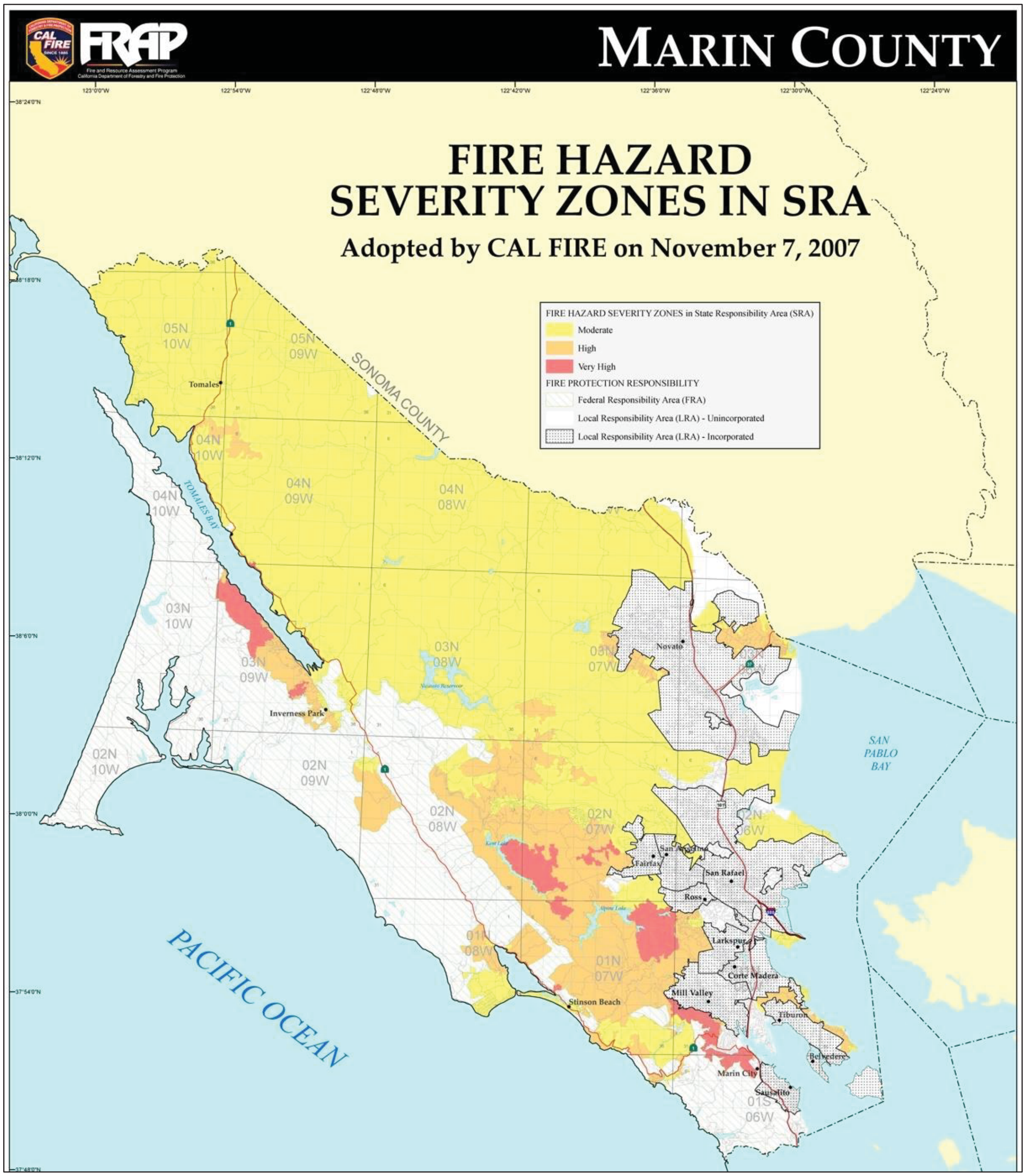
A.1.11 Vegetation Fire Risk

Most of the service area is susceptible to a vegetation fire, particularly along the northern and western edges abutting the Mount Tamalpais watershed.

Wildland Fire Hazard Severity Zones

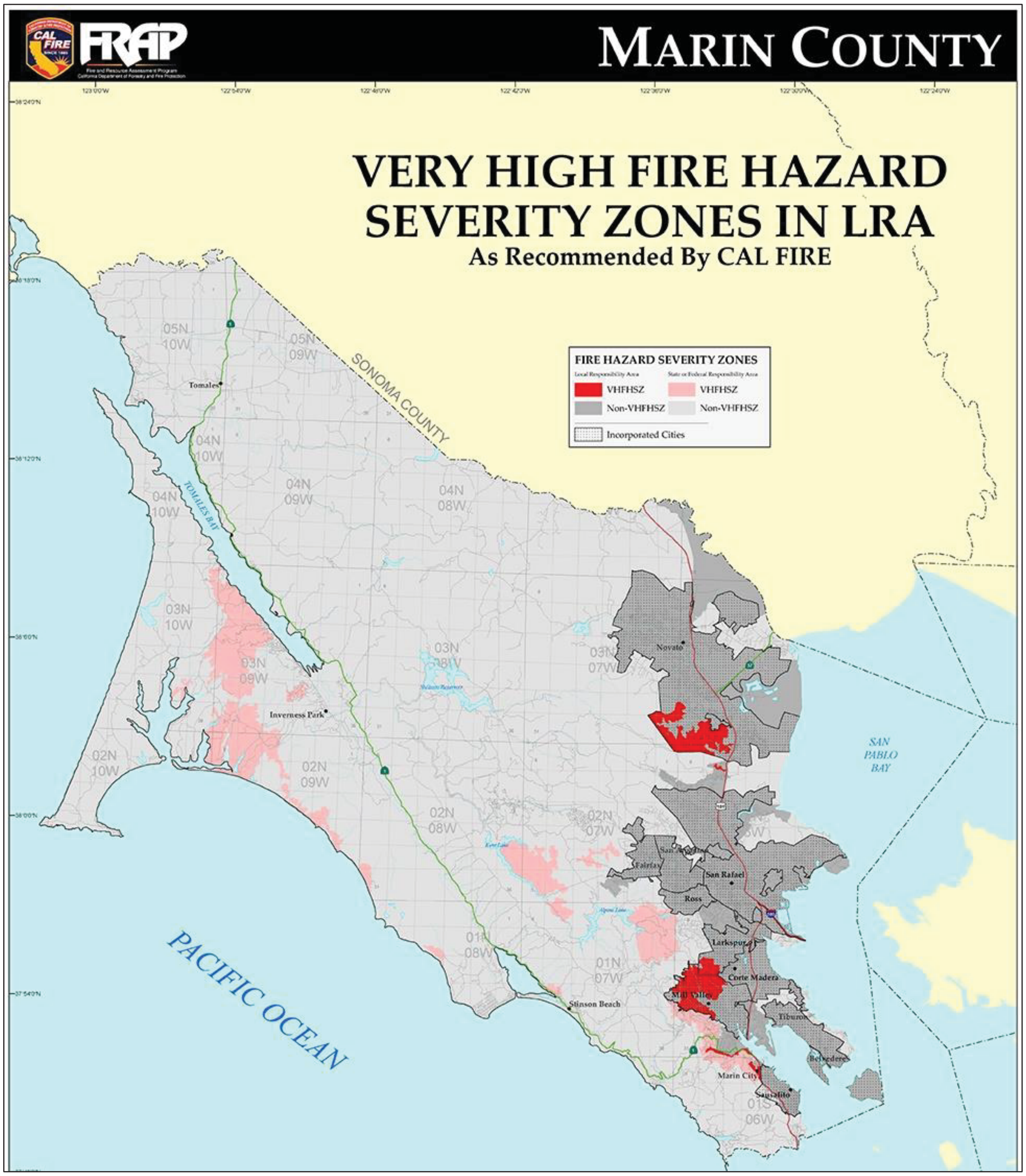
The California Department of Forestry and Fire Protection (CAL FIRE) designates wildland Fire Hazard Severity Zones (FHSZ) throughout the State based on analysis of multiple wildland fire hazard factors and modeling of potential wildland fire behavior. For State Responsibility Areas (SRAs) where CAL FIRE has fiscal responsibility for wildland fire protection, CAL FIRE designates Moderate, High, and Very High FHSZs by county, as shown in Figure 19 for Marin County. Note the ***Moderate***, ***High***, and ***Very High*** FHSZs immediately to the north, northeast, and west of the service area.

Figure 19—SRA Wildland Fire Hazard Severity Zones – Marin County



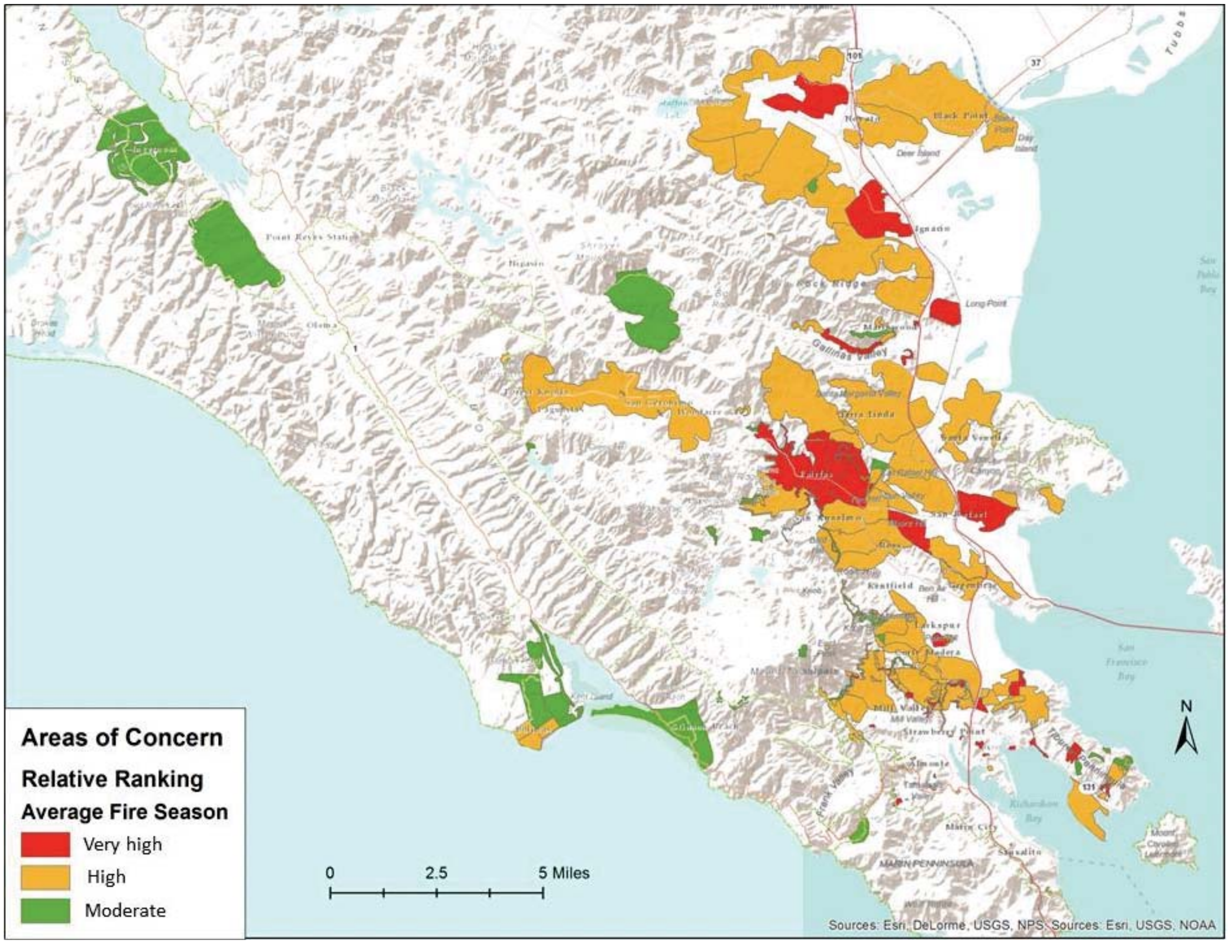
CAL FIRE also identifies recommended FHSZs for Local Responsibility Areas (LRAs), where a local jurisdiction bears the fiscal responsibility for wildland fire protection, including incorporated cities, as shown in Figure 20 for Marin County.

<u>Figure 20—Wildland Fire Hazard Map</u>



Note that there are no recommended FHSZs within the Department's service area. The 2016 Marin County Fire Department Community Wildfire Protection Plan (CWPP), however, identifies significant sections of the service area as **Moderate**, **High** and **Very High** Areas of Concern based on composite geospatial modeling of population density, potential flame length, and potential rate of spread as shown in Figure 21.

<u>Figure 21—Areas of Wildfire Concern – Marin County CWPP</u>



Reference: 2016 Marin County CWPP, Figure 15

Vegetative Fuels

Vegetative fuel factors influencing fire intensity and spread include fuel type (species), height, arrangement, density, and moisture. Vegetative fuels within the service area, in addition to decorative landscape species, include both native and non-native annual and perennial plant species, including grasses, weeds, shrubs, and chamise, and mostly hardwood trees including bay, eucalyptus, madrone, and oak. The majority of the service area has moderate to high vegetative fuel density. Once ignited, vegetation fires can burn intensely and contribute to rapid fire spread under the right fuel, weather, and topographic conditions.

Weather

Weather elements such as temperature, relative humidity, wind, and lightning also affect vegetation fire potential and behavior. High temperatures and low relative humidity dry out vegetative fuels, creating a situation where fuels will more readily ignite and burn more intensely.

Wind is the most significant weather factor influencing vegetation fire behavior; higher wind speeds increase fire spread and intensity. Wildland fire season, when vegetation fires are most likely to occur due to fuel and weather conditions, occurs from approximately June through October in Marin County. Summer weather within the service area typically includes cool mornings, warm afternoons and evenings, and west/northwest breezes that can reach 15-25 miles per hour. Occasional summer gradients can produce temperatures in the high 90s to low 100s, low relative humidity, and offshore winds as high as 40 miles per hour. These weather conditions create the potential for a large, damaging wildfire.

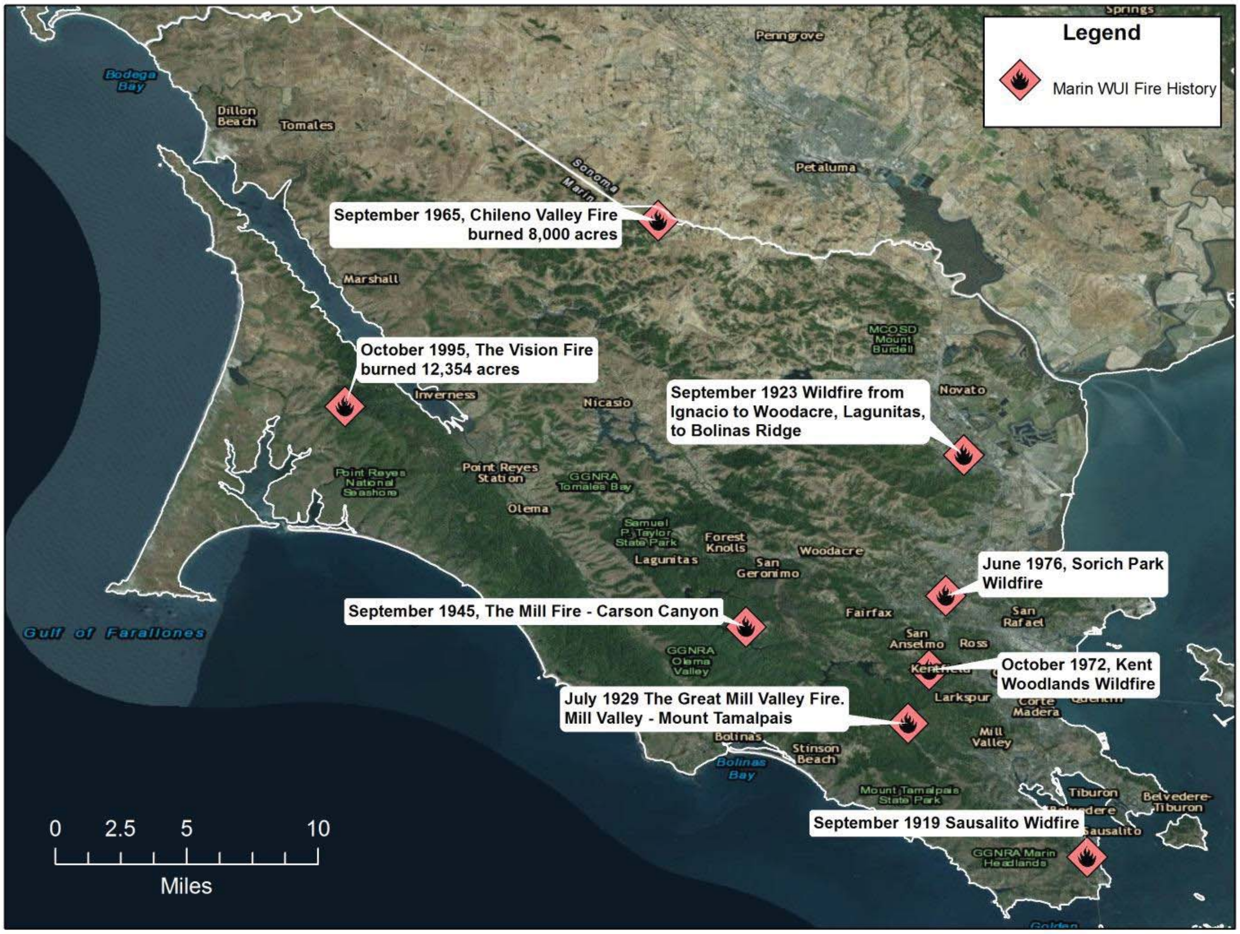
Topography

Vegetation fires tend to burn more intensely and spread faster when burning uphill and up-canyon, except for a wind-driven downhill or down-canyon fire. The service area's terrain varies from flat to steep slopes, which can contribute significantly to wildfire behavior and spread.

Wildfire History

Since the early 1900s, there have been several large wildland fires in Marin County, including the 1972 Kent Woodlands Fire, 1976 Scorich Park Fire, and 1995 Vision Fire (12,354 acres) as shown in Figure 22.

Figure 22—Marin County Wildfire History



Source: Marin County CWPP, Figure 6

Water Supply

Another significant vegetation fire impact severity factor is water supply immediately available for fire suppression. According to Department staff, available fire flow is insufficient in several sections of the service area as shown in Map #2E in **Volume 2** (Map Atlas).

Wildland Fire Hazard Mitigation

Hazard mitigation refers to specific actions or measures taken to prevent a hazard from occurring and/or to minimize the severity of impacts resulting from a hazard occurrence. While none of the hazards subject to this study can be entirely prevented, measures *can* be taken to minimize the consequences or impacts when those hazards do occur.

The Towns of Ross, San Anselmo, and Fairfax, and the Sleepy Hollow Fire Protection District, have adopted the 2016 California Fire Code and the 2015 International Wildland Urban Interface Code with amendments.

The 2016 Marin County CWPP identifies the following wildfire hazard mitigation strategies, in addition to building codes, ordinances, and standards, and defensible space enforcement and public education strategies:

- Residential chipper programs
- Increasing dedicated staffing for vegetation management programs
- Annual weed abatement program
- Implementing an enhanced County Vegetation Management Program (conditional on voter approval of a Municipal Service Tax)
- Fuel breaks
- Eucalyptus and pine tree removal
- Roadside fuel reduction
- Evacuation route fuel reduction
- Creation of shaded fuel breaks in WUI transition zones

Vegetation Fire Service Demand

The Department experienced only 19 vegetation fires over the two-year study period, comprising 0.34 percent of total service demand over the same period, as summarized in Table 36.

Table 36—Vegetation Fire Service Demand

Risk	Year	Planning Zone				Total	Percent Total Service Demand
		Sta. 18	Sta. 19	Sta. 20	Sta. 21		
Vegetation Fire	2017	2	3	1	5	**11**	0.38%
	2018	1	3	2	2	**8**	0.30%
Total		**3**	**6**	**3**	**7**	**19**	**0.34%**
Percent of Total Service Demand		0.41%	0.32%	0.31%	0.36%	0.34%	

Source: Ross Valley Fire Department incident data

As Table 36 shows, overall vegetation fire service demand is extremely low.

Probability of Vegetation Fire Occurrence

Table 37 summarizes Citygate's scoring of vegetation fire probability by planning zone based on vegetation fire service demand from Table 36.

Table 37—Vegetation Fire Probability Scoring

Vegetation Fire	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Probability Score	1.25	1.50	1.25	1.50

Vegetation Fire Impact Severity

Table 38 summarizes Citygate's scoring of probable vegetation fire impact severity by planning zone.

Table 38—Vegetation Fire Impact Severity Scoring

Vegetation Fire	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Impact Severity Score	3.0	3.0	3.0	3.0

Overall Vegetation Fire Risk

Table 39 summarizes the Department's overall vegetation fire risk scores and ratings by planning zone.

Table 39—Overall Vegetation Fire Risk

Vegetation Fire	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Total Risk Score	3.75	4.50	3.75	4.50
Risk Rating	***Low***	***Low***	***Low***	***Low***

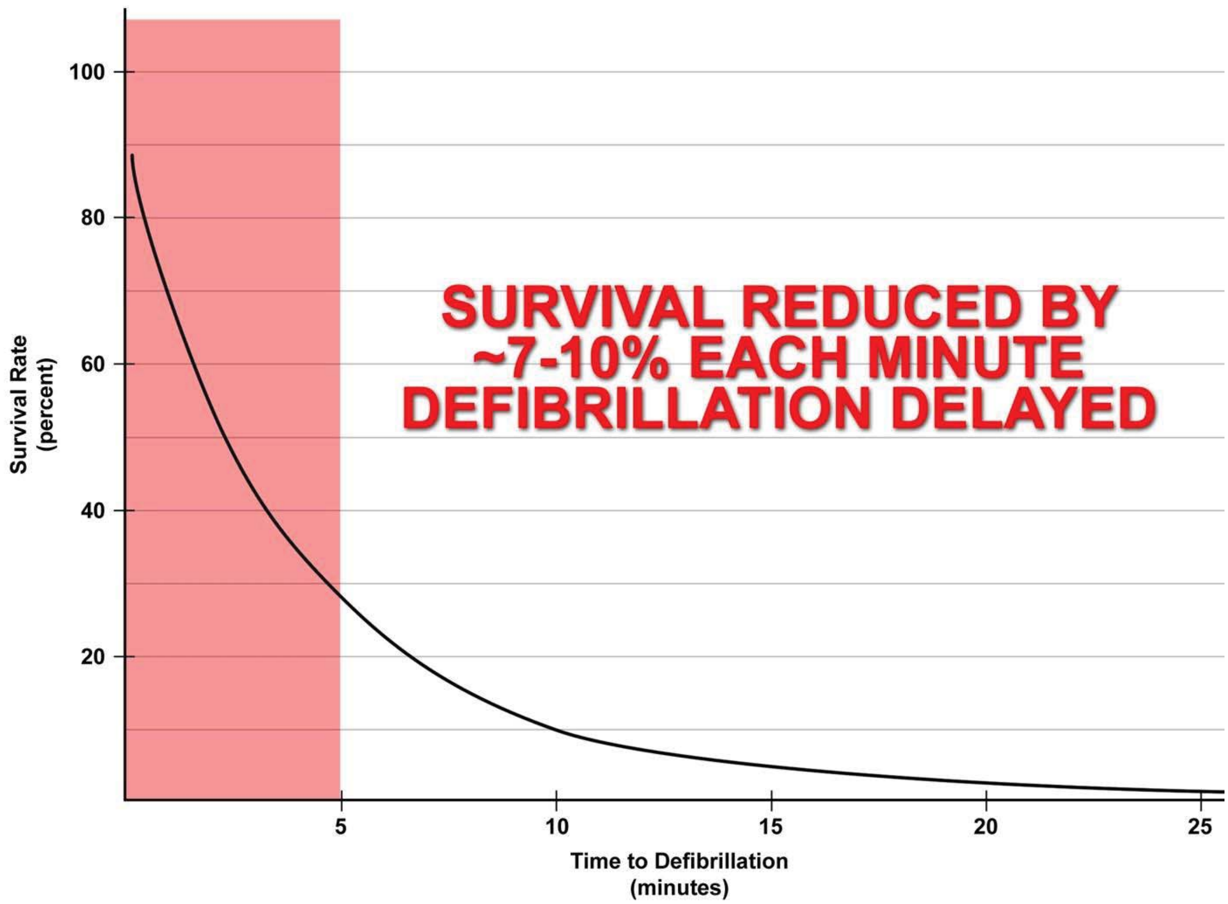
A.1.12 Medical Emergency Risk

Medical emergency risk in most communities is predominantly a function of population density, demographics, violence, health insurance coverage, and vehicle traffic.

Medical emergency risk can also be categorized as either a medical emergency resulting from a traumatic injury or a health-related condition or event. Cardiac arrest is one serious medical emergency among many where there is an interruption or blockage of oxygen to the brain.

Figure 23 illustrates the reduced survivability of a cardiac arrest victim as time to defibrillation increases. While early defibrillation is one factor in cardiac arrest survivability, other factors can influence survivability as well, such as early CPR and pre-hospital advanced life support interventions.

Figure 23—Survival Rate versus Time to Defibrillation



Source: www.suddencardiacarrest.org

Population Density

The Department's service area population density ranges from less than 500 people per square mile to approximately 5,000 per square mile. Risk analysis across a wide spectrum of other Citygate clients shows a direct correlation between population density and the *occurrence* of medical emergencies, particularly in high urban population density zones.

Demographics

Medical emergency risk tends to be higher among older, poorer, less-educated, and uninsured populations. According to the U.S. Census Bureau, nearly 20 percent of the service area population is 65 and older; 4.4 percent of the population is at or below poverty level; only 3.4 percent of the population over 24 years of age has less than a high school education or equivalent; and only two percent of the population does not have health insurance coverage.[7] Overall, this indicates a well-educated and employed population with good health insurance coverage, all factors that can contribute to reducing medical emergency service demand.

Vehicle Traffic

Medical emergency risk tends to be higher in those areas of a community with high daily vehicle traffic volume, particularly those areas with high traffic volume traveling at high speeds. The service area transportation network includes Sir Francis Drake Boulevard, the primary two-lane regional thoroughfare with a very high daily traffic volume, particularly during weekday commute hours and on weekends.

Medical Emergency Service Demand

Medical emergency service demand over the two-year study period includes more than 2,800 calls for service comprising slightly more than 51 percent of total service demand over the same period, as summarized in Table 40.

Table 40—Medical Emergency Service Demand

Risk	Year	Planning Zone				Total	Percent Total Service Demand
		Sta. 18	Sta. 19	Sta. 20	Sta. 21		
Medical Emergency	2017	118	488	243	584	**1,433**	49.81%
	2018	146	499	240	539	**1,424**	53.10%
Total		**264**	**987**	**483**	**1,123**	**2,857**	**51.39%**
Percent of Total Service Demand		36.16%	51.98%	50.21%	57.06%	51.39%	

Source: Ross Valley Fire Department incident data

As Table 40 shows, medical emergency service demand varies by planning zone and is trending consistently over the past two years. Overall, the Department's medical emergency service demand is similar to other California jurisdictions of similar size and demographics.

Probability of Medical Emergency Occurrence

Table 41 summarizes Citygate's scoring of medical emergency probability by planning zone based on medical emergency service demand from Table 40.

[7] Source: U.S. Census Bureau (2017)

Table 41—Medical Emergency Probability Scoring

Medical Emergency	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Probability Score	4.0	4.5	4.25	4.75

Medical Emergency Impact Severity

Table 42 summarizes Citygate's scoring of probable medical emergency impact severity by planning zone.

Table 42—Medical Emergency Impact Severity Scoring

Medical Emergency	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Impact Severity Score	3.0	3.0	3.0	3.0

Overall Medical Emergency Risk

Table 43 summarizes the Department's overall medical emergency risk scores and ratings by planning zone.

Table 43—Overall Medical Emergency Risk

Medical Emergency	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Total Risk Score	12.0	13.5	12.75	14.25
Risk Rating	***High***	***High***	***High***	***High***

A.1.13 Hazardous Material Risk

Hazardous material risk factors include fixed facilities that store, use, or produce hazardous chemicals or waste; underground pipelines conveying hazardous materials; aviation, railroad, maritime, and vehicle transportation of hazardous materials into or through a jurisdiction; vulnerable populations; emergency evacuation planning and related training; and specialized hazardous material service capacity.

Fixed Hazardous Materials Facilities

The Marin County Department of Public Works, serving as the State-designated Certified Unified Program Agency for the County, identified 38 facilities within the Department's service area requiring a State or County hazardous material operating permit as shown on Map #2C in **Volume 2** (Map Atlas).

Transportation-Related Hazardous Materials

The Department also has transportation-related hazardous material risk due to hazardous materials transported into or through its service area, primarily on Sir Francis Drake Boulevard.

Population Density

Because hazardous material emergencies have the potential to adversely impact human health, it is logical that the higher the population density, the greater the potential population exposed to a hazardous material release or spill. The service area population density ranges from less than 500 people per square mile to approximately 5,000 per square mile.

Vulnerable Populations

Persons vulnerable to a hazardous material release/spill include those individuals or groups unable to self-evacuate, generally including children under the age of 10, the elderly, and persons confined to an institution or other setting where they are unable to leave voluntarily. Almost 29 percent of the service area population is under age 10 years or is 65 years of age and older.

Emergency Evacuation Planning, Training, Implementation, and Effectiveness

Another significant hazardous material impact severity factor is a jurisdiction's shelter-in-place / emergency evacuation planning and training. In the event of a hazardous material release or spill, time can be a critical factor in notifying potentially affected persons, particularly at-risk populations, to either shelter-in-place or evacuate to a safe location. Essential to this process is an effective emergency plan that incorporates one or more mass emergency notification capabilities, as well as pre-established evacuation procedures. It is also essential to conduct regular, periodic exercises involving these two emergency plan elements to evaluate readiness and to identify and remediate any planning and/or training gaps to ensure ongoing emergency incident readiness and effectiveness.

The Office of Emergency Services (OES), within the Marin County Sheriff's Office, is responsible for disaster/emergency preparedness and management in the unincorporated areas of the County, including hazard information, coordination with other local/regional emergency management organizations, emergency preparedness, and disaster response, communications, and recovery. OES also manages AlertMarin, a free, subscription-based, mass emergency notification system that can provide emergency alerts, notifications, and other emergency information to email accounts, cell phones, smartphones, tablets, and landline telephones. AlertMarin notifications can be initiated by designated fire or law enforcement agency personnel.

The Sheriff's Office is also responsible for initiating emergency evacuations in the unincorporated areas of the County. No information was identified for this assessment relative to pre-planned evacuation routes, evacuation procedures, or evacuation exercises.

Hazardous Material Service Demand

The Department responded to 91 hazardous material incidents over the two-year study period, comprising 1.64 percent of total service demand over the same period, as summarized in Table 44.

Table 44—Hazardous Material Service Demand

Risk	Year	Planning Zone				Total	Percent Total Service Demand
		Sta. 18	Sta. 19	Sta. 20	Sta. 21		
Hazardous Material	2017	12	18	7	**12**	**49**	**53.8%**
	2018	9	14	10	**9**	**42**	**46.2%**
Total		**21**	**32**	**17**	**21**	**91**	**100%**
Percent of Total Service Demand		2.88%	1.69%	1.77%	1.07%	1.64%	

Source: Ross Valley Fire Department incident data

As Table 44 indicates, hazardous material service demand is relatively consistent across all planning zones and years. While this service demand seems high for this size agency and jurisdiction, it is most likely due to Department personnel cross-staffing the Hazardous Materials Response unit for responses to other regional jurisdictions, rather than hazardous materials incidents within the service area. Overall, the Department's hazardous material service demand is low.

Probability of Hazardous Material Occurrence

Table 45 summarizes Citygate's scoring of hazardous materials probability by planning zone based on hazardous material service demand from Table 44.

Table 45—Hazardous Material Probability Scoring

Hazardous Material	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Probability Score	2.50	2.75	2.25	2.50

Hazardous Material Impact Severity

Table 46 summarizes Citygate's scoring of probable hazardous material impact severity by planning zone.

Table 46—Hazardous Material Impact Severity Scoring

Hazardous Materials	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Impact Severity Score	3.0	3.0	3.0	3.0

Overall Hazardous Material Risk

Table 47 summarizes the Department's overall hazardous material risk scores and ratings by planning zone.

Table 47—Overall Hazardous Material Risk

Hazardous Materials	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Total Risk Score	7.50	8.25	6.75	7.50
Risk Rating	***Moderate***	***Moderate***	***Moderate***	***Moderate***

A.1.14 Technical Rescue Risk

Technical rescue risk factors include active construction projects; structural collapse potential; confined spaces, such as tanks and underground vaults; bodies of water, including rivers and streams; industrial machinery use; transportation volume; and earthquake, flood, and landslide potential.

Construction Activity

There is ongoing residential, commercial, and/or infrastructure construction activity occurring within the Department's service area.

Confined Spaces

There are multiple tanks, vaults, and temporary open trenches within the Department's service area.

Bodies of Water

Bodies of water within the Department's service area include Corte Madera, Fairfax, Ross, San Anselmo, and Sleepy Hollow creeks.

Transportation Volume

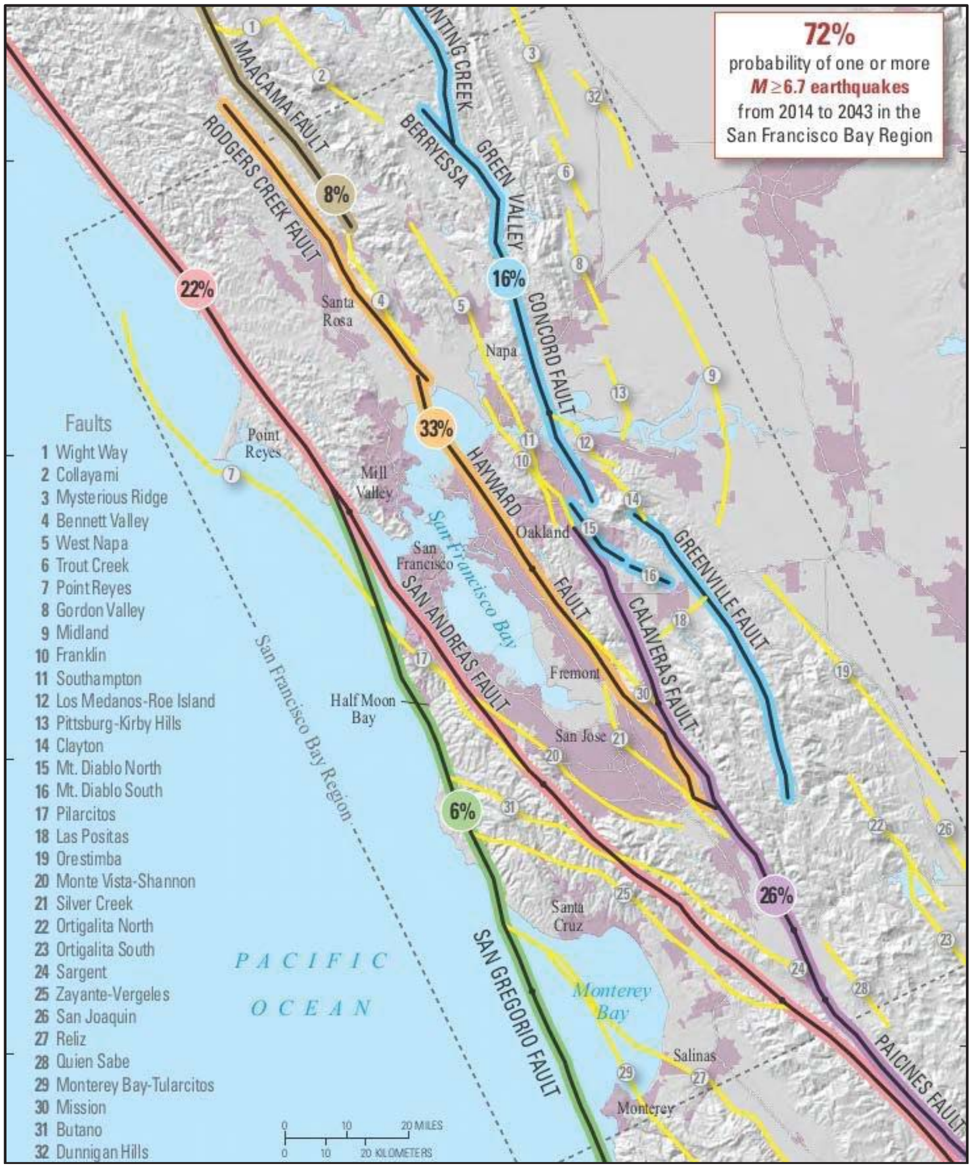
Another factor is transportation-related incidents requiring technical rescue. This risk factor is primarily a function of vehicle, railway, maritime, and aviation traffic. Vehicle traffic volume is the greatest of these factors within the service area, with Sir Francis Drake Boulevard carrying a high daily traffic volume.

Earthquake Risk[8]

The potential for earthquake damage exists throughout Marin County due to the combination of the number of active faults within and near the County and the presence of soils vulnerable to liquefaction. Active faults include the Hayward, Rodgers Creek, and San Andreas as shown in Figure 24. According to the Working Group on California Earthquake Probabilities, there is a 72 percent probability of at least one earthquake of magnitude 6.7 or greater within the Bay Area before 2043. The Association of Bay Area Governments (ABAG) Resilience Program projects a 52 percent chance of a magnitude 6.7 or greater earthquake on one of the faults affecting Marin County by 2036.

[8] Reference: 2018 Marin County Multi-Jurisdictional Local Hazard Mitigation Plan, Section 3

Figure 24—Earthquake Faults



Flood Risk[9]

All of Marin's watersheds are small and largely prone to flash flooding. Several Marin communities, including Ross Valley, are protected by levees. Flooding has historically resulted in extensive damage in many County communities, including most of the Department's service area, from significant flood events in 1955, 1958, 1964, 1969, 1970, 1982, 1983, 1986, 1995, 1997,

[9] Reference: 2018 Marin County Multi-Jurisdictional Local Hazard Mitigation Plan, Section 3

1998, 2005, 2006, and 2017. Figure 25 shows the flood hazard zones within the Department's service area as identified by the Federal Emergency Management Agency (FEMA).

Figure 25—Flood Hazard Areas

Technical Rescue Service Demand

Over the two-year study period, there were a total of six technical rescue incidents comprising 0.11 percent of total service demand for the same period, as summarized in Table 48.

Table 48—Technical Rescue Service Demand

Risk	Year	Planning Zone				Total	Percent Total Service Demand
		Sta. 18	Sta. 19	Sta. 20	Sta. 21		
Technical Rescue	2017	0	0	0	3	**3**	0.10%
	2018	1	1	0	1	**3**	0.11%
Total		**1**	**1**	**0**	**4**	**6**	**0.11%**
Percent of Total Service Demand		0.14%	0.05%	0.00%	0.20%	0.11%	

Source: Ross Valley Fire Department incident data

As Table 48 shows, technical rescue service demand is extremely low.

Probability of Technical Rescue Occurrence

Table 49 summarizes Citygate's technical rescue probability scoring by planning zone based on service demand from Table 48. These probability scores are based predominantly on known historical flood data rather than recent service demand history.

Table 49—Technical Rescue Probability Scoring

Technical Rescue	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Probability Score	1.25	1.25	1.25	1.25

Technical Rescue Impact Severity

Table 50 summarizes Citygate's scoring of probable technical rescue impact severity by planning zone.

Table 50—Technical Rescue Impact Severity Scoring

Technical Rescue	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Impact Severity Score	3.0	3.0	3.0	3.0

Overall Technical Rescue Risk

Table 51 summarizes the Department's overall technical rescue risk scores and ratings by planning zone.

Table 51—Overall Technical Rescue Risk

Technical Rescue	Planning Zone			
	Sta. 18	Sta. 19	Sta. 20	Sta. 21
Total Risk Score	3.75	3.75	3.75	3.75
Risk Rating	***Low***	***Low***	***Low***	***Low***

Report on Residential Fireground Field Experiments

NIST Technical Note 1661

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U.S. Department of Commerce

International Fire Chiefs Association

IAFF AFL-CIO CLC

WPI

CFAI RISK

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Abstract

Service expectations placed on the fire service, including Emergency Medical Services (EMS), response to natural disasters, hazardous materials incidents, and acts of terrorism, have steadily increased. However, local decision-makers are challenged to balance these community service expectations with finite resources without a solid technical foundation for evaluating the impact of staffing and deployment decisions on the safety of the public and firefighters.

For the first time, this study investigates the effect of varying crew size, first apparatus arrival time, and response time on firefighter safety, overall task completion, and interior residential tenability using realistic residential fires. This study is also unique because of the array of stakeholders and the caliber of technical experts involved. Additionally, the structure used in the field experiments included customized instrumentation; all related industry standards were followed; and robust research methods were used. The results and conclusions will directly inform the NPFA 1710 Technical Committee, who is responsible for developing consensus industry deployment standards.

This report presents the results of more than 60 laboratory and residential fireground experiments designed to quantify the effects of various fire department deployment configurations on the most common type of fire — a low hazard residential structure fire. For the fireground experiments, a 2,000 sq ft (186 m^2), two-story residential structure was designed and built at the Montgomery County Public Safety Training Academy in Rockville, MD. Fire crews from Montgomery County, MD and Fairfax County, VA were deployed in response to live fires within this facility. In addition to systematically controlling for the arrival times of the first and subsequent fire apparatus, crew size was varied to consider two-, three-, four-, and five-person staffing. Each deployment performed a series of 22 tasks that were timed, while the thermal and toxic environment inside the structure was measured. Additional experiments with larger fuel loads as well as fire modeling produced additional insight. Report results quantify the effectiveness of crew size, first-due engine arrival time, and apparatus arrival stagger on the duration and time to completion of the key 22 fireground tasks and the effect on occupant and firefighter safety.

Executive Summary

Both the increasing demands on the fire service - such as the growing number of Emergency Medical Services (EMS) responses, challenges from natural disasters, hazardous materials incidents, and acts of terrorism — and previous research point to the need for scientifically based studies of the effect of different crew sizes and firefighter arrival times on the effectiveness of the fire service to protect lives and property. To meet this need, a research partnership of the Commission on Fire Accreditation International (CFAI), International Association of Fire Chiefs (IAFC), International Association of Firefighters (IAFF), National Institute of Standards and Technology (NIST), and Worcester Polytechnic Institute (WPI) was formed to conduct a multiphase study of the deployment of resources as it affects firefighter and occupant safety. Starting in FY 2005, funding was provided through the Department of Homeland Security (DHS) / Federal Emergency Management Agency (FEMA) Grant Program Directorate for Assistance to Firefighters Grant Program — Fire Prevention and Safety Grants. In addition to the low-hazard residential fireground experiments described in this report, the multiple phases of the overall research effort include development of a conceptual model for community risk assessment and deployment of resources, implementation of a generalizable department incident survey, and delivery of a software tool to quantify the effects of deployment decisions on resultant firefighter and civilian injuries and on property losses.

The first phase of the project was an extensive survey of more than 400 career and combination (both career and volunteer) fire departments in the United States with the objective of optimizing a fire service leader's capability to deploy resources to prevent or mitigate adverse events that occur in risk- and hazard-filled environments. The results of this survey are not documented in this report, which is limited to the experimental phase of the project. The survey results will constitute significant input into the development of a future software tool to quantify the effects of community risks and associated deployment decisions on resultant firefighter and civilian injuries and property losses.

The following research questions guided the experimental design of the low-hazard residential fireground experiments documented in this report:

1. How do crew size and stagger affect overall start-to-completion response timing?

2. How do crew size and stagger affect the timings of task initiation, task duration, and task completion for each of the 22 critical fireground tasks?

3. How does crew size affect elapsed times to achieve three critical events that are known to change fire behavior or tenability within the structure:
   a. Entry into structure?
   b. Water on fire?
   c. Ventilation through windows (three upstairs and one back downstairs window and the burn room window).

4. How does the elapsed time to achieve the national standard of assembling 15 firefighters at the scene vary between crew sizes of four and five?

In order to address the primary research questions, the research was divided into four distinct, yet interconnected parts:

- Part 1 — Laboratory experiments to design appropriate fuel load

- Part 2 — Experiments to measure the time for various crew sizes and apparatus stagger (interval between arrival of various apparatus) to accomplish key tasks in rescuing occupants, extinguishing a fire, and protecting property

- Part 3 — Additional experiments with enhanced fuel load that prohibited firefighter entry into the burn prop – a building constructed for the fire experiments

- Part 4 — Fire modeling to correlate time-to-task completion by crew size and stagger to the increase in toxicity of the atmosphere in the burn prop for a range of fire growth rates.

The experiments were conducted in a burn prop designed to simulate a low-hazard[1] fire in a residential structure described as typical in NFPA 1710® *Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*. NFPA 1710 is the consensus standard for career firefighter deployment, including requirements for fire department arrival time, staffing levels, and fireground responsibilities.

Limitations of the study include firefighters' advance knowledge of the burn prop, invariable number of apparatus, and lack of experiments in elevated outdoor temperatures or at night. Further, the applicability of the conclusions from this report to commercial structure fires, high-rise fires, outside fires, terrorism/natural disaster response, HAZMAT or other technical responses has not been assessed and should not be extrapolated from this report.

Primary Findings

Of the 22 fireground tasks measured during the experiments, results indicated that the following factors had the most significant impact on the success of fire fighting operations. All differential outcomes described below are statistically significant at the 95 % confidence level or better.

Overall Scene Time:

The four-person crews operating on a low-hazard structure fire completed all the tasks on the fireground (on average) seven minutes faster — nearly 30 % — than the two-person crews. The four-person crews completed the same number of fireground tasks (on average) 5.1 minutes faster — nearly 25 % — than the three-person crews. On the low-hazard residential structure fire, adding a fifth person to the crews did not decrease overall fireground task times. However, it should be noted that the

1 A low-hazard occupancy is defined in the NFPA Handbook as a one-, two-, or three-family dwelling and some small businesses. Medium hazards occupancies include apartments, offices, mercantile and industrial occupancies not normally requiring extensive rescue or firefighting forces. High-hazard occupancies include schools, hospitals, nursing homes, explosive plants, refineries, high-rise buildings, and other highlife hazard or large fire potential occupancies.

benefit of five-person crews has been documented in other evaluations to be significant for medium- and high-hazard structures, particularly in urban settings, and is recognized in industry standards.[2]

Time to Water on Fire:

There was a 10% difference in the "water on fire" time between the two- and three-person crews. There was an additional 6% difference in the "water on fire" time between the three- and four-person crews. (i.e., four-person crews put water on the fire 16% faster than two person crews). There was an additional 6% difference in the "water on fire" time between the four- and five-person crews (i.e. five-person crews put water on the fire 22% faster than two-person crews).

Ground Ladders and Ventilation:

The four-person crews operating on a low-hazard structure fire completed laddering and ventilation (for life safety and rescue) 30 % faster than the two-person crews and 25 % faster than the three-person crews.

Primary Search:

The three-person crews started and completed a primary search and rescue 25 % faster than the two-person crews. The four- and five-person crews started and completed a primary search 6 % faster than the three-person crews and 30 % faster than the two-person crew. A 10 % difference was equivalent to just over one minute.

Hose Stretch Time:

In comparing four-and five-person crews to two-and three-person crews collectively, the time difference to stretch a line was 76 seconds. In conducting more specific analysis comparing all crew sizes to the two-person crews the differences are more distinct. Two-person crews took 57 seconds longer than three-person crews to stretch a line. Two-person crews took 87 seconds longer than four-person crews to complete the same tasks. Finally, the most notable comparison was between two-person crews and five-person crews — more than 2 minutes (122 seconds) difference in task completion time.

Industry Standard Achieved:

As defined by NFPA 1710, the "industry standard achieved" time started from the first engine arrival at the hydrant and ended when 15 firefighters were assembled on scene.[3] An effective response force was assembled by the five-person crews three minutes faster than the four-person crews. Based on the study protocols, modeled after a typical fire department apparatus deployment strategy, the total number of firefighters on scene in the two- and three-person crew scenarios never equaled 15 and therefore the two- and three-person crews were unable to assemble enough personnel to meet this standard.

Occupant Rescue:

Three different "standard" fires were simulated using the Fire Dynamics Simulator (FDS) model. Characterized in the *Handbook of the Society of Fire Protection Engineers* as slow-, medium-, and fast-growth rate[4], the fires grew exponentially with time. The rescue scenario was based on a non-ambulatory occupant in an upstairs bedroom with the bedroom door open.

Independent of fire size, there was a significant difference between the toxicity, expressed as fractional effective dose (FED), for occupants at the time of rescue depending on arrival times for all crew sizes. Occupants rescued by early-arriving crews had less exposure to combustion products than occupants rescued by late-arriving crews. The fire modeling showed clearly that two-person crews cannot complete essential fireground tasks in time to rescue occupants without subjecting them to an increasingly toxic atmosphere. For a slow-growth rate fire with two-person crews, the FED was approaching the level at which sensitive populations, such as children and the elderly are threatened. For a medium-growth rate fire with two-person crews, the FED was far above that threshold and approached the level affecting the general population. For a fast-growth rate fire with two-person crews, the FED was well above the median level at which 50 % of the general population would be incapacitated. Larger crews responding to slow-growth rate fires can rescue most occupants prior to incapacitation along with early-arriving larger crews responding to medium-growth rate fires. The result for late-arriving (two minutes later than early-arriving) larger crews may result in a threat to sensitive populations for medium-growth rate fires. Statistical averages should not, however, mask the fact that there is no FED level so low that every occupant in every situation is safe.

Conclusion:

More than 60 full-scale fire experiments were conducted to determine the impact of crew size, first-due engine arrival time, and subsequent apparatus arrival times on firefighter safety and effectiveness at a low-hazard residential structure fire. This report quantifies the effects of changes to staffing and arrival times for residential firefighting operations. While resource deployment is addressed in the context of a single structure type and risk level, it is recognized that public policy decisions regarding the cost-benefit of specific deployment decisions are a function of many other factors including geography, local risks and hazards, available resources, as well as community expectations. This report does not specifically address these other factors.

The results of these field experiments contribute significant knowledge to the fire service industry. First, the results provide a quantitative basis for the effectiveness of four-person crews for low-hazard response in *NFPA 1710*. The results also provide valid measures of total effective response force assembly on scene for fireground operations, as well as the expected performance time-to-critical-task measures for low-hazard structure fires. Additionally, the results provide tenability measures associated with a range of modeled fires.

Future research should extend the findings of this report in order to quantify the effects of crew size and apparatus arrival times for moderate- and high-hazard events, such as fires in high-rise buildings, commercial properties, certain factories, or warehouse facilities, responses to large-scale non-fire incidents, or technical rescue operations.

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2 NFPA Standard 1710 - A.5.2.4.2.1 …Other occupancies and structures in the community that present greater hazards should be addressed by additional fire fighter functions and additional responding personnel on the initial full alarm assignment.

3 NFPA 1710 Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments. Section 5.2.1 – Fire Suppression Capability and Section 5.2.2 Staffing.

4 As defined in the handbook, a fast fire grows exponentially to 1.0 MW in 150 seconds. A medium fire grows exponentially to 1 MW in 300 seconds. A slow fire grows exponentially to 1 MW in 600 seconds. A 1 MW fire can be thought-of as a typical upholstered chair burning at its peak. A large sofa might be 2 to 3 MWs.

Background

The fire service in the United States has a deservedly proud tradition of service to community and country dating back hundreds of years. As technology advances and the scope of service grows (e.g., more EMS obligations and growing response to natural disasters, hazardous materials incidents, and acts of terrorism), the fire service remains committed to a core mission of protecting lives and property from the effects of fire.

Firefighting is a dangerous business with substantial financial implications. In 2007, U.S. municipal fire departments responded to an estimated 1,557,500 fires. These fires killed 3,430 civilians (non-firefighters) and contributed to 17,675 reported civilian fire injuries. Direct property damage was estimated at $14.6 billion dollars (Karter, 2008). In spite of the vigorous nationwide efforts to promote firefighter safety, the number of firefighter deaths has consistently remained tragically high. In both 2007 and 2008, the U.S. Fire Administration reported 118 firefighter fatalities (USFA 2008).

Although not all firefighter deaths occur on the fireground — accidents in vehicles and training fatalities add to the numbers — every statistical analysis of the fire problem in the United States identifies residential structure fires as a key component in firefighter and civilian deaths, as well as direct property loss. Consequently, community planners and decision-makers need tools for optimally aligning resources with the service commitments needed for adequate protection of citizens.

Problem

Despite the magnitude of the fire problem in the United States, there are no scientifically based tools available to community and fire service leaders to assess the effects of prevention, fixed sprinkler systems, fire fighting equipment, or deployment and staffing decisions. Presently, community and fire service leaders have a qualitative understanding of the effect of certain resource allocation decisions. For example, a decision to double the number of firehouses, apparatus, and firefighters would likely result in a decrease in community fire losses, while cutting the number of firehouses, apparatus, and firefighters would likely yield an increase in the community fire losses, both human and property. However, decision-makers lack a sound basis for quantifying the total impact of enhanced fire resources on the number of firefighter and civilian lives saved and injuries prevented.

Studies on adequate deployment of resources are needed to enable fire departments, cities, counties, and fire districts to design an acceptable level of resource deployment based upon community risks and service provision commitment. These studies will assist with strategic planning and municipal and state budget processes. Additionally, as resource studies refine data collection methods and measures, both subsequent research and improvements to resource deployment models will have a sound scientific basis.

Review of Literature

Research to date has documented a consistent relationship between resources deployed and firefighter and civilian safety. Studies documenting engine and ladder crew performance in diverse simulated environments as well as actual responses show a basic relationship between apparatus staffing levels and a range of important performance variables and outcome measurements such as mean on-scene time, time-to-task completion, incidence of injury among fire service personnel, and costs incurred as a result of on-scene injuries (Cushman 1981, McManis 1984, Morrison 1990, Ontario 1991, Phoenix 1991, Roberts 1993).

Reports by fire service officials and consulting associates reviewing fire suppression and emergency response by fire crews in U.S. cities were the first publications to describe the relationship between adequate staffing levels and response time, time to completion of various fireground tasks, overall effectiveness of fire suppression, and estimated value of property loss for a wide range of real and simulated environments. In 1980, the Columbus Fire Division's report on firefighter effectiveness showed that for a predetermined number of personnel initially deployed to the scene of a fire, the proportion of incidents in which property loss exceeded $5,000 and horizontal fire spread of more than 25 sq ft (2.3 $m^{2)}$ was significantly greater for crews whose numbers fell below the set thresholds of 15 total fireground personnel at residential fires and 23 at large-risk fires (Backoff 1980). The following year, repeated live experiments at a one-family residential site using modern apparatus and equipment demonstrated that larger units performed tasks and accomplished knockdown more quickly, ultimately resulting in a lower percentage of loss attributable to factors controlled by the fire department. The authors of this article highlighted that the fire company is the fire department's basic working unit and further emphasized the importance of establishing accurate and up-to-date performance measurements to help collect data and develop conclusive strategies to improve staffing and equipment utilization (Gerard 1981).

Subsequent reports from the United States Fire Administration (USFA) and several consulting firms continued to provide evidence for the effects of staffing on fire crews' ability to complete tasks involved in fire suppression efficiently and effectively. Citing a series of tests conducted in 1977 by the Dallas Fire Department that measured the time it took three-, four-, and five-person teams to advance a line and put water on a simulated fire at the rear of the third floor of an old school, officials from the USFA underscored that time-to-task completion and final level of physical exhaustion for crews markedly improved not after any one threshold, but with the addition of each new team member. This report went on to outline the manner in which simulated tests exemplify a clear-cut means to record and analyze the resources initially deployed and finally utilized at fire scenes (NFA 1981). A later publication detailing more Dallas Fire Department simulations — ninety-one runs each for a private residential fire, high-rise office fire, and apartment house fire — showed again that increased staffing levels greatly enhanced the coordination and effectiveness of crews' fire suppression efforts during a finite time span (McManis Associates 1984). Numerous studies of local departments have supported this conclusion using a diverse collection of data, including a report by the National Fire Academy (NFA) on fire department staffing in smaller communities, which showed that a company crew staffed with four firefighters could perform rescue of potential victims approximately 80 % faster than a crew staffed with three firefighters (Morrison 1990).

During the same time period that the impact of staffing levels on fire operations was gaining attention, investigators began to question whether staffing levels could also be associated with the risk of firefighter injuries and the cost incurred as a result of such injuries at the fire scene. Initial results from the Columbus Fire Division showed that "firefighter injuries occurred more often when the total number of personnel on the fireground was less than 15 at residential fires and 23 at large-risk fires" (Backoff 1980), and mounting evidence has indicated that staffing levels are a fundamental health and safety issue for firefighters in addition to being a key determinant of immediate response capacity. One early analysis by the Seattle Fire Department for that city's Executive Board reviewed the average severity of injuries suffered by three-, four-, and five-person engine companies, with the finding that "the rate of firefighter injuries expressed as total hours of disability per hours of fireground exposure were 54 % greater for engine companies staffed with 3 personnel when compared to those staffed with 4 firefighters, while companies staffed with 5 personnel had an injury rate that was only one-third that associated with four-person companies" (Cushman 1981). A joint report from the International Association of Fire Fighters (IAFF) and Johns Hopkins University concluded, after a comprehensive analysis of the minimum staffing levels and firefighter injury rates in U.S. cities with populations of 150,000 or more, that jurisdictions operating with crews of less than four firefighters had injury rates nearly twice the percentage of jurisdictions operating with crews of four-person crews or more (IAFF, JHU 1991).

More recent studies have continued to support the finding that staffing per piece of apparatus integrally affects the efficacy and safety of fire department personnel during emergency response and fire suppression. Two studies in particular demonstrate the consistency of these conclusions and the increasing level of detail and accuracy present in the most recent literature, by looking closely at the discrete tasks that could be safely and effectively performed by three- and four-person fire companies. After testing drills comprised of a series of common fireground tasks at several fire simulation sites, investigators from the Austin Fire Department assessed the physiological impact and injury rates among the variably staffed fire crews. In these simulations, an increase from a three- to four-person crew resulted in marked improvements in time-to-task completion or efficiency for the two-story residential fire drill, aerial ladder evolution, and high-rise fire drill, leading the researchers to conclude that loss of life and property increases when a sufficient number of personnel are not available to conduct the required tasks efficiently, independent of firefighter experience, preparation, or training. Reviews of injury reports by the Austin Fire Department furthermore revealed that the injury rate for three-person companies in the four years preceding the study was nearly one-and-a-half that of crews staffed with four or more personnel (Roberts 1993). In a sequence of similar tests, the Office of the Fire Marshal of Ontario, Canada likewise found that three-person fire companies were unable to safely perform deployment of backup protection lines, interior suppression or rescue operations, ventilation operations that required access to the roof of the involved structure, use of large hand-held hose lines, or establish a water supply from a static source without additional assistance and within the time limits of the study. Following these data, Fire Marshal officials noted that three-person crews were also at increased risk for exhaustion due to insufficient relief at fire scenes and made recommendations for the minimum staffing levels per apparatus necessary for suppression and rescue related tasks (Office of the Fire Marshal of Ontario 1993).

The most comprehensive contemporary studies on the implications of fire crew staffing now include much more accurate performance measures for tasks at the fireground, in addition to the basic metric of response time. They include environmental measures of performance, such as total water supply, which expand the potential for assessing the cost-effectiveness of staffing not only in terms of fireground personnel injury rates but also comparative resource expenditure required for fire suppression. Several examples from the early 1990s show investigators and independent fire departments beginning to gather the kind of specific, comprehensive data on staffing and fireground tasks such as those suggested and outlined in concurrent local government publications that dealt with management of fire services (Coleman 1988). A report by the Phoenix Fire Department laid out clear protocols for responding to structure fires and response evaluation in terms of staffing, objectives, task breakdowns, and times in addition to outlining the responsibilities of responding fire department members and the order in which they should be accomplished for a full-scale simulation activity (Phoenix 1991). One attempt to devise a prediction model for the effectiveness of manual fire suppression similarly reached beyond response time benchmarks to describe fire operations and the step-by-step actions of firefighters at incident scenes by delineating the time-to-task breakdowns for size-up, water supply, equipment selection, entry, locating the fire, and advancing hose lines, while also comparing the predicted time-to-task values with the actual times and total resources (Menker 1994). Two separate studies of local fire department performance, one from Taoyuan County in Taiwan and another from the London Fire Brigade, have drawn ties between fire crews' staffing levels and total water demand as the consequence of both response time and fire severity. Field data from Taoyuan County for cases of fire in commercial, business, hospital, and educational properties showed that the type of land use as well as response time had a significant impact on the water volume necessary for fire suppression, with the notable quantitative finding that the water supply required on-scene doubled when the fire department response increased by ten minutes (Chang 2005).

Response time as a predictor of residential fire outcomes has received less study than the effect of crew size. A Rand Institute study demonstrated a relationship between the distance the responding companies traveled and the physical property damage. This study showed that the fire severity increased with response distance, and therefore the magnitude of loss increased proportionally (Rand 1978). Using records from 307 fires in nonresidential buildings over a three-year period, investigators in the United Kingdom correspondingly found response time to have a significant impact on final fire area, which in turn was proportional to total water demand (Sardqvist 2000).

Recent government and professional literature continues to demonstrate the need for more data that would quantify in depth and illustrate the required tasks, event sequences, and necessary response times for effective fire suppression in order to determine with accuracy the full effects of either a reduction or increase in fire company staffing (Karter 2008). A report prepared for National Institute of Standards and Technology (NIST) stressed the ongoing need to elucidate the relationship between staffing and personnel injury rates, stating that "a scientific study on the relationship between the number of firefighters per engine and the incidence of injuries would resolve a long-standing question concerning staffing and safety" (TriData 2005). While not addressing staffing levels as a central focus, an annual review of fire department calls and false alarms by the National Fire Protection Association (NFPA) exemplified the need to capture not only the number of personnel per apparatus for effective fire suppression but also to clarify the demands on individual fire departments with resolution at the station level (NFPA 2008).

In light of the existing literature, there remain unanswered questions about the relationships between fire service resource deployment levels and associated risks. For the first time this study investigates the effect of varying crew size, first apparatus arrival time, and response time on firefighter safety, overall task completion and interior residential tenability using realistic residential fires. This study is also unique because of the array of stakeholders and the caliber of technical advisors involved. Additionally, the structure used in the field experiments included customized instrumentation for the experiments; all related industry standards were followed; robust research methods were used; and the results and conclusions will directly inform the *NFPA 1710* Technical Committee, as well as public officials and fire chiefs. [5]

5 NFPA is a registered trademark of the National Fire Protection Association, Quincy, Massachusetts. NFPA 1710 defines minimum requirements relating to the organization and deployment of fire suppression operations, emergency medical operations, and special operations to the public by substantially all career fire departments. The requirements address functions and objectives of fire department emergency service delivery, response capabilities, and resources. The purpose of this standard is to specify the minimum criteria addressing the effectiveness and efficiency of the career public fire suppression operations, emergency medical service, and special operations delivery in protecting the citizens of the jurisdiction and the occupational safety and health of fire department employees. At the time of the experiments, the 2004 edition of NFPA 1710 was the current edition.

Purpose and Scope of the Study

This project systematically studies deployment of fire fighting resources and the subsequent effect on both firefighter safety and the ability to protect civilians and their property. It is intended to enable fire departments and city/county managers to make sound decisions regarding optimal resource allocation to meet service commitments using the results of scientifically based research. Specifically, the residential fireground experiments provide quantitative data on the effect of crew size, first-due engine arrival time, and subsequent apparatus stagger on time-to-task for critical steps in response and fire fighting.

The first phase of the multiphase project was an extensive survey of more than 400 career and combination fire departments in the United States with the objective of optimizing a fire service leader's capability to deploy resources to prevent or mitigate adverse events that occur in risk- and hazard-filled environments. The results of this survey are not documented in this report, which is limited to the experimental phase of the project, but they will constitute significant input into future applications of the data presented in this document.

This report describes the second phase of the project, divided into four parts:

- Part 1 — Laboratory experiments to design the appropriate fuel packages to be used in the burn facility specially constructed for the research project
- Part 2 — Field tests for critical time-to-task completion of key tasks in fire suppression
- Part 3 — Field tests with real furniture (room and contents experiments)
- Part 4 — Fire modeling to apply data gathered to slow-, medium-, and fast-growth rate fires

The scope of this study is limited to understanding the relative influence of deployment variables on low-hazard, residential structure fires, similar in magnitude to the hazards described in NFPA® 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*. The standard uses as a typical residential structure a 2,000 sq ft (186 m^2) two-story, single-family dwelling with no basement and no exposures (nearby buildings or hazards such as stacked flammable material).

The limitations of the study, such as firefighters' advance knowledge of the facility constructed for this experiment, invariable number of apparatus, and lack of experiments in extreme temperatures or at night, will be discussed in the Limitations section of this report. It should be noted that the applicability of the conclusions from this report to commercial structure fires, high-rise fires, outside fires, and response to hazardous material incidents, acts of terrorism, and natural disasters or other technical responses has not been assessed and should not be extrapolated from this report.

A Brief Overview of the Fireground Operations

Regardless of the size of a structure on fire, firefighting crews identify four priorities: life safety of occupants and firefighters, confinement of the fire, property conservation, and reduction of adverse environmental impact. Interdependent and coordinated activities of all fire fighting personnel are required to meet the priority objectives.

NFPA 1710 specifies that the number of on-duty fire suppression personnel must be sufficient to carry out the necessary fire fighting operations given the expected fire fighting conditions. During each fireground experiment, the following were dispatched to the test fire building:

- three engine companies
- one truck company
- a command vehicle with a battalion chief and a command aide

Staffing numbers for the engine and truck crews and response times were varied for the purposes of the tests. Additional personnel available to ensure safety will be described later in this report.

The following narrative account describes the general sequence of activities in part 2 of the experiments (time-to-task), when the fuel load permitted firefighter entry:

> The first arriving engine company conducts a size-up or initial life safety assessment of the building to include signs of occupants in the home, construction features, and location of the original fire and any extension to other parts of the structure. This crew lays a supply line from a hydrant close to the building for a continuous water supply.
>
> The truck company usually arrives in close proximity to the first engine company. The truck company is responsible for gaining access or forcing entry into the building so that the engine company can advance the first hose line into the building to locate and extinguish the fire. Usually, they assist the engine company in finding the fire. The NFPA and OSHA 2 In/2 Out[6] crew is also assembled prior to anyone entering an atmosphere that is immediately dangerous to life or health (IDLH). This important safety requirement will have a large impact on availability of firefighters to enter the building when small crews are deployed.
>
> Once a door is opened, the engine crew advances a hose line (attack line) toward the location of the fire. At the same time, members from the truck crew accompany the engine crew and assist in ventilating the building to provide a more tenable atmosphere for occupants and firefighters. Ventilation also helps by improving visibility in an otherwise "pitch black" environment, but it must be coordinated with the attack line crew to ensure it helps control the fire and does not contribute to fire growth. The truck crew performs a systematic rapid search of the entire structure starting in the area where occupants would be in the most danger. The most dangerous area is proximate to the fire and the areas directly above the fire.

Depending upon the travel distance, the battalion chief and command aide will have arrived on the scene and have taken command of the incident and established a command post. The role of the incident commander is to develop the action plan to mitigate the incident and see that those actions are carried out in a safe, efficient, and effective manner. The command aide is responsible for situational assessment and communications, including communications with crew officers to ensure personnel accountability.

Depending on response time or station location, the second (engine 2) and possibly the third engine company (engine 3) arrive. The second arriving engine (engine 2) connects to the fire hydrant where the first engine (engine 1) laid their supply line. Engine 2 pumps water from the hydrant through the supply line to the first engine for fire fighting operations. According to *NFPA 1710*, water should be flowing from the supply line to the attack engine prior to the attack crew's entry into the structure.

The crew from the second engine advances a second hand line as a backup line to protect firefighters operating on the inside and to prevent fire from spreading to other parts of the structure.

The third engine crew is responsible for establishing a Rapid Intervention Team (RIT), a rescue team staged at or near the command post or as designated by the Incident Commander (in the front of the building) with all necessary equipment needed to locate and/or rescue firefighters that become trapped or incapacitated. The RIT plans entry/exit portals and removes hazards, if found, to assist interior crews.

As the fire fighting, search and rescue, and ventilation operations are continuing, two members of the truck company are tasked with placing ground ladders to windows and the roof to provide a means of egress for occupants or firefighters. The truck crew is responsible for controlling interior utilities such as gas and electric after their ventilation, search, and rescue duties are completed.

Once the fire is located and extinguished and occupants are

6 The "2 In/2 Out" policy is part of paragraph (g)(4) of OSHAs revised respiratory protection standard, 29 CFR 1910.134. This paragraph applies to private sector workers engaged in interior structural fire fighting and to Federal employees covered under Section 19 of the Occupational Safety and Health Act. States that have chosen to operate OSHA-approved occupational safety and health state plans are required to extend their jurisdiction to include employees of their state and local governments. These states are required to adopt a standard at least as effective as the Federal standard within six months.

OSHAs interpretation on requirements for the number of workers required to be present when conducting operations in atmospheres that are immediately dangerous to life and health (IDLH) covers the number of persons who must be on the scene before fire fighting personnel may initiate an attack on a structural fire. An interior structural fire (an advanced fire that has spread inside of the building where high temperatures, "heat" and dense smoke are normally occurring) would present an IDLH atmosphere and therefore, require the use of respirators. In those cases, at least two standby persons, in addition to the minimum of two persons inside needed to fight the fire, must be present before fire fighters may enter the building.
Letter to Thomas N. Cooper, Purdue University, from Paula O. White, Director of Federal-State Operations, U.S. Department of Labor, Occupational Safety & Health Administration, November 1, 1995.

removed, the incident commander reassesses the situation and provides direction to conduct a very thorough secondary search of the building to verify that the fire has not extended into void spaces and that it is fully extinguished. (In a nonexperimental fire situation, salvageable property would be covered or removed to minimize damage.)

Throughout the entire incident, each crew officer is responsible for the safety and accountability of his or her personnel along with air management. The location and wellness of crews is tracked by the command aide through a system of personal accountability checks conducted at 20-minute intervals.

Following extinguishment of the fire, an onsite review is conducted to identify actions for improvement. Crews are monitored, hydrated and rested before returning to work in the fire building.

The Relation of Time-to-Task Completion and Risk

Delayed response, particularly in conjunction with the deployment of inadequate resources, reduces the likelihood of controlling the fire in time to prevent major damage and possible loss of life and increases the danger to firefighters.

Figure 1 illustrates a hypothetical sequence of events for response to a structure fire. During fire growth, the temperature of a typical compartment fire can rise to over 1,000° F (538° C). When a fire in part of a compartment reaches flashover, the rapid transition between the growth and the fully developed fire stage, flame breaks out almost at once over the surface of all objects in the compartment, with results for occupants, even firefighters in full gear, that are frequently deadly.

Successful containment and control of a fire require the coordination of many separate tasks. Fire suppression must be coordinated with rescue operations, forcible entry, and utilities control. Ventilation typically occurs only after an attack line is in place and crews are ready to move in and attack the fire. The incident commander needs up-to- the-minute knowledge of crew activities and the status of task assignments which could result in a decision to change from an offensive to a defensive strategy.

Standards of Response Cover

Developing a standard of response cover — the policies and procedures that determine the distribution, concentration, and reliability of fixed and mobile resources for response to fire (as well as other kinds of technical response) — related to service commitments to the community is a complex task. Fire and rescue departments must evaluate existing (or proposed) resources against identified risk levels in the community and against the tasks necessary to conduct safe, efficient and effective fire suppression at structures identified in these various risk levels. Leaders must also evaluate geographic distribution and depth or concentration of resources deployed based on time parameters.

Recognition and reporting of a fire sets off a chain of events before firefighters arrive at the scene: call receipt and processing, dispatch of resources, donning protective gear, and travel to the scene. *NFPA 1710* defines the overall time from dispatch to scene arrival as the *total response time*. The standard divides total

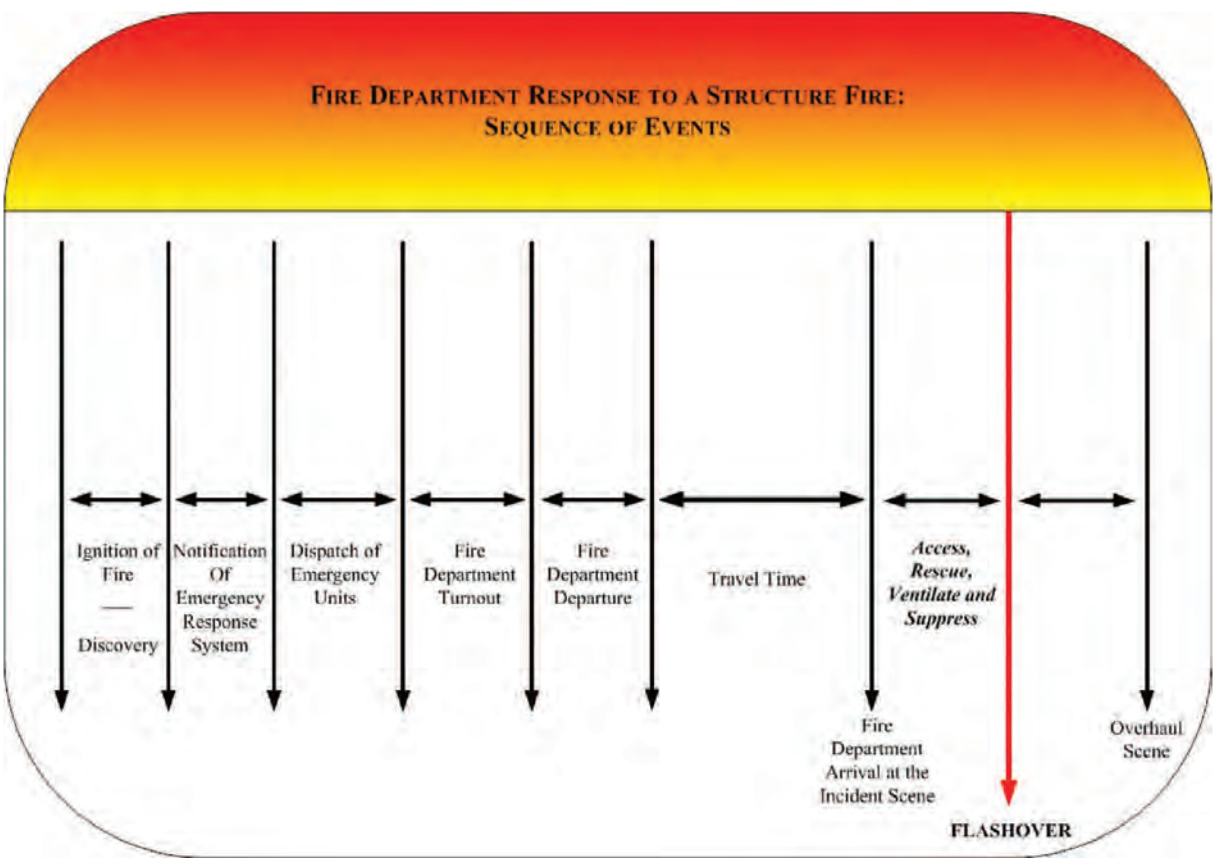


Figure 1: Hypothetical Timeline of Fire Department Response to Structure Fire

response time into a number of discrete segments, of which travel time — the time interval from the beginning of travel to the scene to the arrival at the scene — is particularly important for this study.

Arrival of a firefighting response force must be immediately followed by organization of the resources into a logical, properly phased sequence of tasks, some of which need to be performed simultaneously. Knowing the time it takes to accomplish each task with the allotted number of personnel and equipment is critical. Ideally crews should arrive and intervene in sufficient time to prevent flashover or spread beyond the room of origin.

Decision-making about staffing levels and geographic distribution of resources must consider those times when there will be simultaneous events requiring resource deployment. There should be sufficient redundancy or overlap in the system to allow for simultaneous calls and high volume of near simultaneous responses without compromising the safety of the public or firefighters.

Policy makers have long lacked studies that quantify changes in fireground performance based on apparatus staffing levels and on-scene arrival time intervals. These experiments were designed to observe the impact of apparatus staffing levels and apparatus arrival times on the time it takes to execute essential fireground tasks and on the tenability inside the burn prop for a full initial alarm assignment response. It is expected that the results of this study will be used to evaluate the related performance objectives in *NFPA 1710*.

Part 1: Planning for the Field Experiments

Laboratory Experiments

The purpose of the first segment, the laboratory experiments, was to characterize the burning behavior of the wood pallets as a function of:

- number of pallets and the subsequent peak heat release rate (HRR)
- compartment effects on burning of wood pallets
- effect of window ventilation on the fire
- effect on fire growth rate of the loading configuration of excelsior (slender wood shavings typically used as packing material)

Characterization of the fuel package was critical in order to ensure that the field experiments would not result in a flashover condition, one of the primary safety considerations in complying with the protocols in *NFPA 1403: Standard on Live fire Training Evolutions*.[7] Appendix A of this report contains the methods and full results for the laboratory experiments, which are summarized below. Figure 2 shows a test burn of pallets in the laboratory.

Figure 2: Test Burn of Pallets in Laboratory

Results of Laboratory Experiments

The objective of the laboratory experiments was to quantify the spread of heat and smoke throughout the planned burn prop in order to ensure that the fuel package would result in a fire large enough to generate heat and smoke consistent with a residential structure fire, yet not so large as to transition to flashover. The full results of the laboratory experiments and modeling are shown in Appendix A and Appendix B. To summarize briefly, a four-pallet configuration, which produced a peak of approximately 2 MW, was determined to be the largest fuel load the room could support without the threat of transitioning to flashover. The compartment produced a negligible effect on the heat release rate of the fire compared to open burning conditions. The presence of an open window in the burn room reduced the production of carbon monoxide and carbon dioxide gases, primarily through enhanced oxygen availability and dilution, respectively. The location and quantity of excelsior had a significant impact on the growth rate of fire. More excelsior located nearer the bottom of the pallets resulted in a more rapid achievement of peak burning.

The results of the fuel load experiments to inform the building and experimental design indicated development of untenable conditions in the field experiments between 5 min and 15 min, depending upon several factors: fire growth rate, ventilation conditions, the total leakage of heat into the building and through leakage paths, and manual fire suppression. This time frame allowed for differentiation of the effectiveness of various fire

7 NFPA 1403 contains the minimum requirements for training all fire suppression peronnel engaged in firefighting operations under live fire conditions.

Part 2: Field Experiment Methods

department response characteristics.

In part 2, fire experiments were conducted in a residential-scale burn prop at the Montgomery County Public Safety Training Academy in Rockville, MD.

Field Site

Montgomery County (MD) Fire and Rescue Department provided an open space to construct a temporary burn prop, with ready access to water and electrical utilities, at the Montgomery County Fire and Rescue Training Facility in Rockville, MD.

The burn prop was constructed as a two-story duplex with a common stairwell and movable walls between the sections to allow for multiple experiments daily. Symmetrically dividing the structure about the short axis allowed one side of the test structure to cool and dry out after a fire test with suppression. The burn prop contained two mirror-image, two-story units each totaling 2,000 ft^2 (186 m^2), without basement or nearby exposures — each therefore a typical model of a low-hazard single-family residence identified in *NFPA 1710*. An exterior view of the burn prop is shown in Figure 3. For each experiment there was a confirmed fire in the living room in the first floor rear of one unit of the structure.

Details and dimension are shown in the floor plan in Figure 4.

The black lines in Figure 4 indicate load-bearing reinforced concrete walls and red lines indicate the gypsum over steel stud partition walls. The ceiling height was 94 in (2.4 m) throughout the entire structure except in the burn compartments, where additional hardening was installed to protect against repeated exposure to fire during the experiments. This additional fire proofing slightly reduced the ceiling height. Complete details about the building construction are included in Appendix C.

Noncombustible furniture (angle iron and gypsum board construction) was fashioned to represent obstacles of realistic size and location for firefighters navigating the interior of the structure. The dimensions were typical of residential furnishings. Figure 5 shows an example of the noncombustible furniture used in the time-to-task experiments.

Figure 3: Exterior View of Burn Prop

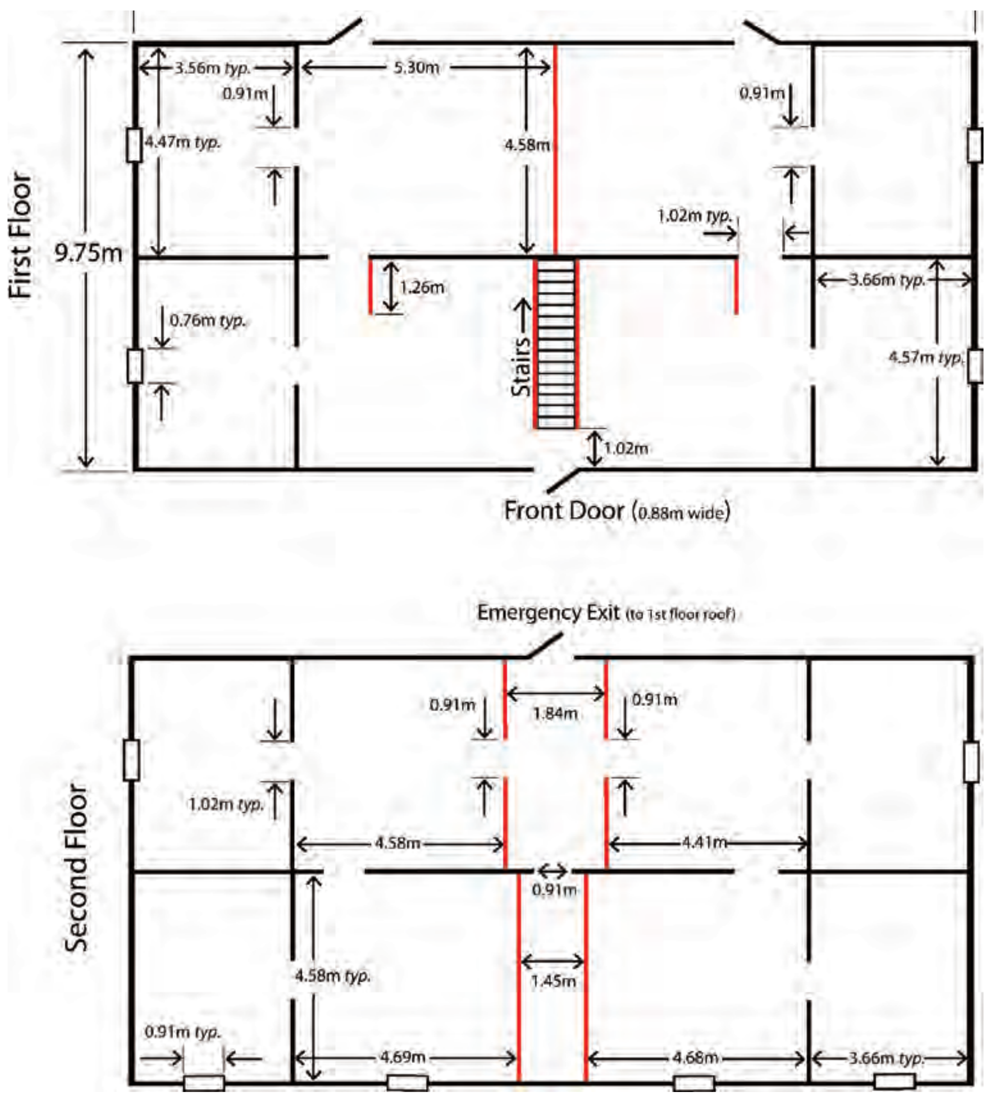


Figure 4: Dimensions of the Burn Prop Floor Plan

Overview of Field Experiments

In order to evaluate the performance representative of a *NFPA 1710*-compliant fire department, the field experiments consisted of two parts (the second and third parts of the four described in this report). In the first of the two parts of the field experiments, firefighter participants from Montgomery County (MD) and Fairfax County (VA) Fire Departments simulated an initial alarm assignment response to a structure described in *NFPA 1710* as a low-hazard residential structure to which firefighters respond on a regular basis. The staffing level of fire apparatus was varied incrementally from two to five personnel per piece. The interval between apparatus on-scene arrival times was varied at either 60 s or 120 s. Trained timing staff were used to record the start and completion times of 22 tasks deemed essential for mitigation of a residential fire incident by the study's technical experts. The pallet and excelsior configuration chosen from the laboratory experiments repeatably produced a consistent and realistic quantity of heat and smoke, similar to what firefighters encounter at a residential structure fire.

Although the fire source used in part 2 of the field experiments created a realistic amount of heat and smoke, the requirements of *NFPA 1403* prevented use of a fire source which could potentially reach flashover within the structure. Therefore, part 3 of the fire experiments was conducted in order to change the fuel package to be representative of realistic fuel loading that could be found in a living room in a residential structure (sleeper-sofa, upholstered chairs, end tables, etc). The intent of this part of the study was to determine how the times of firefighter interactions, averaged with respect to the staffing and arrival intervals, impacted the interior tenability conditions. Fire fighting tactics were performed in a manner which complied with *NFPA 1403*; ventilation was performed with proper personal protective equipment (PPE) and hand tools from the exterior of the burn prop. Suppression was performed with an interior remote suppression device operated from the exterior of the burn prop.

Instrumentation

Instrumentation to measure gas temperature, gas concentrations, heat flux, visual obscuration, video, and time during the experiments was installed throughout the burn prop. The data were recorded at 1-second intervals on a computer-based data acquisition system. Figure 6 presents a schematic plan view of the instrumentation. All instruments were wired to a centralized data collection room attached as a separate space on the west side of the building, which is described later in this report ensuring physical separation for the data collection personnel from the effects of the fire, while minimizing the wire and tube lengths to the data logging equipment. See Appendix C for additional details about the instrumentation.

Figure 5: Noncombustible Furniture Used in the Time-to-Task Experiments

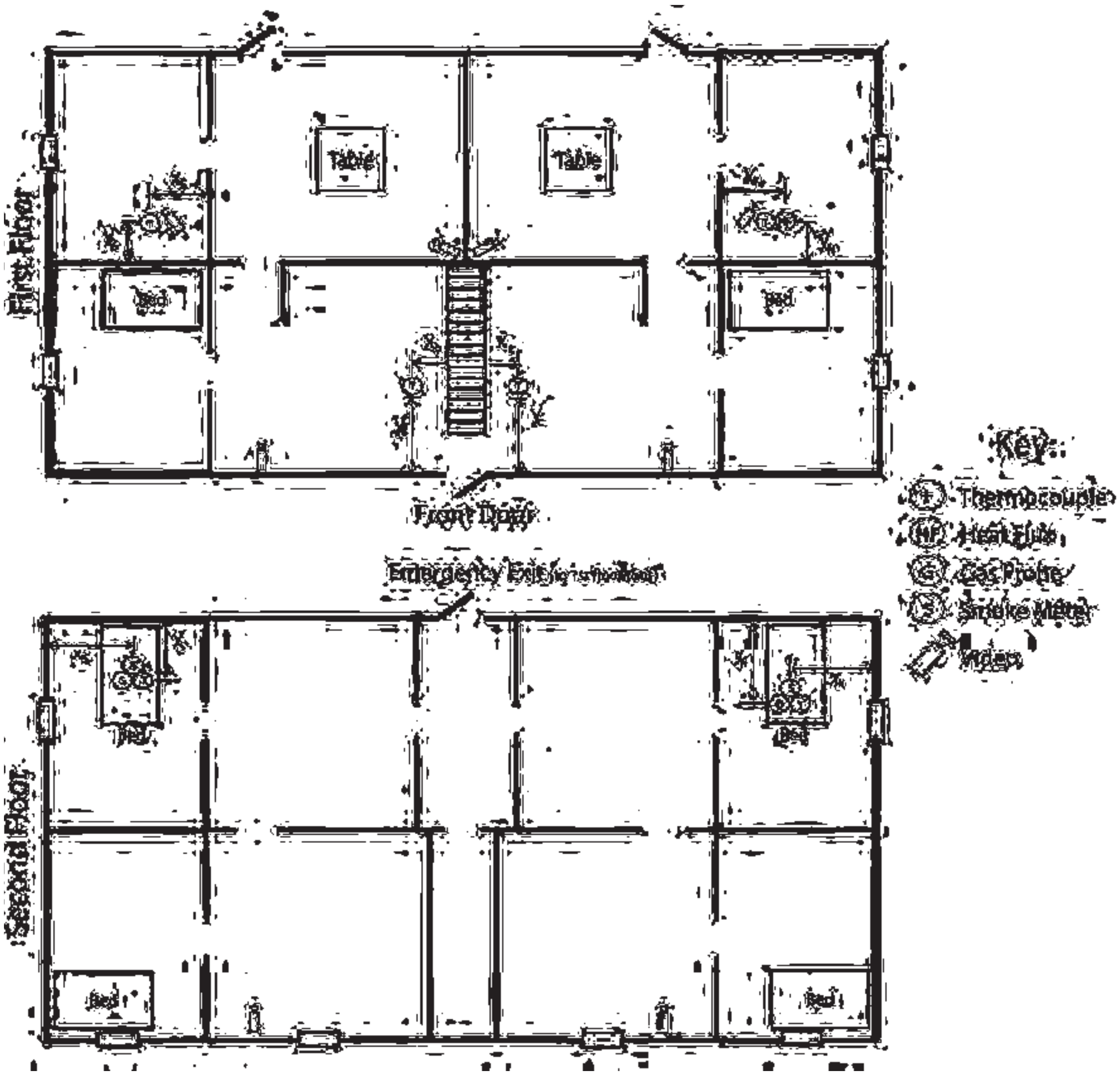


Figure 6: Instrumentation and Furniture Prop Layout

Figure 7: Fireground Safety Officer

Safety Protocols

Firefighter safety was always a primary concern in conducting the research. Participants were drawn from two departments — Fairfax County, VA and Montgomery County, MD — that regularly conduct NFPA 1403 compliant live fire training for their staff and recruits.

A safety officer was assigned to the experiments by the Montgomery County Fire and Rescue Department to assure compliance with *NFPA 1403*. The safety officer (Figure 7) participated in all orientation activities, daily briefings, and firefighter gear checks and was always actively involved in overseeing all experiments. The safety officer had full authority to terminate any operation if any safety violation was observed. In addition to the safety officer, a rapid intervention team (RIT), assigned from dedicated crews not in the actual experiment, was in place for each experiment, and a staffed ambulance was on standby at the site. Radio communication was always available during the experiments should a "mayday" emergency arise.

Experiments were stopped for any action considered to be a protocol breach or safety concern. For example, all ladders — 24 ft (7.3 m) or 28 ft (8.5 m) — were to be raised by two firefighters. As crew sizes were reduced, some firefighters attempted to place ladders single-handedly in an effort to complete the task more quickly. This procedure, while vividly illustrating how firefighters try to do more with less in the field, is unsafe and could potentially result in strain or impact injuries.

Additional safety features were built in to the field structure. A deluge sprinkler system oriented to the known location of the fuel package could be remotely activated for rapid fire suppression. All first floor rooms had direct access to the exterior of the building through either doors or windows. The second story had an emergency exit to the roof of the attached instrumentation room.

A closely related concern to ensure firefighter safety and readiness to repeat experiments with equivalent performance was adequate rehabilitation (see Figure 8). At the beginning and end of each day, crews completed a health and safety check. The importance of staying well-hydrated before and during experiments was especially emphasized.

Figure 8: Crew Rehabilitation

Time-to-Task Experiments

On-Scene Fire Department Tasks

The on-scene fire department task part of the study focused on the tasks firefighters perform after they arrive on the scene of a low-hazard residential structure fire. A number of nationally recognized fire service experts were consulted during the development of the on-scene fire department tasks in order to ensure a broad applicability and appropriateness of the task distribution.[8] The experiments compared crew performance and workload for a typical fire fighting scenario using two-, three-, four-, and five-person crews. 24 total experiments were conducted to assess the time it took various crew sizes to complete the same tasks on technically similar fires in the same structure. In addition to crew sizes, the experiments assessed the effects of stagger between the arriving companies. Close stagger was defined as a 1-minute time difference in the arrival of each responding company. Far stagger was defined as a 2-minute time difference in the arrival of each responding company. One-minute and two-minute arrival stagger times were determined from analysis of deployment data from more than 300 U.S. fire departments responding to a survey of fire department operations conducted by the International Association of Fire Chiefs (IAFC) and the International Association of Fire Fighters (IAFF). Considering both crew size and company stagger there were eight experiments conducted in triplicate totaling twenty-four tests, as shown in the full replicate block in Table 1. A full replicate was completed in a randomized order (determined by randomization software) before a test configuration was repeated.

Crew Size	Apparatus Stagger
2 Person	Close Stagger (One minute)
3 Person	Close Stagger (One minute)
4 Person	Close Stagger (One minute)
5 Person	Close Stagger (One minute)
2 Person	Far Stagger (Two minutes)
3 Person	Far Stagger (Two minutes)
4 Person	Far Stagger (Two minutes)
5 Person	Far Stagger (Two minutes)

Table 1: Primary Variables for Time-to-Task Experiments

Crew Size

For each experiment, three engines, a ladder-truck and a battalion chief and an aide were dispatched to the scene of the residential structure fire. The crew sizes studied included two-, three-, four-, and five-person crews assigned to each engine and truck dispatched. Resultant on-scene staffing totals for each experiment follow: (FF = firefighter)

- Two Person crews = 8 FFs + Chief and Aide = 10 total on-scene
- Three Person crews = 12 FFs + Chief and Aide= 14 total on-scene
- Four Person crews = 16 FFs + Chief and Aide = 18 total on-scene
- Five Person crews = 20 FFs + Chief and Aide = 22 total on-scene[9]

Department Participation

The experiments were conducted in Montgomery County, MD at the Montgomery County Fire Rescue Training Academy during the months of January and February 2009. All experiments took place in daylight between 0800 hours and 1500 hours. Experiments were postponed for heavy rain, ice, or snow and rescheduled for a later date following other scheduled experiments.

Montgomery County (MD) and Fairfax County (VA) firefighters participated in the field experiments. Each day both departments committed three engines, a ladder truck and associated crews, as well as a battalion chief to the experiments. The two battalion chiefs, alternated between the roles of battalion chief and aide. Firefighters and officers were identified by participating departments and oriented to the experiments. Each experiment included engine crews, truck crews and command officers from each participating department. Participants varied with regard to age and experience. Crews that normally operated together as a company were kept intact for the experiments to assure typical operation for the crew during the scenarios. However, in all experiments crews were used from both departments, including engine crews, truck crews, and officers.

This allocation of resources made it possible to conduct back-to-back experiments by rotating firefighters between field work and rehabilitation areas.

Crew Orientation

All study participants were required to attend an orientation prior to the beginning of the experiments (see Figure 9, page 25). The orientations were used to explain experiment procedures, task flows, division of labor between crews, and milestone events in the scenario.

Daily orientations were conducted for all shifts to assure every participant attended. Orientations included a description of the overall study objectives as well as the actual experiments in which they would be involved. Per the requirements of *NFPA 1403*, full disclosure regarding the structure, the fire, and the tasks to be completed were provided. Crews were also oriented to the fireground props, instrumentation used for data collection, and the specific scenarios to be conducted. Every crew member was provided a walkthrough of the structure during the orientation and each day prior to the start of the experiments.

8 Technical experts included Dennis Compton, Russell Sanders, William “Shorty” Bryson, Vincent Dunn, David Rohr, Richard Bowers, Michael Clemens, James Walsh, Larry Jenkins and Doug Hinkle. More information about the experts is presented in the Acknowledgments later in this report.

9 Note that the on-scene totals account for only the personnel assigned to “work” the fire. Additional personnel were provided for an RIT team, a staffed ambulance on site, and a safety officer specific to the experiments. The additional personnel are not included in thee staffing described above.

Tasks

Twenty-two fireground tasks were completed in each experiment. Meticulous procedures gathered data to measure key areas of focus, such as individual task start times, task completion times, and overall scenario performance times. Each task was assigned a standardized start and end marker, such as crossing the threshold to enter the building with a hose line or touching a ladder to raise it to a second story window. The 22 tasks, with the events for measuring start and stop times, are shown in Table 2 (page26). Figures 10 — 19 illustrate firefighter activity in a number of the tasks to complete experiments or prepare for the next experiment.

For reasons of both safety and cost efficiency, two tasks — forcible entry of the front door and ventilation of the windows on the first and second stories — required special procedures. The study could not accommodate replacing the doors and windows daily for the fire suppression experiments. Before the start of experiments with the full sequence of tasks, these two tasks were measured in a realistic manner using training props constructed at the site of the fireground experiments. As with the overall experiments, these two tasks were repeated in triplicate and the times averaged. The average time to complete the tasks was then used in the larger scale experiment. As firefighters came to the point of breaching the door or windows, the timers would hold them for the time designated by the earlier experiments and then give them the approval to open the door or windows. The start and end times were then recorded just as other tasks were.

Figure 9: Crew Orientation and Walkthrough

Figure 10: Ground Ladders

Figure 11: Ventilation

Figure 12: Ground Level Window Breakage Prop

Figure 13: Second Story Window Breakage Prop

Figure 14: Door Forcible Entry Prop

Figure 15: Crew Preparation and Cue Cards

Table 2: Tasks and Measurement Parameters

Tasks	Measurement Parameters
1. Stop at Hydrant, Wrap Hose	START - Engine stopped at hydrant STOP - Firefighter back on engine and wheels rolling
2. Position Engine 1	START - Wheels rolling from hydrant STOP - Wheels stopped at structure
3. Conduct Size-up (360-degree lap), transmit report, establish command	START - Officer off engine STOP - Completes radio transmission of report
4. Engage Pump	START - Driver off engine STOP - Driver throttles up pump
5. Position Attack Line (Forward Lay)	START - Firefighter touches hose to pull it from engine STOP - Flake, charge and bleed complete (hose at front door prepared to advance)
6. Establish 2 In/2 Out	Company officer announces – "2 In/2 Out established" (4 persons assembled on scene OR at the call of the Battalion Chief/Company Officer)
7. Supply Attack Engine	START - Firefighter touches hydrant to attach line STOP - Water supply to attack engine
8. Establish RIT	Time that Company Officer announces RIT is established
9. Gain/Force Entry	START - Action started (HOLD time= 10 seconds) STOP - Door opened for entry
10. Advance Attack Line	START – Firefighter touches hose STOP – Water on fire
11. Advance Backup Line (stop time at front door)	START - Firefighter touches hose to pull from engine bed STOP - Backup line charged to nozzle
12. Advance Backup Line/Protect Stairwell	START - Firefighter crosses threshold STOP - Position line for attack at stairwell
13. Conduct Primary Search	START - Firefighters enter front door STOP - Firefighters transmit "search complete"
14. Ground Ladders in Place	START - Firefighter touches ladder to pull it from truck STOP - 4 Ladders thrown: 3 ladders on the 2nd-story windows and 1 to the roof
15. Horizontal Ventilation (Ground)	START- Firefighter at 1st window to begin ventilation (HOLD for 8 seconds) STOP - Hold time complete - window open
16. Horizontal Ventilation (2nd Story)	START - Firefighter grabs ladder for climb. (Firefighter must leg lock for ventilation. HOLD time at each window is 10 seconds) STOP - All 2nd-story windows open - descend ladder - feet on ground.
17. Control Utilities (Interior)	START - Radio transmission to control utilities STOP - When firefighter completes the task at the prop
18. Control Utilities (Exterior)	START - Radio transmission to control utilities STOP - When firefighter completes the task at the prop
19. Conduct Secondary Search	START - Firefighters enter front door STOP - Firefighters transmit "secondary search complete"
20. Check for Fire Extension (walls)	START- Firefighters pick up check-for-extension prop STOP- Completion of 4 sets total (1 set = 4 in and 4 out) This task may be done by more than one person.
21. Check for Fire Extension (ceilings)	START - Firefighters pick up check-for-extension prop STOP - Completion of 4 sets total (1 set = 3 up and 5 down) This task may be done by more than one person.
22. Mechanical Ventilation	START - Firefighters touch fans to remove from truck STOP - Fans in place at front door and started

Data Collection: Standardized Control Measures

Several control measures were used to collect data, including crew cue cards, radio communications, task timers, and video recording. Performance was timed for each task in each scenario including selected milestone tasks such as door breach, water-on-fire, and individual window ventilation. Data were collected for crew performance on each task, and individual firefighter performance was not considered.

Task Flow Charts and Crew Cue Cards

Task procedures were standardized for each experiment/scenario. Technical experts worked with study investigators to break down crew tasks into individual tasks based on crew size. Task flow charts were created and then customized for the various crew sizes. The carefully designed task flow ensured that the same overall workload was maintained in each experiment, but was redistributed based on the number of personnel available for the work. See Appendix D for additional details.

All tasks were included in each scenario and cue cards were developed for each individual participant in each scenario. For example, a four-person crew would have a cue card for each person on the crew including the officer, the driver, and the two firefighters. Cards were color coded by crew size to assure proper use in each scenario.

Figure 16: Connecting to the Hydrant

Figure 17: Crews Responding


Figure 18: Ceiling Breach/Molitor Machine


Figure 19: Incident Command


Figure 20: Task Timers

Figure 21: Video Recording for Quality Control

Radio communications

Interoperability of radio equipment used by both participating departments made it possible to use regular duty radios for communication during the experiments. Company officers were instructed to use radios as they would in an actual incident. Montgomery County Fire and Rescue Communications recorded all radio interaction as a means of data backup. Once all data quality control measure were complete, the records were then overwritten as a routine procedure.

Task Timers

Ten observers/timers, trained in the use of a standard stop watch with split-time feature, recorded time-to-task data for each field experiment. To assure understanding of the observed tasks, firefighters were used as timers, each assigned specific tasks to observe and to record the start and end times.

To enhance accuracy and consistency in recording times, the data recording sheets used several different colors for the tasks (see Appendix D). Each timer was assigned tasks that were coded in the same color as on the recording sheet. All timers wore high-visibility safety gear on the fireground (see Figure 20).

Video records

In addition to the timers, video documentation provided a backup for timed tasks and for quality control (see Figure 21). No less than six cameras were used to record fireground activity from varied vantage points. Observer/timer data were compared to video records as part of the quality control process.

Crew Assignment

Crews from each department that regularly operated together were assigned to work as either engine or truck companies in each scenario. Both Fairfax County and Montgomery County crews participated in each experiment.

Crews assigned to each responding company position in one scenario were assigned to another responding company position in subsequent scenarios, with the objective of minimizing learning from one experiment to another. For example, crews in the role of engine 1 in a morning scenario might be assigned to the engine 3 position in the afternoon, thus eliminating learning from exact repetition of a task as a factor in time to completion. Additionally, participating crews from both Montgomery County and Fairfax County were from three different shifts, further reducing opportunities for participant repetition in any one position.

Response Time Assumptions

Response time assumptions were made based on time objectives set forth in the *NFPA 1710*. Time stagger allocations were set by the project technical advisors in order to assess the impact of arriving unit time separation on task start and completion times, as well as the overall scene time.

Below are the values assigned to the various time segments in the overall response time. The total of the response time segments may also be referred to as the total reflex time.

1. Fire ignition = time zero
2. 60 s for recognition (detection of fire) and call to 9-1-1
3. 60 s for call processing/dispatch
4. 60 s for turnout[10]
5. Close Stagger = 240 s travel time FIRST engine with 60 s ladder-truck lag and 90 s lag for each subsequent engine
   a. Truck arrives at 300 s from notification
   b. Second engine at 330 s from notification
   c. Third engine at 420 seconds from notification
6. Far Stagger = 240 s travel time FIRST engine with 120 s ladder-truck lag and 150 s lag for each subsequent engine
   a. Truck arrives at 360 s from notification
   b. Second engine arrives at 390 s from notification
   c. Third engine arrives at 540 s from notification.

The design of this part of the experiments allowed firefighter entry into the burn building. The next part of the experiments required a modified methodology.

10 After the experiments were complete, the NFPA 1710 technical committee released a new edition of the standard that prescribes 80 seconds for turnout time.

Part 3: Room and Contents Fires

As previously discussed, *NFPA 1403* prohibits firefighters in a training exercise from entering a structure with sufficient fuel load to result in room flashover. But the value of the data from the time-to-task experiments lies not just in the duration and time-of-completion statistics for tasks, but also in measuring the tenability of the atmosphere for occupants urgently needing firefighter assistance. Therefore Part 3 of the experiments (room and contents fires) used a larger fuel load to focus on the seven of the 22 tasks that cause a change in the fire behavior through ventilation or active suppression:

The Tornado Remote Controlled Monitor is Produced by Task Force Tips, Valparaiso, Indiana, USA. Permission to publish courtesy of Task Force Tips

Figure 22: Remotely Controlled Fire Suppression Nozzle for Room and Contents Fires

1. Forced entry of the front door
2. Water on fire
3. Second floor window #1 ventilated (burn room window)
4. Second floor window #2 ventilated (front window, near corner)
5. Second floor window #3 ventilated (front window, near front door)
6. First floor window #1 ventilated (window beside the fire room)
7. First floor window #2 ventilated (self-ventilated at flashover)

Because the fuel load was sufficient for flashover, all firefighter activity was conducted outside the building. Tasks that in Part 3 required entry into the building, such as search or interior utility control, were factored into this part by delaying the next task for the average duration of the task from Part 2. Firefighters in full gear opened the door with a gloved hand or opened windows from the ground with a tool such as a pike pole or angle iron, again at the time specified by the averages from Part 2. Averages were derived from the three iterations of each scenario. The different number of iterations in Part 3 will be explained later in this report.

Because firefighters could not enter the building, a nozzle controlled from the instrumentation room was installed. The nozzle was placed in the room directly outside the burn room and oriented toward the burn room near the doorway in order to best emulate the nozzle location of live firefighter suppression (see Figure 22). The nozzle was encased with mineral wool and heavy-duty aluminum foil (bottom picture in Figure 22) to protect the electronics and wiring from the intense radiation energy emitted by the fire. Blocks were used to anchor the nozzle against the lateral forces exerted by the momentum of the water supply. The activation time for suppression was determined by the data from the time-to-task test results.

A 15º spray pattern was directed toward the seat of the fire and swept horizontally from side to side. While the remotely controlled hose line knocked down the majority of the fire, it was not as effective as a live firefighter with a better view into the room of origin. Therefore, after the fire was diminished, a supplemental stream was applied through the burn room window in order to control the fire (see Figure 23). All personnel on the hose line were in full turnout gear and self-contained breathing apparatus during the exterior application of water.

Fuel Packages for the Room and Contents Fires

In order to maximize the repeatability of the fire development, nominally identical rooms of furniture of identical manufacturer, style, and age were used for each test. A plan-view schematic of the furniture is shown in Figure 24 and pictures of the burn room prior to testing are shown in Figure 25. Key dimensions, mass, and materials for combustible furnishings are detailed in Appendix C.

Figure 23: Supplemental Suppression Applied for Room and Contents Tests

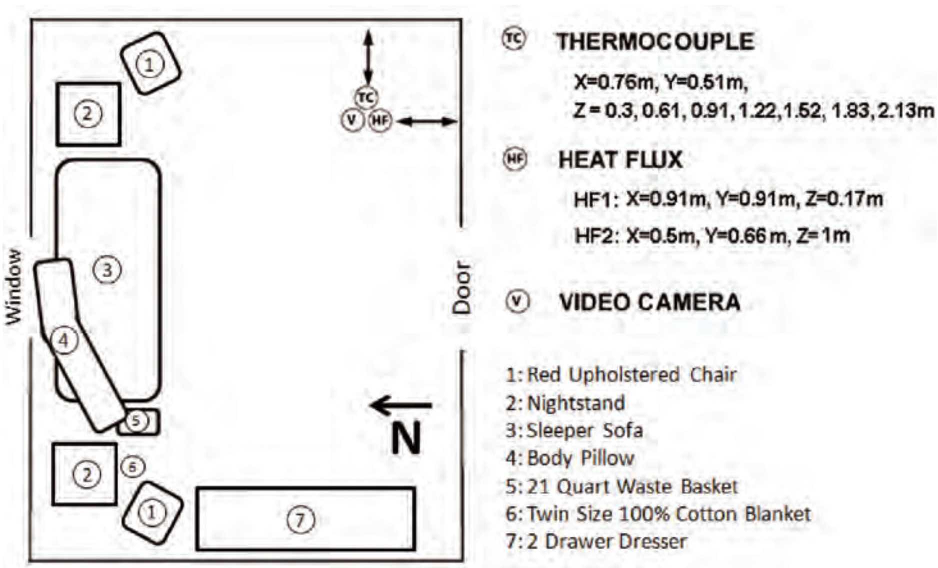


Figure 24: Configuration of Furnishings in Burn Room (Room and Contents Fires)

Figure 25: Pictures of the Room and Contents Furnishings

The ignition source consisted of a cardboard book of 20 matches that was ignited by an electrically heated wire, often referred to as an electric match. The electric match was placed near the bottom of a 21 qt (19.9 L) polypropylene waste container. The height of the waste container was 15.5 in (394 mm) with interior dimensions at the top opening of 14.5 in (368 mm) by 11.3 in (287 mm). Approximately 0.7 lbs (0.3 kg) of dry newspaper was added to the waste container. The majority of the newspaper was folded flat, and placed on edge along the sides of the waste container. Four sheets of newspaper, 22 in (559 mm) by 25 in (635 mm) were crumpled into "balls" approximately 3.9 in (100 mm) diameter and placed on top of the electric match in the center of the waste container.

Experimental Matrix for Room and Contents Fires

Sufficient amounts of furniture for 16 rooms were available for the room and contents fires, so eight experiment scenerios were conducted — each with a replicate. Because the time to untenable conditions was a primary variable of interest in the room and contents fires, the arrival time of the first due engine was a paramount consideration. Because the effects of the subsequent apparatus stagger were explored in the time-to-task tests, the stagger was fixed at the "close arrival" time. Additionally, a baseline measurement was required to compare the effectiveness of response to the absence of a fire department response. Therefore, a five-person, later arrival combination was eliminated in favor of a no-response scenario (with replicate). Table 3 summarizes the 16 tests conducted.

The first due engine arrival times were determined using the following assumptions: ignition of the fire occurs at

Crew Size	First Due Arrival Time
2-Person	Early Arrival of First Engine (6.5 min) – close stagger
3-Person	Early Arrival of First Engine (6.5 min) – close stagger
4-Person	Early Arrival of First Engine (6.5 min) – close stagger
5-Person	Early Arrival of First Engine (6.5 min) – close stagger
2-Person	Later Arrival of First Engine (8.5 min) – close stagger
3-Person	Later Arrival of First Engine (8.5 min) – close stagger
4-Person	Later Arrival of First Engine (8.5 min) – close stagger
No Response (Baseline)	N/A

Table 3: Experimental Matrix for Room and Contents Tests (Each Conducted in Replicate)

time zero. Smoke detector activation and a call to 9-1-1 occurs at 60 seconds after the fire starts. Call intake and processing requires an additional 90 seconds. The firefighters take 60 seconds to complete their turnout at the station and begin travel to the scene. Thus travel time begins 3.5 minutes into experiment. The two levels of arrival time are then determined by two different travel times: early arrival assumes a three-minute travel time, while later arrival assumes a five-minute travel time. For all scenarios in the room and contents experiments, the close stagger (60 seconds) between subsequent apparatus times was used.

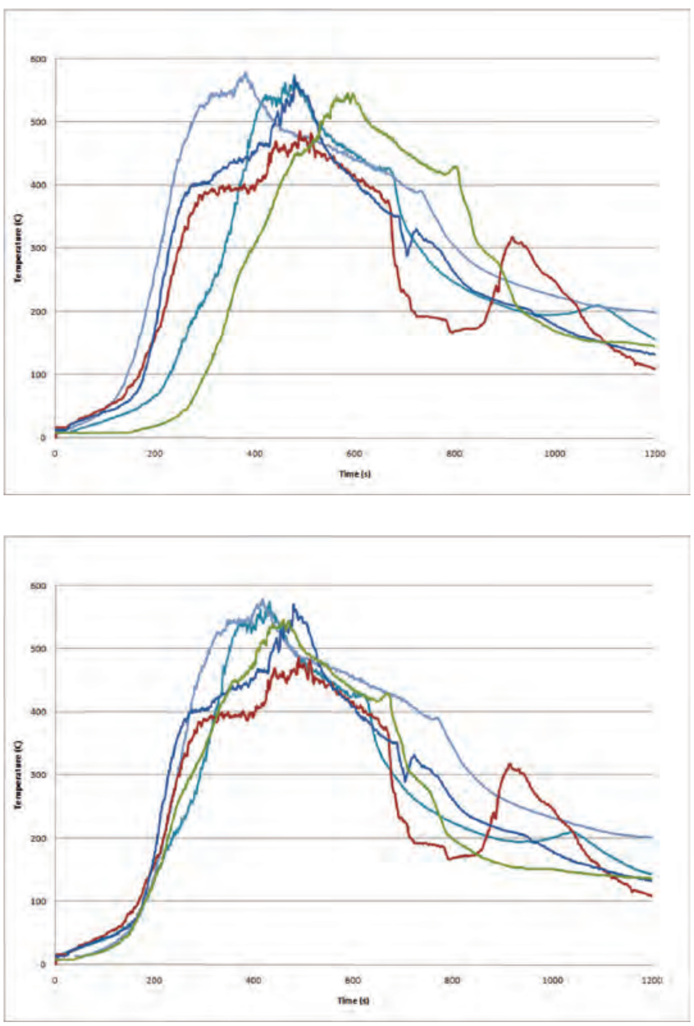


Figure 26: Direct Comparison of Temperatures, Before (Top) and After Adjustment (Bottom)

Procedure for Minimizing the Effect of Variance in Fire Growth Rate

Fires involving furnishings have inherent variance in burning behaviors. Factors such as humidity and minor variations in materials (particularly worn furnishings that may have different foam compression or fabric wear patterns), can result in uncertainty of 20 % or more, despite significant efforts to enhance repeatability. The early growth period of fire development is often associated with the greatest variance, since minor factors (as discussed above) can influence the thermal environment more easily when the fire is small. Therefore, the room and contents fires were normalized to the 212 °F (100 °C) temperature near the ceiling in the burn room in order to minimize the variance of the room and contents fires. The time at which the burn room reached this temperature (usually in approximately 180 seconds) rather than the actual ignition time, was designated as the "zero time."

Figure 26 shows the time-temperature curves before and after normalizing at 100°C. This approach was implemented during the experiments by watching the time temperature data in real-time from the instrumentation room and announcing the "zero-time" over the fireground radio system. The normalization procedure did not negatively affect tenability measurements in the target room because when the fire is small, products of combustion do not reach the room because of lack of momentum. Therefore, adjusting all room and contents tests to the same upper layer temperature was an appropriate way to minimize variance.

Milestone Times for Critical Tasks

As stated earlier, firefighters could not enter the burn building during the room and contents experiments because of the danger for potential flashover in an experimental scenario. Therefore, prescribed tasks were performed at specified times based on data from part 2. In this section we report on significant data gathered from instrumentation and describe an additional part of the experiments designed to extend our understanding of the effect of crew size and stagger on the tenability of the atmosphere in a burning structure.

Table 4 (page 32) identifies significant tasks selected as key milestones because of the way they affect fire behavior and atmospheric tenability inside the structure.

Milestone Tasks	2-Person Close Stagger
	Time from ignition (min : s)
Breached Door	8:44
Water On Fire	9:56
Upper Fire Window	13:01
Ground Non-fire Window	14:51
Upper Corner Window	17:55
Upper Front Door Window	19:55
Ground Fire Window	4:30
Milestone Tasks	**3-Person Close Stagger**
	Time from ignition (min : s)
Breached Door	7:48
Water On Fire	8:54
Upper Fire Window	11:26
Ground Non-fire Window	13:31
Upper Corner Window	15:54
Upper Front Door Window	17:58
Ground Fire Window	4:30
Milestone Tasks	**4-Person Close Stagger**
	Time from ignition (min : s)
Breached Door	7:46
Water On Fire	8:41
Upper Fire Window	9:23
Ground Non-fire Window	10:32
Upper Corner Window	11:46
Upper Front Door Window	13:45
Ground Fire Window	4:30
Milestone Tasks	**5-Person Close Stagger**
	Time from ignition (min : s)
Breached Door	7:35
Water On Fire	8:03
Upper Fire Window	10:11
Ground Non-fire Window	10:54
Upper Corner Window	12:31
Upper Front Door Window	12:47
Ground Fire Window	04:30

Table 4: Tasks That Affect Fire Behavior and Atmospheric Tenability

Analysis of Experimental Results

This section describes the analytic approaches used to address the research objectives of the study. First the statistical methods used to analyze the fireground time-to-task observations are presented. Then the time-to-task data and the room and contents data were combined to assess crew performance in relation to tenability within the structure.

Time-to-Task Analysis

Time-to-task data were compiled into a database and assessed for outliers and missing entries. Because all time-to-task experiments were conducted in triplicate, missing data were apparent and were reviewed via video and radio tapes. Missing data attributable to timer error were replaced by a time observed in the video. Where video and/or radio documentation was not adequate, missing data were recoded to the mean of the task times from the other two experiments.

Data Queries

The statistical methods used to analyze the time-to-task data were driven by a principal goal of this research project — to assess the effect of crew size, first-due engine arrival time, and subsequent apparatus stagger on time-to-task for critical steps in response and fire fighting. This research goal motivated the development of four specific research questions (see Figure 27) that in turn pointed to specific statistical analyses for generating inference and insight.

Statistical Methods – Time-to-Task

The analysis of the time-to-task data involved a sequence of multiple linear regressions using Ordinary Least Squares to generate and test the effects of staffing and stagger on timings. The regressions were of the form:

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_k x_{ik} + \varepsilon_i$$

where the x_{ik} reflect factors such as stagger and crew size, and the y represents our dependent/outcome variable.

Time-related outcomes (i.e., the dependent variables in the regression equations) could include task duration, elapsed time to start the task, and elapsed time until task completion, all measured in seconds. Table 5 (page 34) lists the time-related outcomes used to test the effect of crew size and stagger for the tasks in the field experiments.

The effects of crew size and stagger were explored using indicator variables in the regression analyses. The coefficient for a given indicator (for example, crew size of four relative to a crew size of two) indicated the number of seconds the larger crew size added or reduce the timing outcome of a task. Crew sizes were collapsed in some regressions to test whether the timings of "larger" crew sizes of four and five were significantly different than "smaller" crew sizes of two and three. Interaction terms were not assessed in these regression analyses because of the small number of experiments available for analysis.

Standard t-tests examined statistical significance (i.e., to see if the hypothesis of "no impact" could be rejected) to estimate the impact of several specific configurations:

- crew sizes of three versus two
- crew sizes of four versus three
- crew sizes of five versus four
- (occasionally) five versus two, and four versus two
- larger (four & five combined) versus smaller (two & three combined) and
- stagger

The specific tests for each task (regression analysis) are shown in the Appendix E. The actual coefficients of each regression and their corresponding standard errors are presented in Appendix F. To infer impact, significant tests were conducted at the 0.05 significance level. Only statistically significant contrasts of crew size and/or stagger are included in this section of the report. Graphic expositions of relevant time/task related findings are then presented as well. Where stagger was statistically significant, the effects are graphed separately. Where stagger was not statistically significant, the data for crew size were combined.

Time-to-Task Research Questions

1) How do crew size and stagger (i.e., timing of between first engine and subsequent apparatuses) affect overall (i.e., start to completion) response timing?

   a. To what extent do variations in crew size affect overall response timing?

   b. To what extent do variations in both crew size and stagger affect overall response timing?

2) How do crew size and stagger affect the timings of task initiation, task duration, and task completion for each of the tasks comprising the suite of 22 tasks?

   a. To what extent do variations in crew size affect timings across the suite of tasks?

   b. To what extent do variations in both crew size and stagger affect response timings across the suite of tasks?

3) How does crew size affect elapsed times to achieve three critical events known to change fire behavior or atmospheric tenability for occupants?

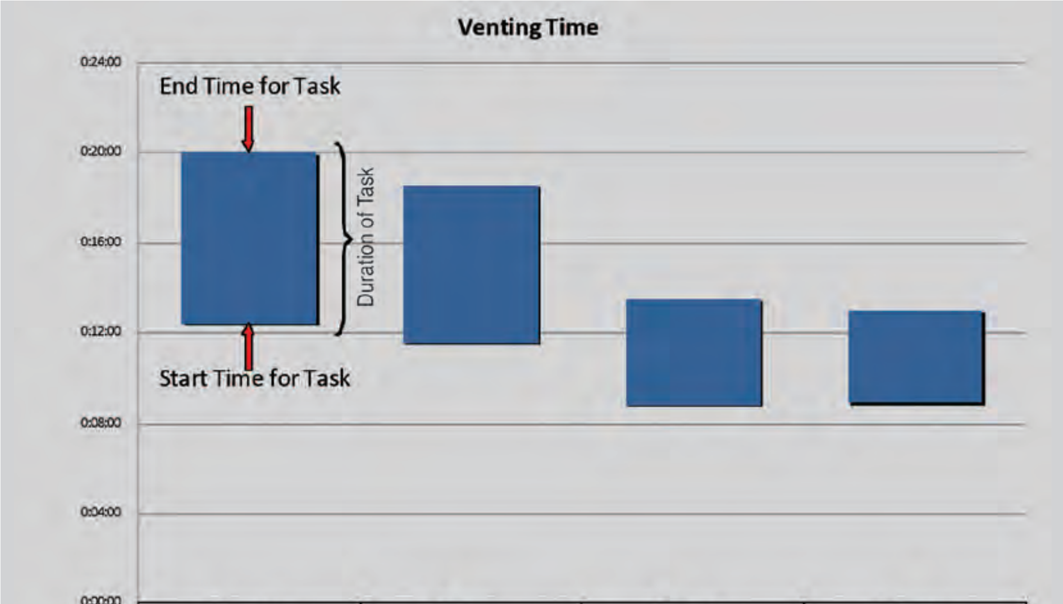
   a. Entry into structure

   b. Water on fire

   c. Ventilation of each window (three upstairs and one downstairs window and the burn room window)

4) How does the elapsed time to achieve the national standard of assembling 15 firefighters at the scene (measured using "at hydrant" as the start time) vary by crew sizes of 4 and 5?

Figure 27: Research Questions for Time-to-Task Experiments



	2-Person	3-Person	4-Person	5-Person
End Time	0:20:02	0:18:33	0:13:30	0:12:59
Duration	0:07:36	0:07:01	0:04:42	0:04:04
Start Time	0:12:26	0:11:32	0:08:48	0:08:55

Figure 28: Example Time-to-Task Graph

	Time-to-Task Outcome Measures		
Task:	*Elapsed Time Until Start**	*Elapsed Time for Task Completion**	*Duration**
Conduct size-up	X	X	X
Position attack line	X		X
Establish 2 in - 2 out		X	
Establish RIT		X	
Gain forced entry	X		
Advance line	X		
Advance line		X	
Advance backup line to door	X	X	
Advance backup line to stairwell	X		
Advance backup line 2		X	
Conduct primary search 1	X		
Ground ladders in place		X	X
Horizontal ventilation, second story, window 3	X	X	
Horizontal ventilation, second story, window 2	X	X	
Horizontal ventilation, second story, window 1	X	X	
Horizontal ventilation, first story, window 2	X	X	
Control utilities interior	X		
Control utilities exterior	X		
Conduct secondary search	X		
Check for fire extension walls	X		
Check for fire extension ceiling	X		

* The columns of this table show the dependent variables, and the rows indicate the Tasks; an 'X' in a cell indicates that a separate regression analysis was conducted for a given dependent variable.

Table 5: Dependent Variables Used in a Regression Analysis of the Effect of Crew Size and Stagger on Time-to-Task Outcomes

Regression analyses

Appendix F presents the regression results for each task and relevant outcome, along with their corresponding standard errors. The results of conducting significance tests at the 0.05 level of significance are shown in Appendix E. Rather than detailing each of the lengthy lists of coefficients found to be significant, only the answers to the primary research questions are presented for each task.

Measurement Uncertainty

The measurements of length, temperature, mass, moisture content, smoke obscuration, and stopwatch timing taken in these experiments have unique components of uncertainty that must be evaluated in order to determine the fidelity of the data. Appendix G summarizes the uncertainty of key measurements taken during the experiments. Importantly, the magnitudes of uncertainties associated with these measurements have no impact on the statistical inferences presented in this report.

How to Interpret Time-to-Task Graphs

Figure 28 presents a sample time-to-task analysis, in this case results for venting time. Each crew size has a column graphic showing the start time and completion time for the task. Visually, columns starting lower on the graph depict deployment configurations that resulted in earlier start times. The height of the column graphic is a visualization of the duration of the task, taller columns indicating longer times to task completion. Time data are also shown in a table below the graph. Where stagger was statistically significant, the effects are graphed separately. Where stagger was *not* statistically significant, as in the illustration, the data for crew size were combined.

Time-to-Task Graphs

Overall Scene Time (Time to Complete All 22 Tasks)

The four-person crews operating on a low-hazard structure fire completed the same number of tasks on the fireground (on average) 7 minutes faster than the two-person crews (see Figure 29). The four-person crews completed the same number of fireground tasks (on average) 5.1 minutes faster than the three-person crew. The four-person crews were able to complete necessary fireground tasks on a low-hazard residential structure fire nearly 30 % faster than the two-person crews and nearly 25 % faster than the three-person crews. Although on the low-hazard residential structure fire, adding a fifth person to the crews did not show any additional decrease in fireground task times, the benefits of a five-person vs. a four-person crew are significant in other measurements, particularly the "water-on-fire" time. Additionally, the greater need for five-person crews for medium- and high-hazard structures, particularly in urban settings, has been documented in other studies (Backoff et al., 1980; Cushman, 1982; McManis Associates et al., 1984) and five-person crews are required for areas that contain medium and high-hazard structures in fire protection consensus standards.[11]

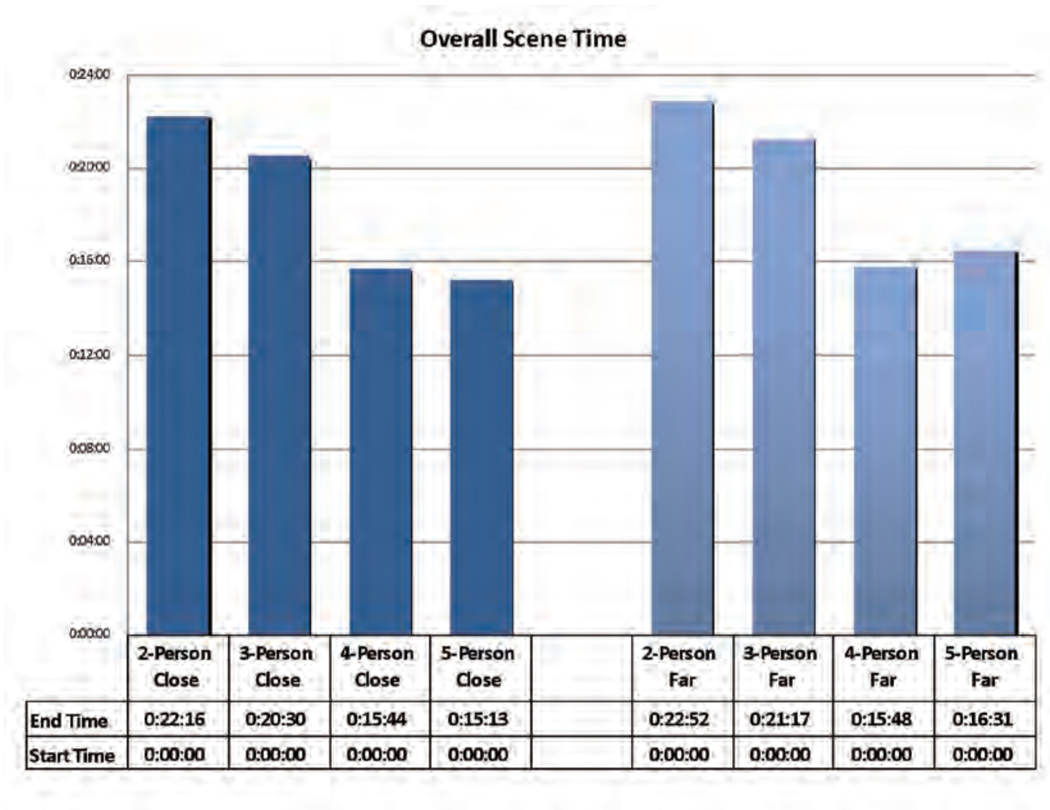


Figure 29: Overall Scene Time

11 NFPA 1710, Section 5.2.3.1.2 and Section 5.2.3.2.2: In jurisdictions with tactical hazards, high-hazard occupancies, high incident frequencies, geographical restrictions, or other pertinent factors as identified by the AHJ, these companies shall be staffed with a minimum of five or six on duty members.

Overall Scene Time and Crew Sizes

The graphs in Figure 30 show average times for each task by crew size.

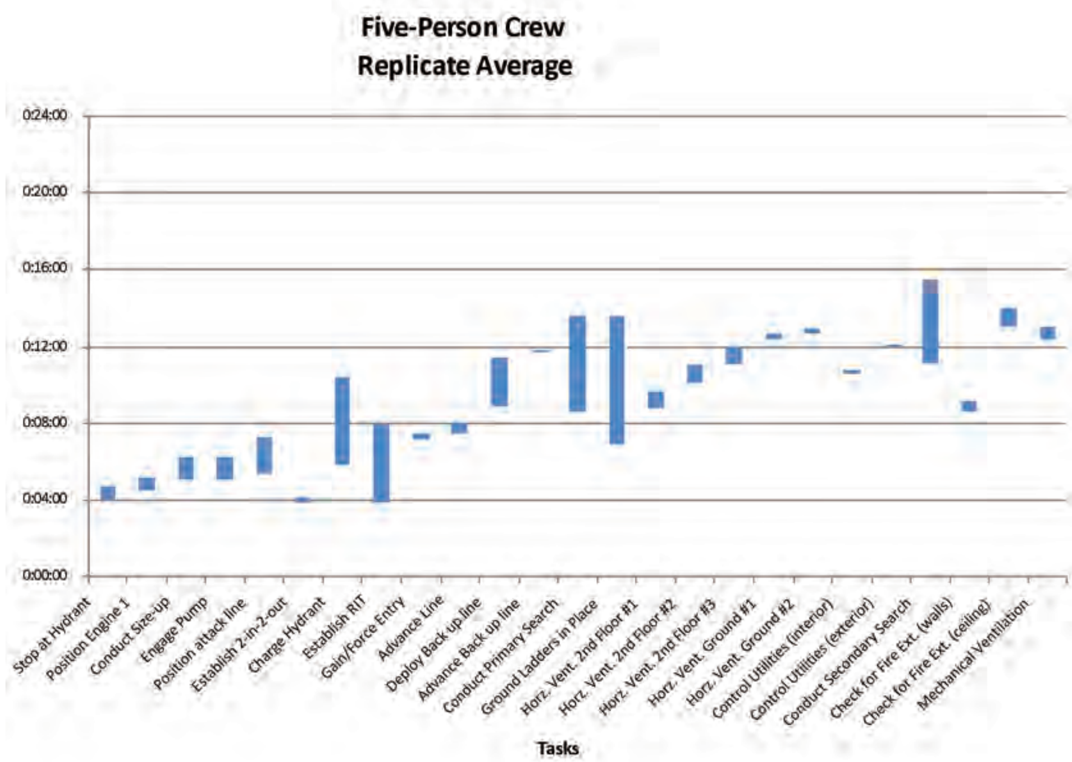


Figure 30 a: Overall Scene Time-FIve Person Crew

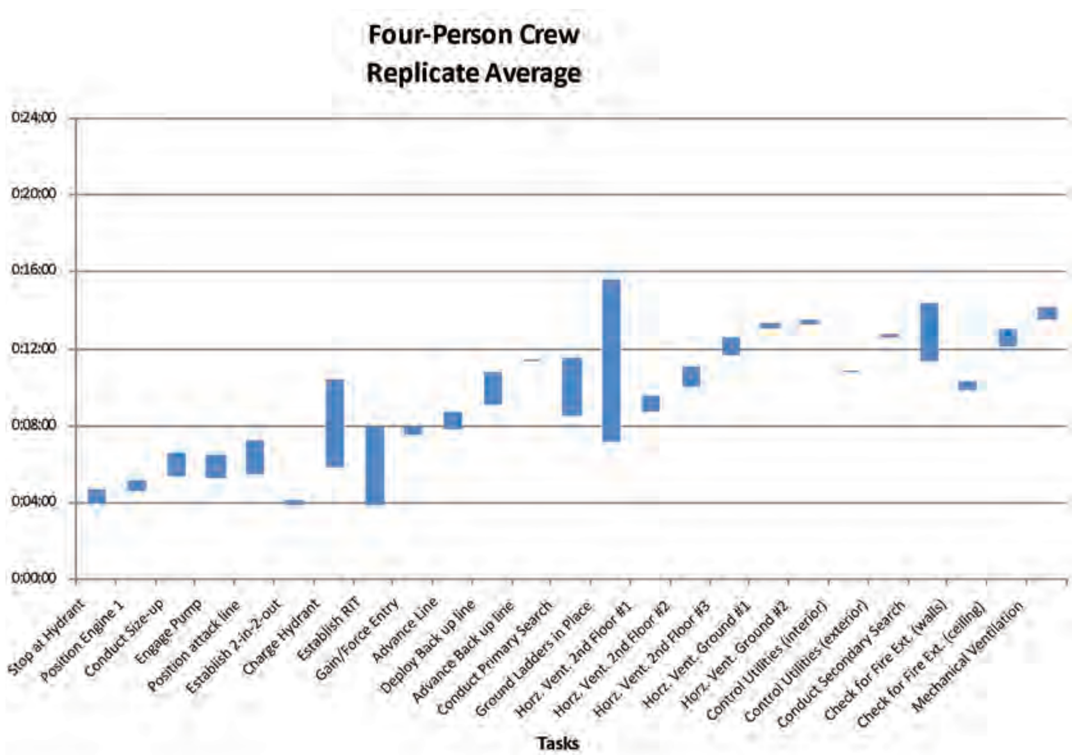


Figure 30 b: Overall Scene Time-Four Person Crew

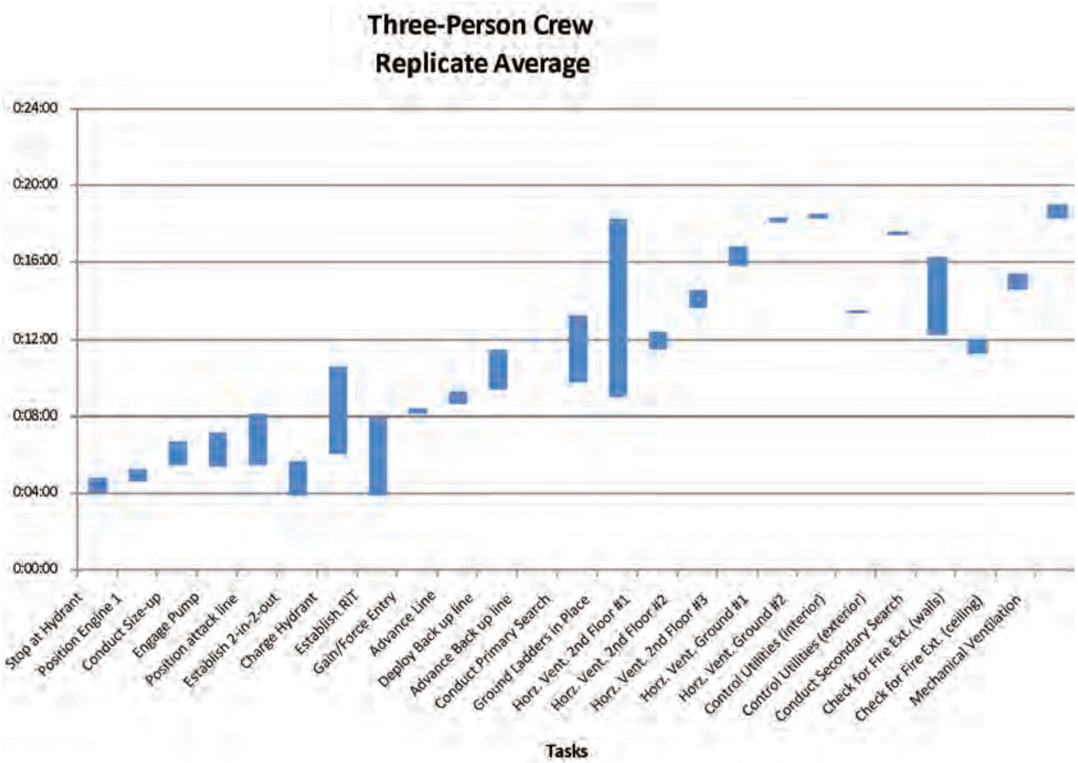


Figure 30 c: Overall Scene Time-Three Person Crew

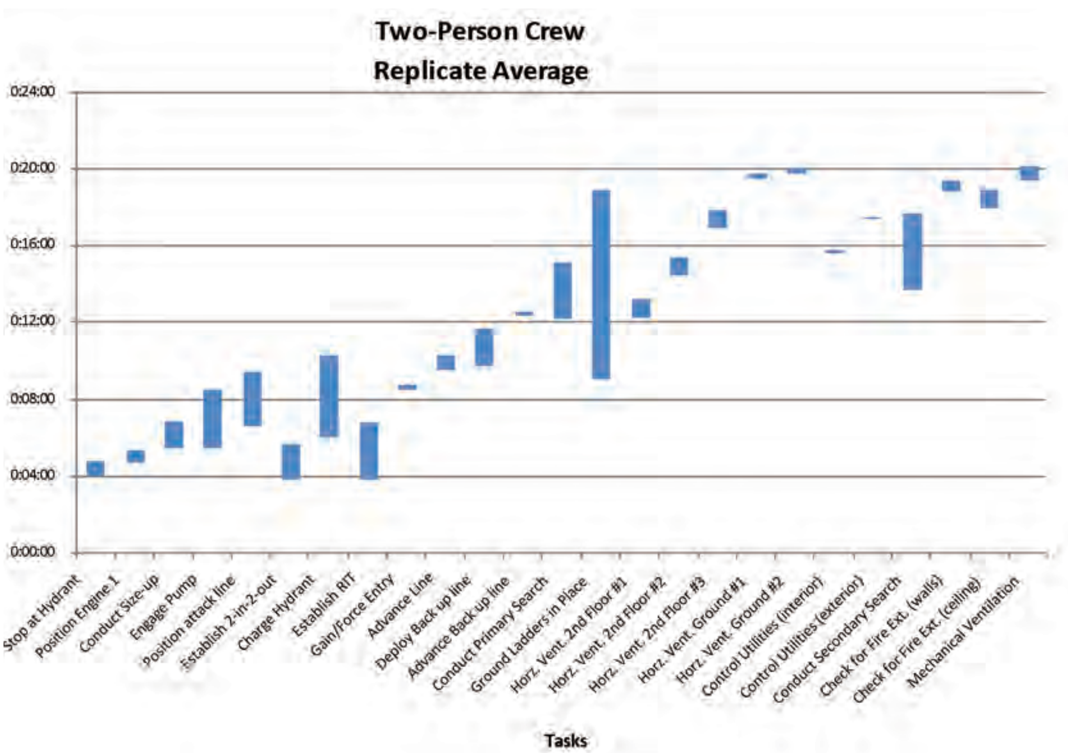
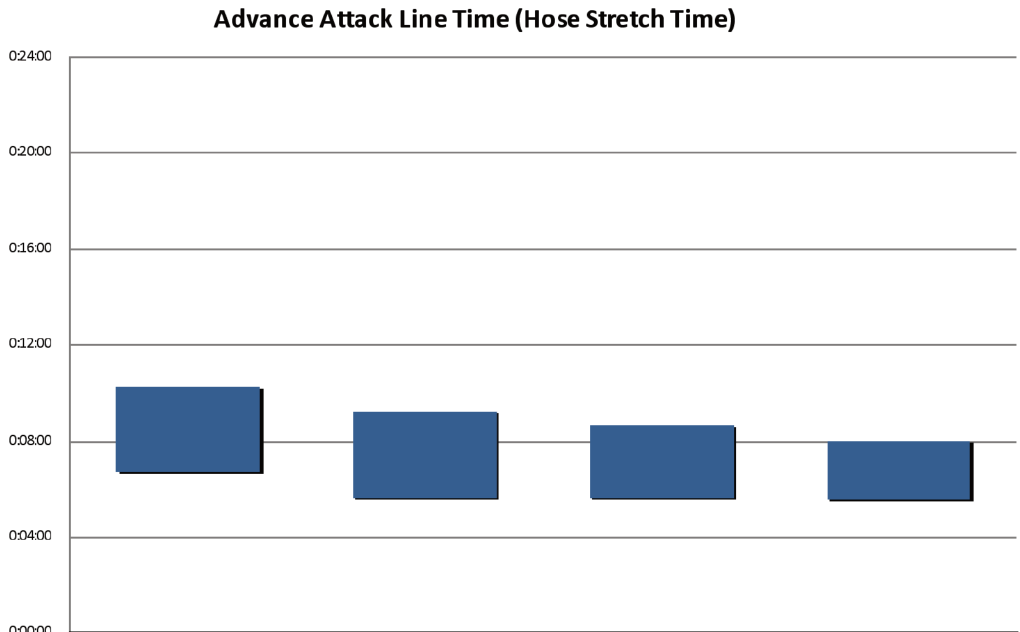


Figure 30 d: Overall Scene Time-Two Person Crew

Advance Attack Line Time (Hose Stretch Time)

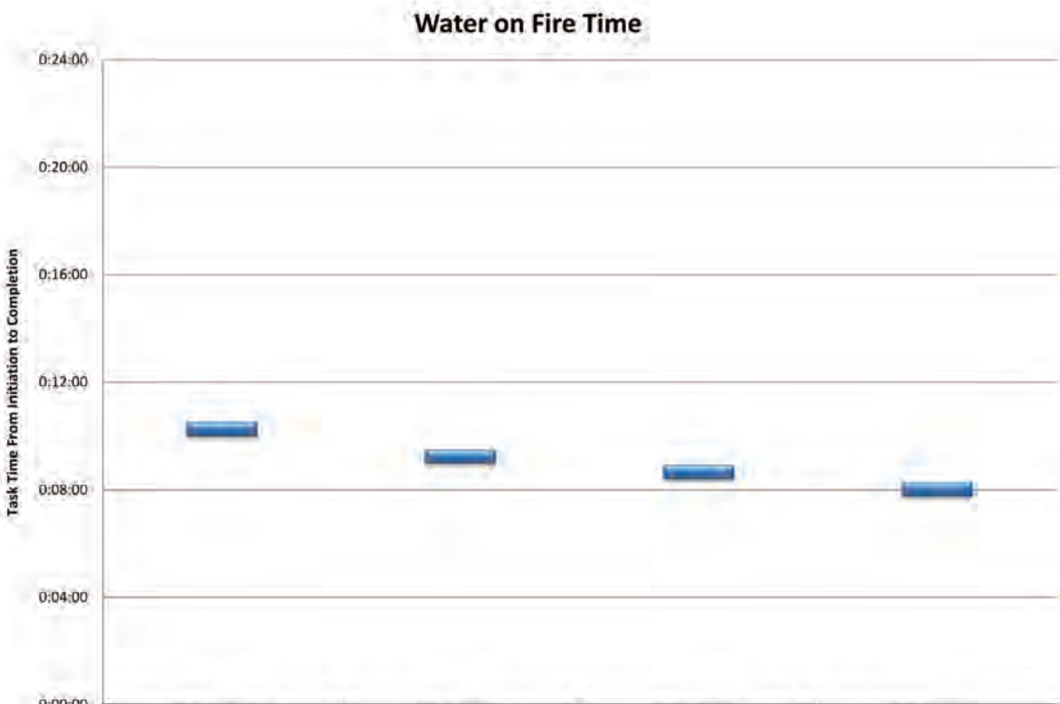
Figure 31 measures the interval from the start of the task "Position Attack Line" to the end of the task "Advance Attack Line." In comparing four- and five-person crews to two and three-person crews collectively, the time difference for this measure was statistically significant at 76 seconds (1 minute 16 seconds). In conducting more specific analysis comparing all crew sizes to a two-person crew the differences are more distinct. A two-person crew took 57 seconds longer than a three-person crew to stretch a line. A two-person crew took 87 seconds longer than a four-person crew to complete the same task. Finally, the most notable comparison was between a two-person crew and a five-person crew, with a 122-second difference in task completion time.[12, 13]



	2-Person	3-Person	4-Person	5-Person
End Time	0:10:16	0:09:15	0:08:41	0:08:01
Duration	0:03:34	0:03:36	0:03:02	0:02:29
Start Time	0:06:43	0:05:39	0:05:39	0:05:33

Figure 31: Advance Line Time (Hose Stretch Time) by Crew Size

12 Apparatus stagger was not statistically significant, so the data for crew size were combined.
13 Where subtracting the start time from the end time yields a result that differs from the duration noted in the chart by one second, it is the result of rounding fractional seconds to the nearest whole second.

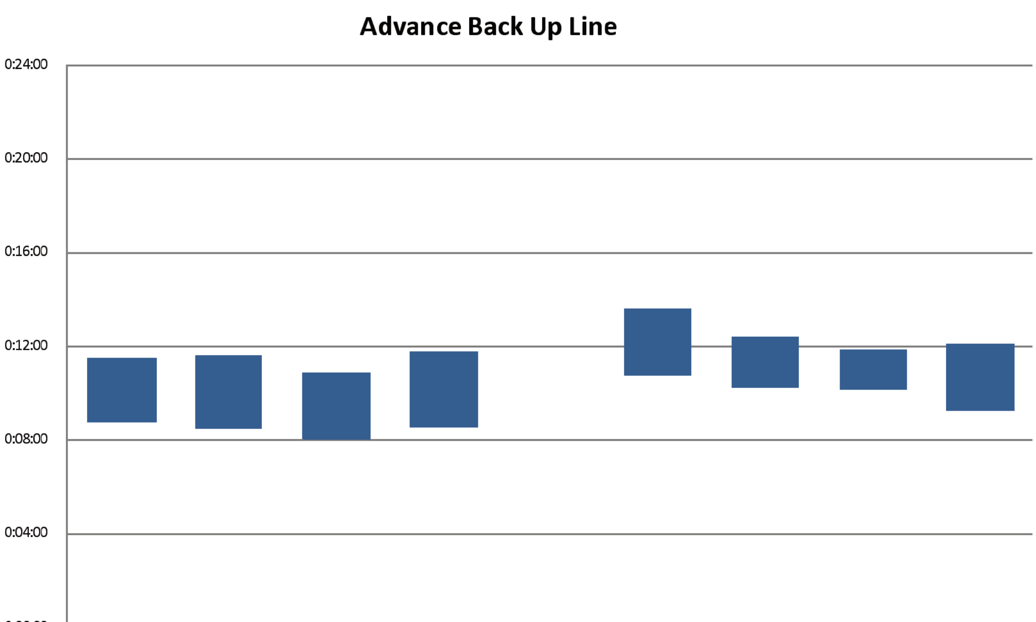


	2-Person	3-Person	4-Person	5-Person
End Time	0:10:16	0:09:15	0:08:41	0:08:01

Figure 32: Water on Fire Time by Crew Size and Stagger

Time to Water on Fire

There was a 10% difference in the “water on fire” time between the two- and three-person crews. There was an additional 6% difference in the "water on fire" time between the three- and four-person crews. (i.e., four-person crews put water on the fire 16% faster than two person crews). There was an additional 6% difference in the “water on fire” time between the four- and five-person crews (i.e. five-person crews put water on the fire 22% faster than two-person crews).

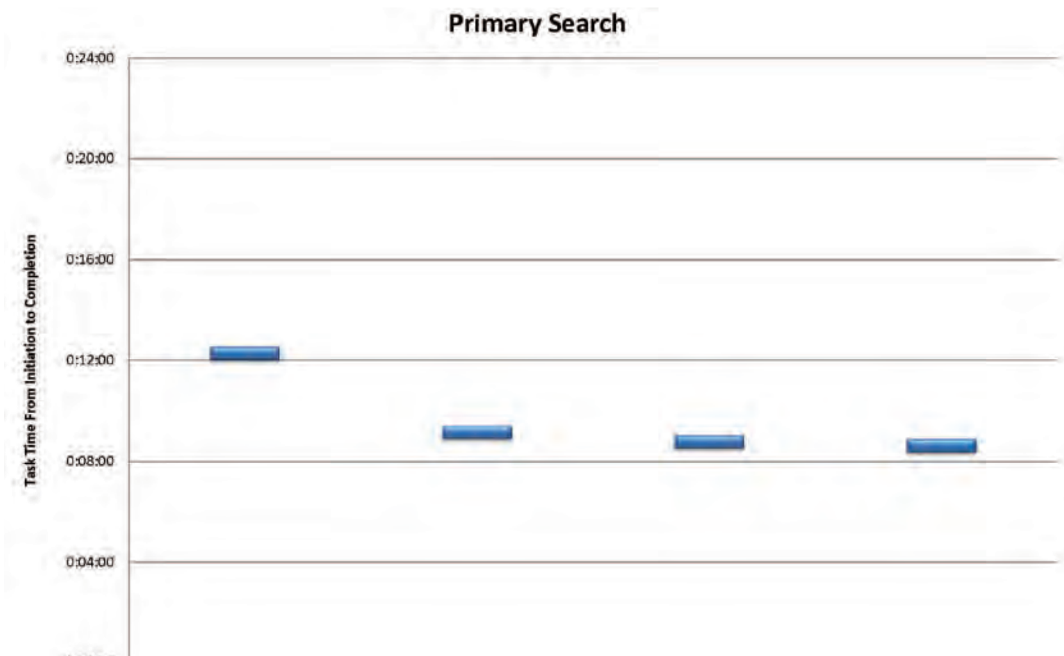


	2-Person Close	3-Person Close	4-Person Close	5-Person Close		2-Person Far	3-Person Far	4-Person Far	5-Person Far
End Time	0:11:28	0:11:33	0:10:55	0:11:48		0:13:37	0:12:23	0:11:54	0:12:04
Duration	0:02:34	0:02:58	0:02:46	0:03:09		0:02:45	0:02:04	0:01:41	0:02:44
Start Time	0:08:54	0:08:35	0:08:08	0:08:39		0:10:52	0:10:19	0:10:13	0:09:20

Figure 33: Times to Advance Backup Line by Crew Size and Stagger

Advancing a Backup Line

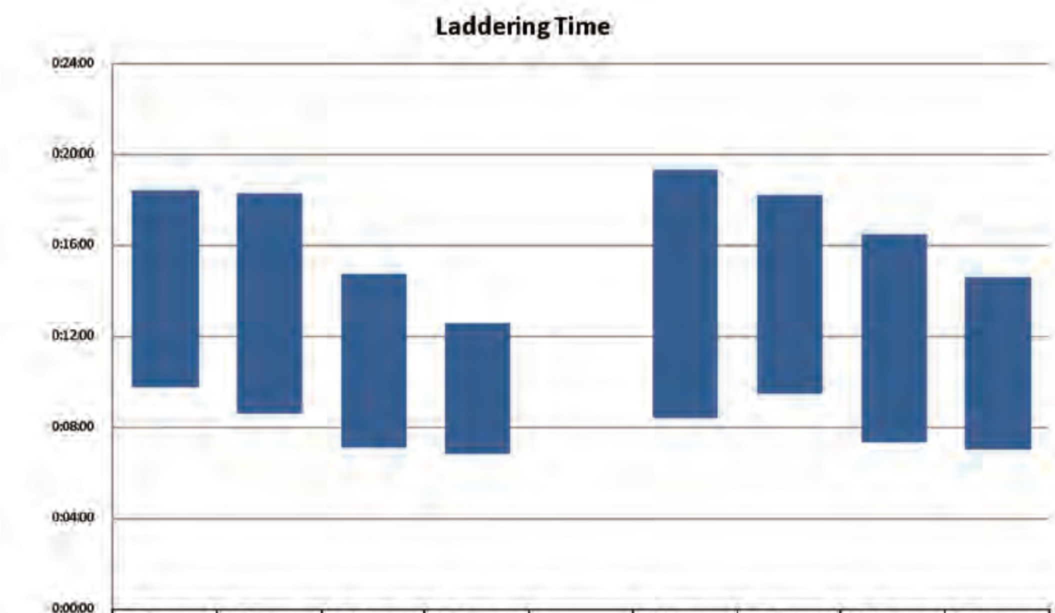
Advancing a backup line to the door and stairwell was started 16 % faster and completed 9 % for replicates with shorter staggers between company arrivals. Advancing a backup line is typically a task completed by the third arriving engine on a full alarm assignment and is critical to the safety of firefighters already in the building on the initial attack line. For this task, stagger of arrival was statistically significant and is an important consideration for overall station location and full alarm response capability. The differences can be seen in Figure 33, which shows the time from the start for the task “Deploy Backup Line” to the end of the task “Advance Backup Line.”



	2-Person	3-Person	4-Person	5-Person
Start Time	0:12:16	0:09:10	0:08:47	0:08:38

Figure 34: Times to Conduct Primary Search by Crew Size

14 Stagger was not significant, so data from close and far were combined to increase statistical power.

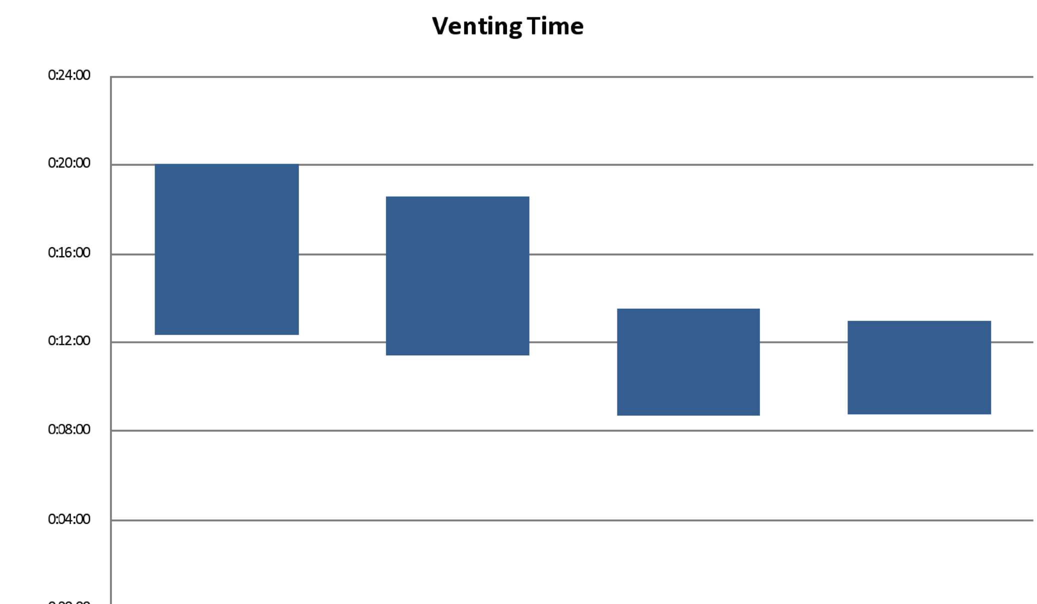


	2-Person Close	3-Person Close	4-Person Close	5-Person Close		2-Person Far	3-Person Far	4-Person Far	5-Person Far
End Time	0:18:24	0:18:19	0:14:45	0:12:34		0:19:23	0:18:12	0:16:29	0:14:38
Duration	0:08:31	0:09:35	0:07:31	0:05:40		0:10:51	0:08:40	0:09:03	0:07:31
Start Time	0:09:54	0:08:44	0:07:14	0:06:54		0:08:31	0:09:32	0:07:26	0:07:07

Figure 35: Laddering Time by Crew Size

Primary Search

Figure 34 summarizes the times that crews took to start the primary search. On the low-hazard, two-story single-family dwelling 2,000 sq ft (186 m^2) , the three-person crew started a primary search/rescue more than 25 % faster than the two-person crew. In the same structure, the four- and five-person crews started a primary search 6 % faster than the three-person crews and 30 % faster than the two-person crew. Note that there is no end time included in this figure. Primary search end times were reliant upon radio communication by firefighters inside the structure. On occasion this communication did not occur or was delayed. Therefore data reliability was insufficient for analysis of task duration and end time.[14]



	2-Person	3-Person	4-Person	5-Person
End Time	0:20:02	0:18:33	0:13:30	0:12:59
Duration	0:07:36	0:07:01	0:04:42	0:04:04
Start Time	0:12:26	0:11:32	0:08:48	0:08:55

Figure 36: Ventilation Times by Crew Size[15]

Laddering and Venting Time

A four-person crew operating on a low-hazard structure fire completed laddering and ventilation (for life safety and rescue) 30 % faster than a two-person crew and 25 % faster than a three-person crew.

Ground laddering time started with the removal of the first ladder from the truck and stopped at end time of the last ladder put in place. A total of four ladders were raised on each experiment.

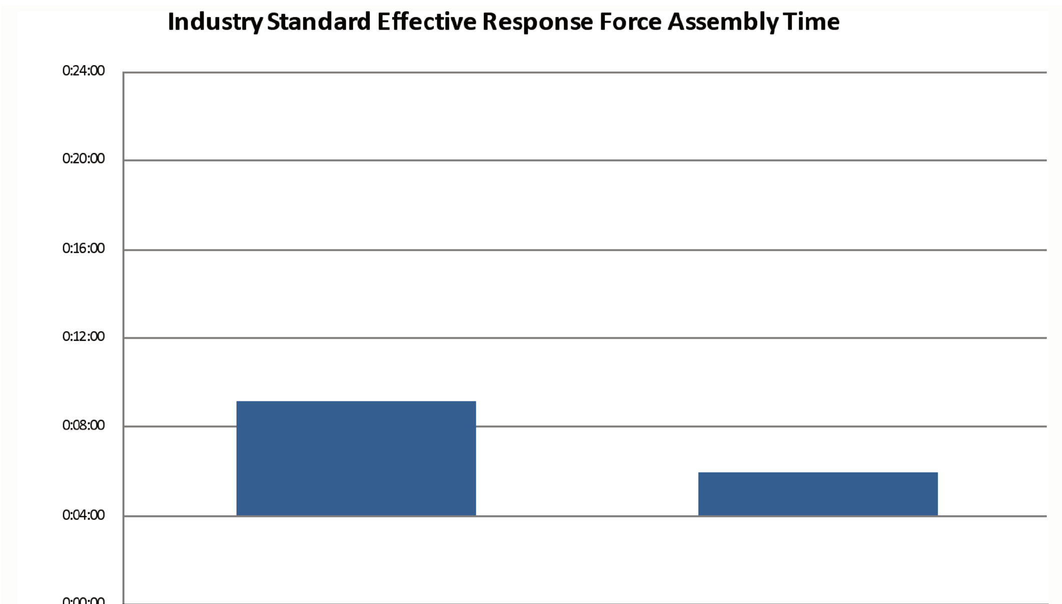
Truck operations ventilation time is the time from the start time of ventilation of the first window until the last window ventilation was complete.

The differences in start times and duration of the tasks can be seen in Figure 35 and Figure 36.

15 Stagger was not statistically significant, so the data for crew size were combined.

Industry Standard Effective Response Force Assembly Time

NFPA 1710 requires that a fire department have the capability to deploy an initial full-alarm assignment to a scene within eight-minutes (480 seconds). The number of people required falls between 15 and 17, depending on whether an aerial apparatus is used, and/or if two engines are being used to provide a continuous water supply. In these experiments, the measurement for an effective response force assembly time started from the first engine arrival at the hydrant and ended when 15 firefighters were assembled on scene. Figure 37 reveals the differences in assembly times between the four and five-person crews. An effective response force was assembled by the five-person crews a full three minutes faster than the four-person crews. It is important to note that (by definition), the two-and three-person crews were unable to meet this standard at any time during the experiments.[16]



	4-Person	5-Person
End Time	0:09:10	0:05:57
Duration	0:05:02	0:01:48
Start Time	0:04:09	0:04:09

Figure 37: Industry Standard Effective Response Force Assembly Time

16 Stagger was not statistically significant, so the data for far and near stagger were combined.

Part 4: Fire Modeling

In the room and contents experiments conducted in Part 3 of the study, instrumentation measured oxygen, carbon dioxide, and carbon monoxide concentrations. Data were grouped by the type of experiment conducted with respect to crew size and first due engine arrival time. As previously shown in the experimental matrix, each group contained two replicate tests. In each group of data the results of the replicates were averaged to simplify the data for further comparison. Figure 38 and Figure 39 show the typical concentration curves for the experiments.

These two graphs show the ranges representative of those found in the experiments. Charts of gas curves for the remainder of the experiments — for both the burn room and the target room — can be found in Appendix H.

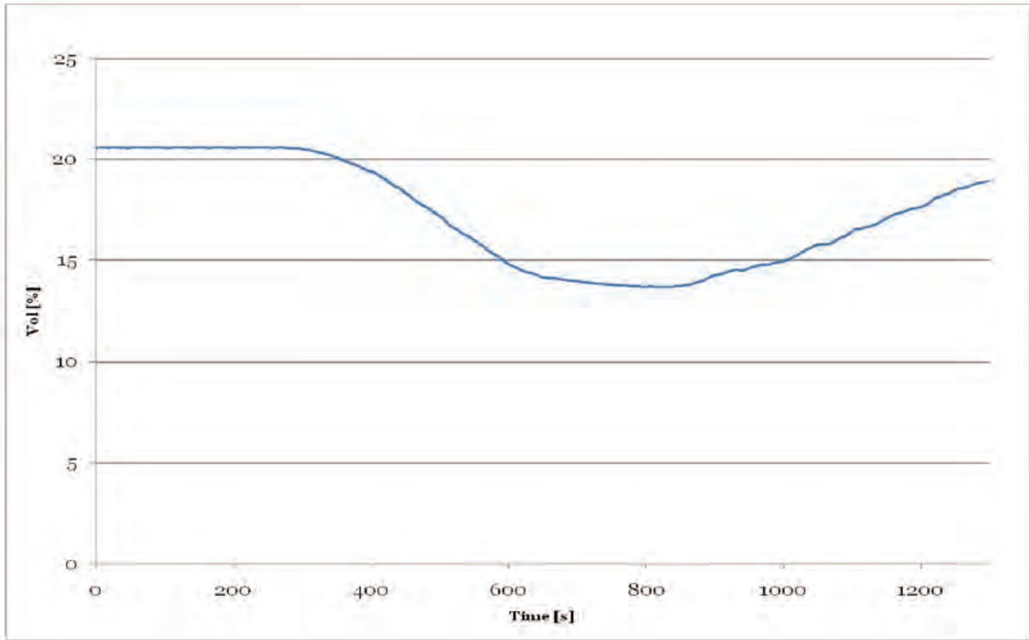


Figure 38: Representative Oxygen Concentration

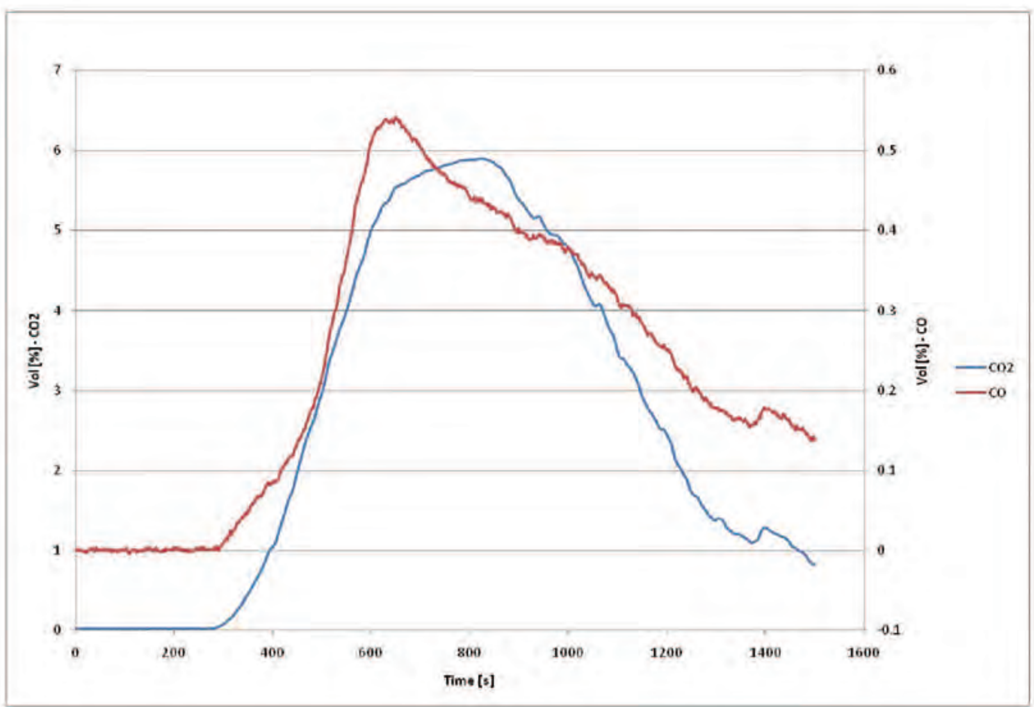


Figure 39: Representative Carbon Monoxide and Carbon Dioxide Concentrations

Fire Modeling Methods

A primary goal of fire department response is to prevent civilian injuries and deaths. Because the significant majority of fire deaths in the United States occur in residences, a rapid fire service response provides the last line-of-defense against civilian fire deaths. Further, because the fire service is less likely to rescue occupants intimate with the fire (i.e., inside the room of origin where conditions deteriorate rapidly), tenability measurements were taken in a remote bedroom on the second floor of the residential burn structure. The gas and temperature measurements were taken at the 5 ft (1.5 m) height above the floor, 3 ft (0.9 m) from the west wall in order to simulate a nonambulatory occupant (e.g, someone asleep, under the influence of alcohol or drugs, or otherwise mobility impaired).

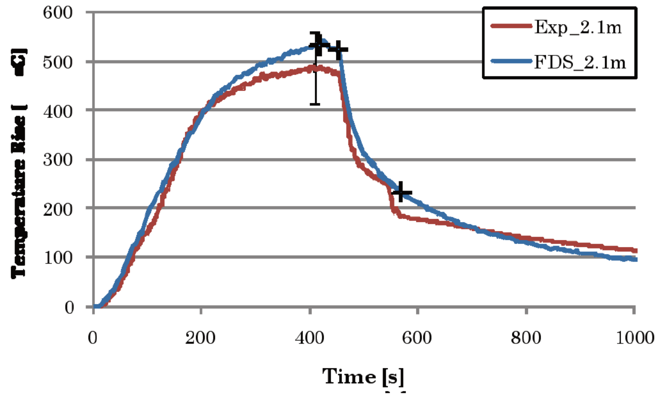


Figure 40: Measured vs. Predicted Temperature at the 2.1 m (6.9 ft) Thermocouple Location in the Burn Compartment

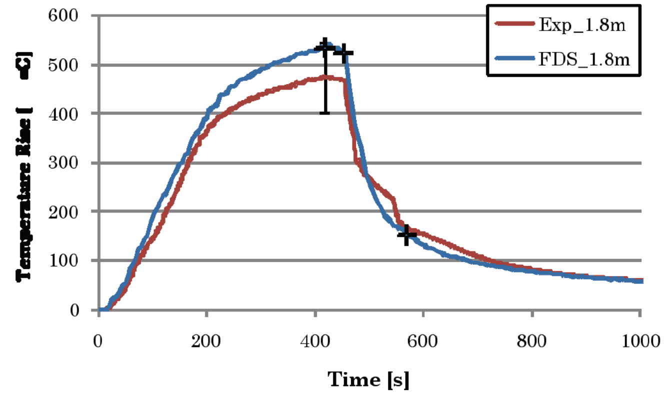


Figure 41: Measured vs. Predicted Temperature at the 1.8 m (5.9 ft) Thermocouple Location in the Burn Compartment

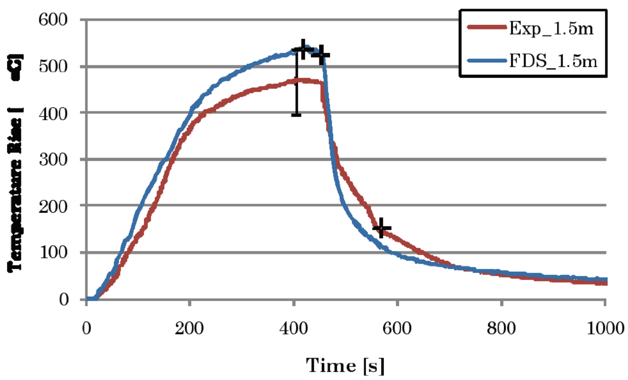


Figure 42: Measured vs. Predicted Temperature at the 1.5 m (4.9 ft) Thermocouple Location in the Burn Compartment

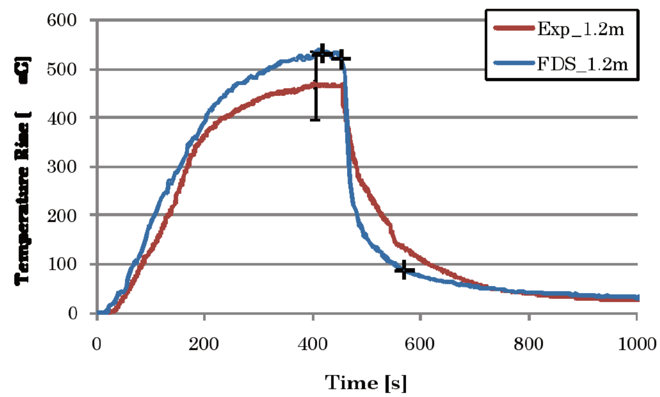


Figure 43: Measured vs. Predicted Temperature at the 1.2 m (3.9 ft) Thermocouple Location in the Burn Compartment

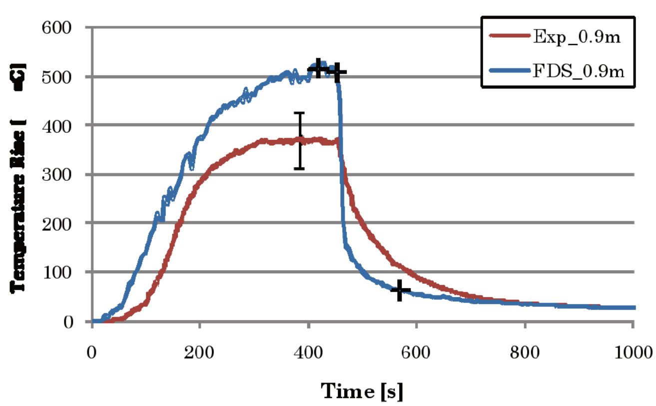


Figure 44: Measured vs. Predicted Temperature at the 0.9 m (2.9 ft) Thermocouple Location in the Burn Compartment

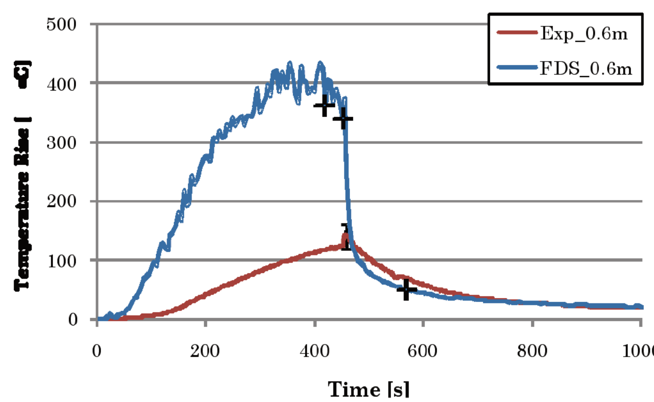


Figure 45: Measured vs. Predicted Temperature at the 0.6 m (1.9 ft) Thermocouple Location in the Burn Compartment

Computational fire models used the average suppression timings obtained from the time-to-task experiments under specific deployment configurations as inputs to the model. This quantitative approach eliminated the experimental variance of the fire. The resulting "computational" fire is repeatable, and therefore, any differences in occupant exposure to toxic gases will be due to the intervention times associated with a specific deployment configuration rather than the random variation that naturally occurs from fire to fire.

Fire simulations were completed using the NIST Fire Dynamics Simulator (FDS). FDS is a computational fluid dynamics model of fire-driven fluid flow. The first version of the FDS was released in 2000. FDS has been extensively verified and validated (USNRC 2007). Since the initial release, numerous improvements have been made and new features added. This study used FDS version 5.4.2 (Sub-version #4957), which was released on October 19, 2009. In order to calibrate the model, simulations were performed to replicate the experimental results observed in the room-and-contents fires. Once the ability of the model to replicate experimental results was established, the different fire growth rates and deployment configurations were simulated to characterize the effectiveness of different responses relative to different fire growth rates.

The occupant exposure to toxic gases was assumed to occur until the occupant is rescued by the truck crew (start time of primary search plus one minute). Table 6 shows the "rescue time" for the various crew sizes that correspond to the test matrix for the room and contents experiments.

Part 4 of the experiments used fire modeling to correlate response times to atmospheric tenability in a burning structure. In order to calibrate the computer fire model, simulations were performed to replicate the experimental results observed in the room-and-contents fires. Model inputs include building geometry and material properties, ventilation paths (doors, windows, leakage paths), and heat release rate of the fuel package. While the building geometry is easily measured and material properties (such as the thermal properties of drywall and concrete) are readily estimated, the heat release rate was not directly measured during the experiments. The heat release rate of the fuel package is the primary determinant of the production rate of heat, smoke, and gas species (e.g., carbon dioxide, carbon monoxide).

Figures 40 through 45 compare the experimental and simulated burn room temperatures using the burn room thermocouple tree. The tree contained thermocouples located at 0.6 m (1.9 ft), 0.9 m (2.9 ft), 1.2 m (3.9 ft), 1.5 m (4.9 ft), 1.8 m (5.9 ft), and 2.1 m (6.9 ft) above the floor. For additional information about the instrumentation type location, see Appendix C. The results for thermocouples located in the hot gas layer show excellent agreement. The temperature at the lower two thermocouples show an overprediction of the hot gas layer depth in the computer simulation. A small difference in the location of the interface height (the steep temperature gradient between the relatively cool lower gas layer and the hot upper gas layer), can result in significant predicted temperature differences with relatively little effect on the bulk heat and mass transport accuracy. This explanation is supported by the agreement of the temperatures in the remote bedroom.

Figure 46 compares the experimental and predicted oxygen concentration levels in the upstairs bedroom (measured at 5 ft (1.5 m) above the floor, centered above the bed). Figures 47 through 52 compare the experimental and simulated temperatures in the upstairs (target room) bedroom. As expected, the temperatures are moderated by mixing (cool ambient air mixes with hot combustion gases during transport between the burn room and the target room) and by thermal losses to the (cooler) surfaces between the two rooms.

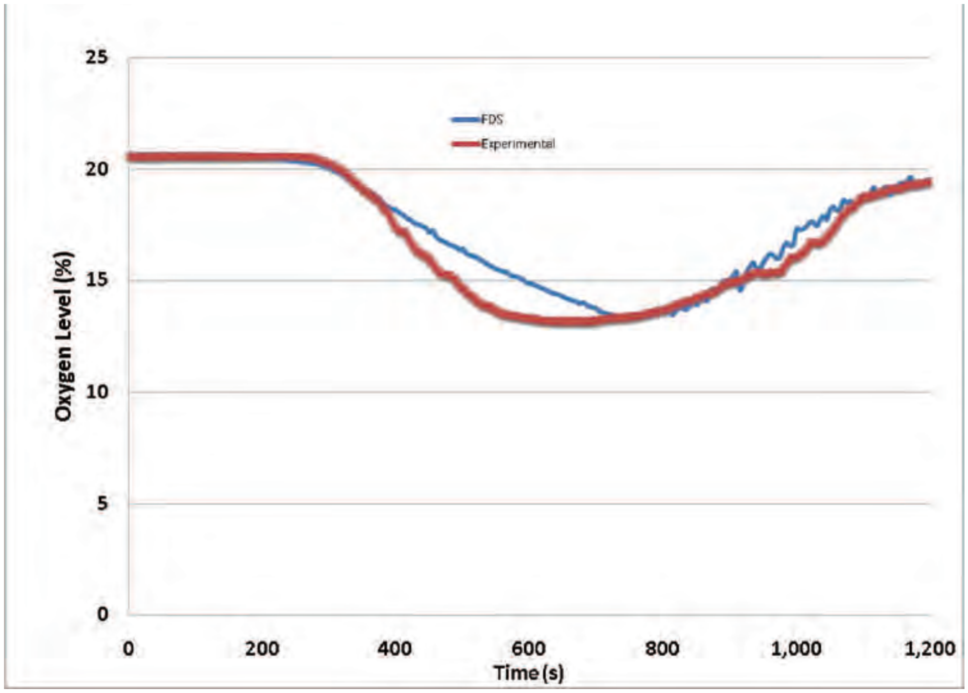


Figure 46: Measured Versus Predicted Oxygen Levels in the Upstairs Bedroom at 5 ft (1.5 m)

Once the model inputs were determined to agree with the experimental results, the input heat release rate was changed to represent three fire growth rates representative of a range of fire hazard development – slow, medium, and fast, which are described in greater detail in the following sections.

Time to Untenable Conditions: Research Questions

In the real world, fires grow at many different rates – from very slow, smoldering fires all the way to ultra-fast, liquid fuel or spray fires. In order to extend the applicability of the findings of this report beyond the one fire growth rate observed in part 3 of this report (residential room and contents fires), computer fire modeling was used to quantify the effectiveness of fire department operations in response to an idealized range of fire growth rates (characterized as slow, medium, and fast). Based on the research questions shown in Figure 53, fire modeling methods were then selected to maximize the applicability of the times to task results.

1) How do performance times relate to fire growth as projected by standard fire time/temperature curves?

2) How do these performance times vary by crew size, first due arrival time, and stagger?

3) How do crew size, stagger, and arrival time affect occupant tenability within the structure?

Figure 53: Research Questions for Time to Untenable Conditions

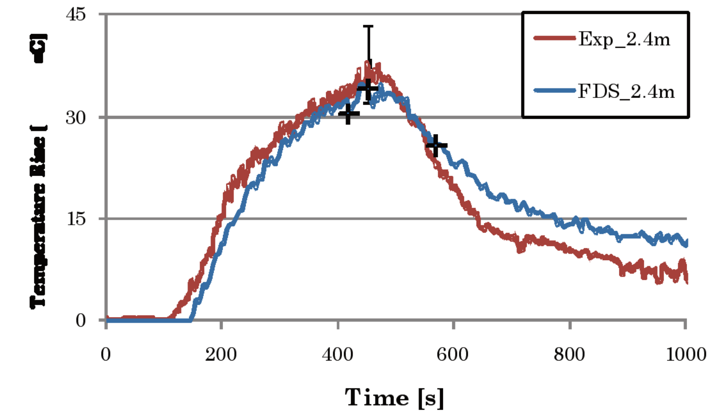


Figure 47: Measured vs. Predicted Temperature at the 2.4 m (7.8 ft) Thermocouple Location in the Bedroom

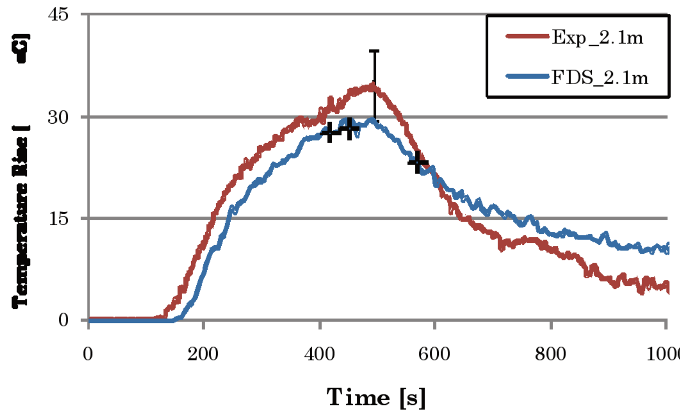


Figure 48: Measured vs. Predicted Temperature at the 2.1 m (6.8 ft) Thermocouple Location in the Bedroom

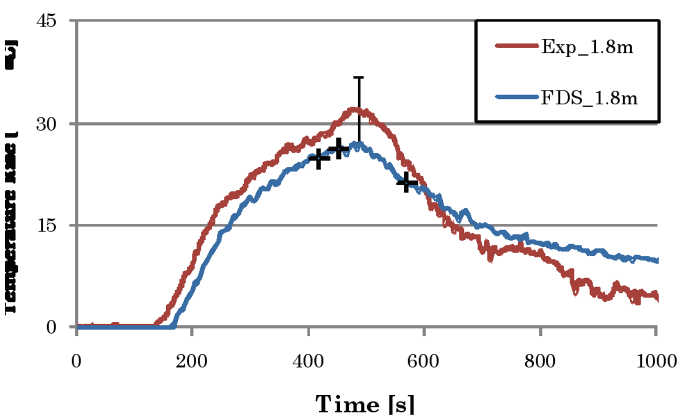


Figure 49: Measured vs. Predicted Temperature at the 1.8 m (5.9 ft) Thermocouple Location in the Bedroom

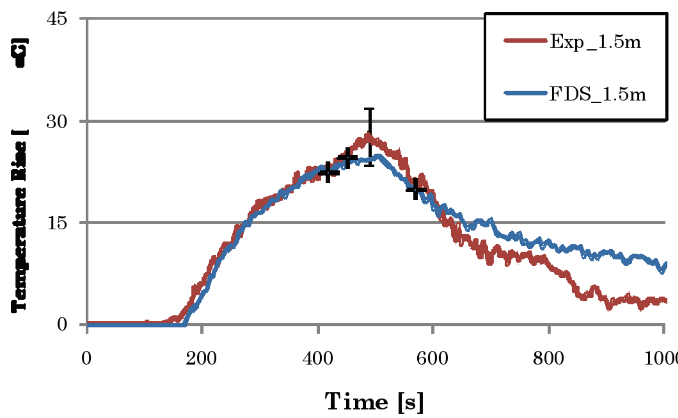


Figure 50: Measured vs. Predicted Temperature at the 1.5 m (4.9 ft) Thermocouple Location in the Bedroom

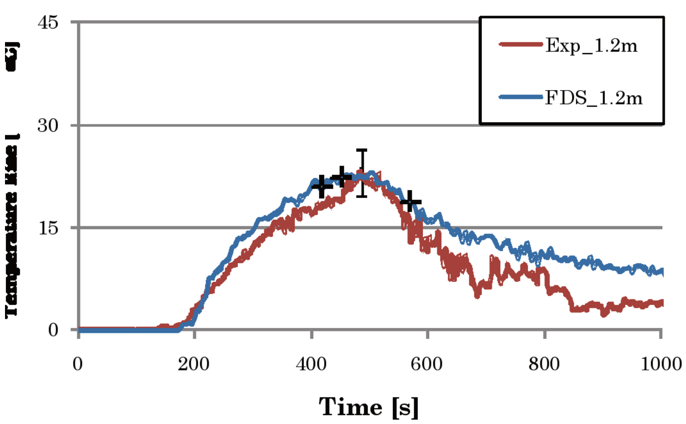


Figure 51: Measured vs. Predicted Temperature at the 1.2 m (3.9 ft) Thermocouple Location in the Bedroom

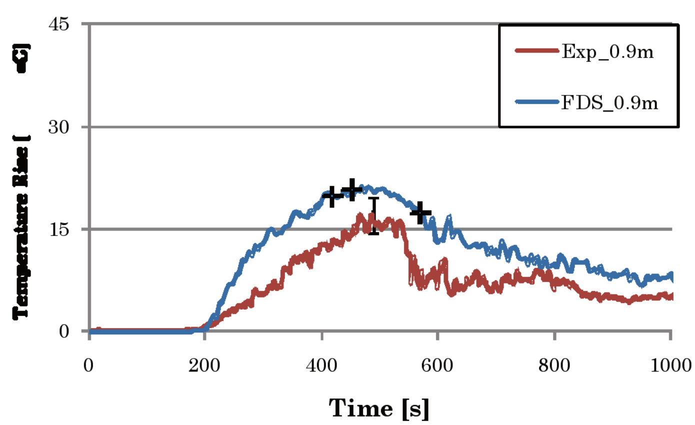


Figure 52: Measured vs. Predicted Temperature at the 0.9 m (2.9 ft) Thermocouple Location in the Bedroom

Fire Growth Rates

Three fire growth rates were used in the computer fire modeling to assess the effectiveness of different fire department deployment configurations in response to fires that were similar to, faster growing, and slower growing than the fires observed in the room-and-contents fires. The slow, medium, and fast fire growth rates are defined by the Society of Fire Protection Engineers according to the time at which they reach 1 megawatt (MW). A typical upholstered chair burning at its peak would produce a 1-MW fire, while a large sofa at its burning peak would produce roughly a 2-MW fire.

The growth rate of fires is often approximated by simple correlation of heat release rate to the square of time. If a fire is not suppressed before full-room involvement, the probability of spread beyond the room of origin increases dramatically if there is nearby fuel load to support fire spread. If a nearby fuel load is available, the 12 ft (3.7 m) by 16 ft (4.9 m) compartment used in the fire experiments would become fully involved at approximately 2 MW. Table 7 shows the time in seconds at which 1-MW and 2-MW (fully involved) fires in this compartment would be reached in the absence of suppression.

A fire department rescue operation is a race between the deteriorating interior conditions inside the structure and the rescue and suppression activities of the fire department. Each fire growth rate was used as a baseline heat release rate for the simulation. Intervention times (window and door opening times and suppression time) from the time-to-task tests were systematically input into the model to evaluate the effects on interior tenability conditions. The interior tenability conditions were calculated in a remote upstairs bedroom (above the room of fire origin on the first floor) in order to maximize the opportunity for differentiation among different crew configurations.

Fire Growth Rate	Time in Seconds Reach 1 MW	Time in Seconds to Reach to 2 MW
Slow	600	848
Medium	300	424
Fast	150	212

Table 7: Time to Reach 1 MW and 2 MW by Fire Growth Rate In the Absence of Suppression

Fractional Effective Dose (FED)

In order to convert instantaneous measurements of local gas conditions, the fractional effective dose (FED) formulation published by the International Standards Organization (ISO) in document 13571 *Life-threatening Components of Fire – Guidelines for the Estimation of Time Available for Escape Using Fire Data* (ISO 2007) were used. FED is a probabilistic estimate of the effects of toxic gases on humans exposed to fire effluent. The formulation used in the simulations accounts for carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2) depletion. Other gases, including hydrogen cyanide (HCN) and hydrogen chloride (HCl), were not accounted for in this analysis and may alter FED for an actual occupant.

$$FED = \sum_{i=1}^{n} \frac{C_i}{(C_t)_i} \Delta t \quad \text{Eq.1}$$

Where C_i is the concentration of the ith gas and $(C_t)_i$ is the toxic concentration of ith gas and Δt is the time increment.

There are three FED thresholds generally representative of different exposure sensitivities of the general population. An FED value of 0.3 indicates the potential for certain sensitive populations to become incapacitated as a result of exposure to toxic combustion products. Sensitive populations may include elderly, young, or individuals with compromised immune systems. Incapacitation is the point at which occupants can no longer effect their own escape. An FED value of 1.0 represents the median incapacitating exposure. In other words, 50 % of the general population will be incapacitated at that exposure level. Finally, an FED value of 3.0 represents the value where occupants who are particularly tolerant of combustion gas exposure (extremely fit persons, for example) are likely to become incapacitated.

These thresholds are statistical probabilities, not exact measurements. There is variability in the way individuals respond to toxic atmospheric conditions. FED values above 2.0 are often fatal doses for so-called typical occupants. There is no threshold so low that it can be said to be safe for every exposed occupant.[17]

Deployment Configuration (All times with close stagger adjusted for early and late arrival of first due engine)	Rescue Time for Deployment Configuration (Min : Sec)
2-Person Early	12:47
3-Person Early	9:03
4-Person Early	9:10
5-Person Early	8:57
2-Person Late	14:47
3-Person Late	11:03
4-Person Late	11:10

Table 6: Rescue Time for Different Deployment Configurations

17 See the following sections of ISO Document 13571:
5.2 Given the scope of this Technical Specification, FED and/or FEC values of 1,0 are associated, by definition, with sublethal effects that would render occupants of average susceptibility incapable of effecting their own escape. The variability of human responses to toxicological insults is best represented by a distribution that takes into account varying susceptibility to the insult. Some people are more sensitive than the average, while others may be more resistant (see Annex A.1.5). The traditional approach in toxicology is to employ a safety factor to take into consideration the variability among humans, serving to protect the more susceptible subpopulations.
5.2.1 As an example, within the context of reasonable fire scenarios FED and/or FEC threshold criteria of 0,3 could be used for most general occupancies in order to provide for escape by the more sensitive subpopulations. However, the user of this Technical Specification has the flexibility to choose other FED and/or FEC threshold criteria as may be appropriate for chosen fire safety objectives. More conservative FED and/or FEC threshold criteria may be employed for those occupancies that are intended for use by especially susceptible subpopulations. By whatever rationale FED and FEC threshold criteria are chosen, a single value for both FED and FEC must be used in a given calculation of the time available for escape.

Results from Modeling Methods

Table 8 shows the FED for slow-, medium-, and fast-growth rate fires correlated to rescue times based on crew size and arrival time in the study. As with the room-and-contents fire in part 3, results in Table 8 included only the close-stagger rescue time data. The effect of far-stagger rescue times on occupant tenability should be investigated in future studies. Values above 0.3 are shown in yellow, and those above the median incapacitating exposure of 1.0 are shown in red.

Figure 54 shows that with slow-growth fires in the experimental residential structure, all crew configurations could achieve rescue time before FED reached incapacitating levels. Figure 55 illustrates the greater danger of medium-growth fires, where the FED at rescue time for two-person crews is well above the 0.3 level, and almost to that level for the other crews.

Figure 56 (page 49) vividly illustrates the extreme danger of fast-growth fires. By the time a two-person crew is able to facilitate a rescue, the FED has far exceeded the median 1.0 level. For other crew sizes, the FED has exceeded 0.3, which is a threshold level for vulnerable populations.

Crew Configuration	Rescue Time	Fire Growth Rates		
		Slow	Medium	Fast
2 Early	12:47	.12	.72	1.49
2 Late	14:47	.35	1.37	2.56
3 Early	9:03	.01	.11	.40
3 Late	11:03	.04	.36	.84
4 Early	9:10	.01	.11	.42
4 Late	11:10	.05	.38	.91
5 Early	8:57	.01	.10	.38

KEY		
	White	89% or more of population may be capable of effecting their own escape if they are able.
	Yellow	Potential for certain sensitive populations (such as children and the elderly) to become incapacitated.
	Red	More than 50% of the population would be incapable of effecting their own escape.

Table 8: FED as a Function of Deployment Configuration and Fire Growth Rate

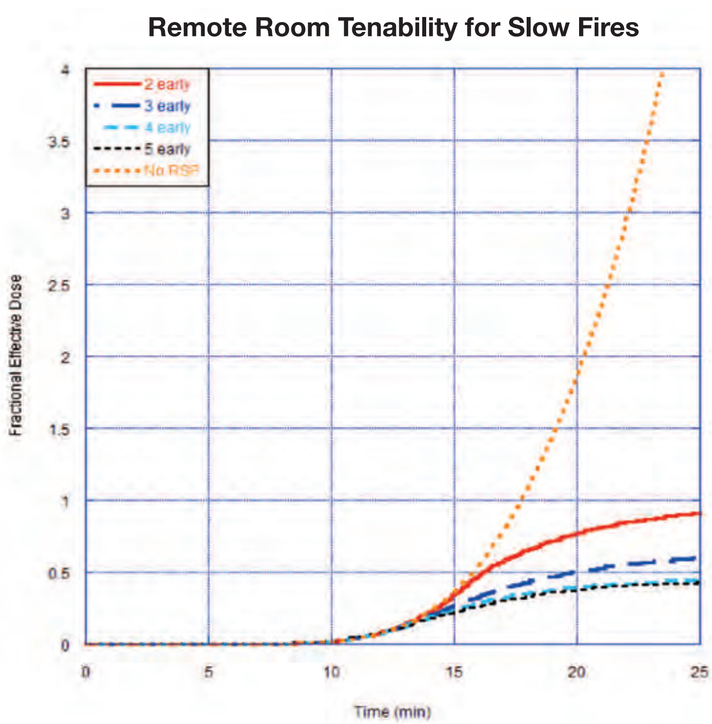


Figure 54: FED Curves for Early Arrival for All Crew Sizes at Slow-Growth Fires

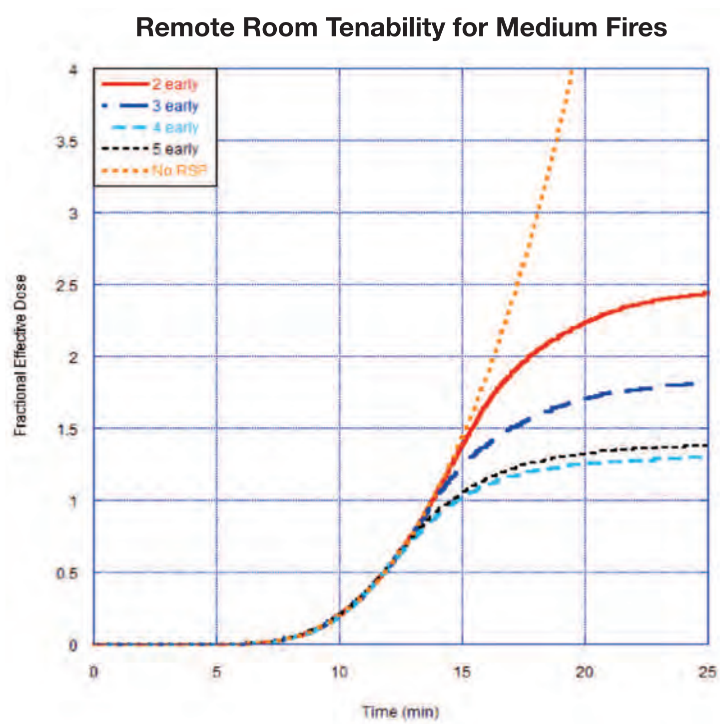


Figure 55: Average FED Curves for Early Arrival for All Crew Sizes at Medium-Growth Fires

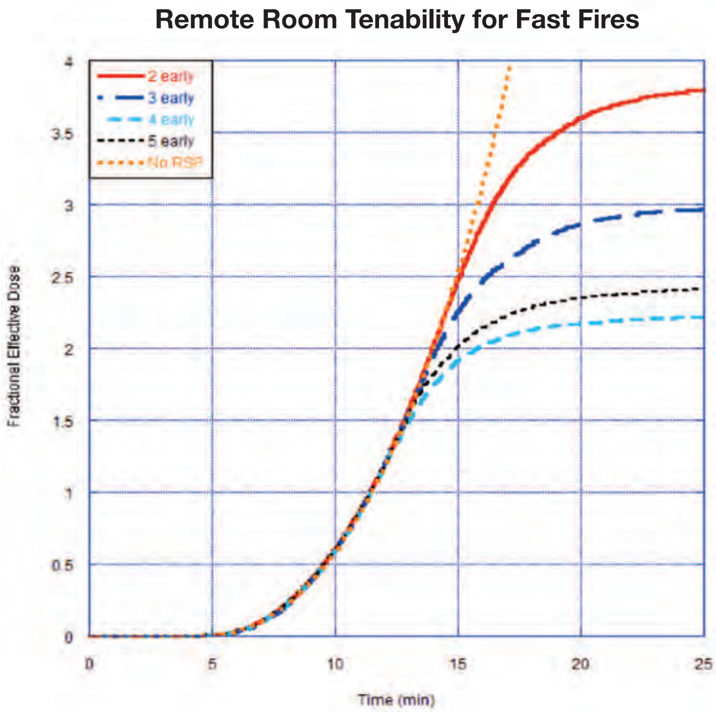


Figure 56: Average FED Curves for Early Arrival for All Crew Sizes at Fast-Growth Fires

Interior Firefighting Conditions and Deployment Configuration

The available time to control a fire can be quite small. Risks to firefighters are lower for smaller fires than larger fires because smaller fires are easier to suppress and produce less heat and fewer toxic gases. Therefore, firefighter deployment configurations that can attack fires earlier in the fire development process present lower risk to firefighters. The longer the duration of the fire development process without intervention, the greater the increase in risk for occupants and responding firefighters. Therefore, time is critical.

Stopping the escalation of the event involves firefighter intervention via critical tasks performed on the fireground. Critical tasks, as described previously, include those tasks that directly affect the spread of fire as well as the associated structural tenability.

There are windows of opportunity to complete critical tasks. A fire in a structure with a typical residential fuel load at six minutes post-ignition is very different from the same fire at eight minutes or at ten minutes post-ignition. Some tasks that are deemed "important" (e.g., scene size-up) for a fire in early stages of growth become critical if intervention tasks are delayed. Time can take away opportunities. If too much time passes, then the window of opportunity to affect successful outcomes (e.g., rescue victim or stop fire spread) closes.

For a typical structure fire event involving a fire department response, there is an incident commander on the scene who determines both the strategy and tactics that will be employed to stop the spread of the fire, rescue occupants, ventilate the structure, and ultimately extinguish the fire. Incident commanders must deal with the fire in the present and make intelligent command decisions based on the circumstances at hand upon arrival. Additionally, arrival time and crew size are factors that contribute to the incident commander's decisions and affect the capability of the firefighters to accomplish necessary tasks on scene in a safe, efficient, and effective manner.

Table 9 illustrates vividly the more dangerous conditions small crews face because of the extra time it takes to begin and complete critical tasks (particularly fire suppression). In the two minutes more it took for the two-person crew (early arrival) than the five-person crew (early arrival) to get water on the fire, a slow growth rate fire would have increased from 1.1 MW to 1.5 MW. This growth would have been even more extreme for a medium-or fast-growth rate fire. The difference is even more substantial for the two-person crew with late arrival as the fire almost doubled in size in the time difference between this crew and the five-person crew.

Based on fire modeling for the low hazard structure studied with a typical residential fuel load, it is likely that medium- and fast-growth rate fires will move beyond the room of origin prior to the arrival of firefighters for all crew sizes. Note that results in Table 8 included only the close-stagger rescue time data. The effect of far-stagger rescue times on occupant tenability should be investigated in future studies. Therefore, the risk level of the event upon arrival will be higher for all crews which must be considered by the incident commander when assigning firefighters to on-scene tasks.

Deployment Configuration	Time to Water on Fire (Min : Sec)	Fire Size at Time of Suppression for Slow-Growth Fires
2-Person, Late Arrival	14:26	2.1 MW
2-Person, Early Arrival	12:26	1.5 MW
3-Person, Late Arrival	13:24	1.8 MW
3-Person, Early Arrival	11:24	1.3 MW
4-Person, Late Arrival	13:11	1.7 MW
4-Person, Early Arrival	11:11	1.3 MW
5-Person, Late Arrival	12:33	1.6 MW
5-Person, Early Arrival	10:33	1.1 MW

Table 9: Fire Size at Time of Fire Suppression

Physiological Effects of Crew Size on Firefighters

Reports on firefighter fatalities consistently document overexertion/overstrain as the leading cause of line-of-duty fatalities. There is strong epidemiological evidence that heavy physical exertion can trigger sudden cardiac events (Mittleman et al. 1993; Albert et al. 2000). Therefore, information about the effect of crew size on physiological strain is very valuable.

During the planning of the fireground experiments, investigators at Skidmore College recognized the opportunity to conduct an independent study on the relationship between firefighter deployment configurations and firefighter heart rates. With the approval of the Institutional Review Board of Skidmore College, they were able to leverage the resources of the field experiments to conduct a separate analysis of the cardiac strain on fire fighters on the fireground.

For details, consult the complete report (Smith 2009). Two important conclusions from the report reinforce the importance of crew size:

- Average heart rates were higher for members of small crews, particularly two-person crews.
- Danger is increased for small crews because the stress of fire fighting keeps heart rates elevated beyond the maximum heart rate for the duration of a fire response, and so the higher heart rates were maintained for sustained time intervals.

Study Limitations

The scope of this study is limited to understanding the relative influence of deployment variables to low-hazard, residential structure fires, similar in magnitude to the hazards described in *NFPA 1710*. The applicability of the conclusions from this report to commercial structure fires, high-rise fires, outside fires, terrorism/natural disaster response, HAZMAT or other technical responses has not been assessed and should not be extrapolated from this report.

Every attempt was made to ensure the highest possible degree of realism in the experiments while complying with the requirements of *NFPA 1403*, but the dynamic environment on the fireground cannot be fully reproduced in a controlled experiment. For example, *NFPA 1403* required a daily walkthrough of the burn prop (including identifying the location of the fire) before ignition of a fire that would produce an Immediately Dangerous to Life and Health (IDLH) atmosphere, a precaution not available to responders dispatched to a live fire.

The number of responding apparatus for each fireground response was held constant (three engines and one truck, plus the battalion chief and aide) for all crew size configurations. The effect of deploying either more or fewer apparatus to the scene was not evaluated.

The fire crews who participated in the experiments typically operate using three-person and four-person staffing. Therefore, the effectiveness of the two-person and five-person operations may have been influenced by a lack of experience in operating at those staffing levels. Standardizing assigned tasks on the fireground was intended to minimize the impact of this factor, which has an unknown influence on the results.

The design of the experiments controlled for variance in performance of the incident commander. In other words, a more-or less-effective incident commander may have a significant influence on the outcome of a residential structure fire.

Although efforts were made to minimize the effect of learning across experiments, some participants took part in more than one experiment, and others did not.

The weather conditions for the experiments were moderate to cold. Frozen equipment such as hydrants and pumps was not a factor. However, the effect of very hot weather conditions on firefighter performance was not measured.

All experiments were conducted during the daylight hours. Nighttime operations could pose additional challenges.

Fire spread beyond the room of origin was not considered in the room and contents tests or in the fire modeling. Therefore, the size of the fire and the risk to the firefighter may be somewhat underestimated for fast-growing fires or slower-response configurations.

There is more than one effective way to perform many of the required tasks on the fireground. Attempts to generalize the results from these experiments to individual departments must take into account tactics and equipment that vary from those used in the experiments.

Conclusions

More than 60 laboratory and full-scale fire experiments were conducted to determine the impact of crew size, first-due engine arrival time, and subsequent apparatus arrival times on firefighter safety and effectiveness at a low-hazard residential structure fire. This report quantifies the effects of changes to staffing and arrival times for low-hazard residential firefighting operations. While resource deployment is addressed in the context of a single structure type and risk level, it is recognized that public policy decisions regarding the cost-benefit of specific deployment decisions are a function of many factors including geography, available resources, community expectations, as well as all local hazards and risks. Though this report contributes significant knowledge to community and fire service leaders in regard to effective resource deployment for fire suppression, other factors contributing to policy decisions are not addressed.

The objective of the experiments was to determine the relative effects of crew size, first-due engine arrival time, and stagger time for subsequent apparatus on the effectiveness of the firefighting crews relative to intervention times and the likelihood of occupant rescue using a parametric design. Therefore, the experimental results for each of these factors are discussed below.

Of the 22 fireground tasks measured during the experiments, the following were determined to have especially significant impact on the success of fire fighting operations. Their differential outcomes based on variation of crew size and/or apparatus arrival times are statistically significant at the 95 % confidence level or better.

Overall Scene Time:

The four-person crews operating on a low-hazard structure fire completed all the tasks on the fireground (on average) seven minutes faster — nearly 30 % — than the two-person crews. The four-person crews completed the same number of fireground tasks (on average) 5.1 minutes faster — nearly 25 % — than the three-person crew. For the low-hazard residential structure fire, adding a fifth person to the crews did not decrease overall fireground task times. However, it should be noted that the benefit of five-person crews has been documented in other evaluations to be significant for medium- and high-hazard structures, particularly in urban settings, and should be addressed according to industry standards.[18]

Time to Water on Fire:

There was a nearly 10 % difference in the "water on fire time" between the two and three-person crews and an additional 6 % difference in the "water on fire time" between the three- and four-person crews (i.e., 16 % difference between the four and two-person crews). There was an additional 6 % difference in the "water on fire'" time between the four- and five-person crews (i.e., 22 % difference between the five and two-person crews).

Ground Ladders and Ventilation:

The four-person crew operating on a low-hazard structure fire can complete laddering and ventilation (for life safety and rescue) 30 % faster than the two-person crew and 25 % faster than the three-person crew.

Primary Search:

The three-person crew started and completed a primary search and rescue 25 % faster than the two-person crew. In the same structure, the four- and five-person crews started and completed a primary search 6 % faster than the three-person crews and 30 % faster than the two-person crew. A 10 % difference was equivalent to just over one minute.

Hose Stretch Time:

In comparing four-and five-person crews to two-and three-person crews collectively, the time difference to stretch a line was 76 seconds. In conducting more specific analysis comparing all crew sizes to a two-person crew the differences are more distinct. A two-person crew took 57 seconds longer than a three-person crew to stretch a line. A two-person crew took 87 seconds longer than a four-person crew to complete the same tasks. Finally, the most notable comparison was between a two-person crew and a five-person crew — more than 2 minutes (122 seconds) difference in task completion time.

Industry Standard Achieved:

The "industry standard achieved" time started from the first engine arrival at the hydrant and ended when 15 firefighters were assembled on scene.[19] An effective response force was assembled by the five-person crews three minutes faster than the four-person crews. According to study deployment protocal, the two- and three-person crews were unable to assemble enough personnel to meet this standard.

Occupant Rescue:

Three different "standard" fires (slow-, medium-, and fast-growth rate) were simulated using the Fire Dynamics Simulator (FDS) model. The fires grew exponentially with time. The fire modeling simulations demonstrated that two-person, late arriving crews can face a fire that is twice the intensity of the fire faced by five-person, early arriving crews. The rescue scenario was based on a nonambulatory occupant in an upstairs bedroom with the bedroom door open.

Independent of fire size, there was a significant difference between the toxicity, expressed as fractional effective dose (FED), for occupants at the time of rescue depending on arrival times for all crew sizes. Occupants rescued by crews starting tasks two minutes earlier had lesser exposure to combustion products.

The fire modeling showed clearly that two-person crews cannot complete essential fireground tasks in time to rescue occupants without subjecting either firefighters or occupants to an increasingly hazardous atmosphere. Even for a slow-growth rate fire, the FED was approaching the level at which sensitive populations, such as children and the elderly are threatened. For a medium-growth rate fire with two-person crews, the FED was far above that threshold and approached the level affecting the median sensitivity in general population. For a fast-growth rate fire, the FED was well above the median level at which 50 % of the general population would be incapacitated. Larger crews responding to slow-growth rate fires can rescue most occupants prior to incapacitation along with early-arriving larger crews responding to medium-growth rate fires. The result for late-arriving (two minutes later than early-arriving) larger crews may result in a threat to sensitive populations for medium-growth rate fires." The new sentence is consistent with our previous description for two-person crews where we identify a threat to sensitive populations.. Statistical averages should not, however, mask the fact that there is no FED level so low that every occupant in every situation is safe.

18 NFPA Standard 1710 - A.5.2.4.2.1 …Other occupancies and structures in the community that present greater hazards should be addressed by additional fire fighter functions and additional responding personnel on the initial full alarm assignment.

19 NFPA 1710 Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments. Section 5.2.1 – Fire Suppression Capability and Section 5.2.2 Staffing.

Summary:

The results of these field experiments contribute significant knowledge to the fire service industry. First, the results establish a technical basis for the effectiveness of company crew size and arrival time in *NFPA 1710*. The results also provide valid measures of total effective response force assembly on scene for fireground operations, as well as the expected performance of time-to-critical-task measures for a low-hazard structure fires. Additionally, the results provide tenability measures associated with the occupant exposure rates to the range of fires considered by the fire model.

Future Research

In order to realize a significant reduction in firefighter line-of-duty death (LODD) and injury, fire service leaders must focus directly on resource allocation and the deployment of resources, both contributing factors to LODD and injury. Future research should use similar methods to evaluate firefighter resource deployment to fires in medium- and high-hazard structures, including multiple-family residences and commercial properties. Additionally, resource deployment to multiple-casualty disasters or terrorism events should be studied to provide insight into levels of risks specific to individual communities and to recommend resource deployment proportionate to such risk. Future studies should continue to investigate the effects of resource deployment on the safety of both firefighters and the civilian population to better inform public policy.

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References

- Albert CM, Mittleman MA, Chae CU, Lee IM, Hennekens CH, Manson JE (2000). Triggering of sudden death from cardiac causes by vigorous exertion. N Engl J Med 343(19):1355-1361.
- Backoff, R. W.; et al. (1980). Firefighter Effectiveness - A Preliminary Report. Columbus Fire Division, The Ohio State University.
- Barnard RJ, Duncan HW [1975]. Heart rate and ECG responses of firefighters. J Occup Med 17: 247-250.
- Blevins, L. G. and Pitts, W. M. (1999). Modeling of Bare and Aspirated Thermocouples in Compartment Fires. Fire Safety Journal, Vol. 33, 239-259.
- Bryant, R. A., et al. (2004). The NIST 3 Megawatt Quantitative Heat Release Rate Facility - Description and Procedure. Natl. Inst. Stand. Technol. NIST IR 7052
- Centaur Associates. (1982). Report on the Survey of Fire Suppression Crew Size Practices.
- Center for Public Safety Excellence. (2008.) CFAI: STANDARDS OF COVER, FIFTH EDITION. Chantilly, Va.
- Center for Public Safety Excellence. (2009.) FIRE & EMERGENCY SERVICE SELF-ASSESSMENT MANUAL. Chantilly, VA.
- Chang, C. Huang, H. (2005). A Water Requirements Estimation Model for Fire Suppression: A Study Based on Integrated Uncertainty Analysis, Fire Technology, Vol. 41, NO. 1, Pg. 5.
- Coleman, Ronny J. (1988). MANAGING FIRE SERVICES, 2nd Edition, International City/County Management Association, Washington, DC.
- Cushman, J. (1982). Report to Executive Board, Minimum Manning as Health & Safety Issue. Seattle, WA Fire Department, Seattle, WA.
- Gerard, J.C. and Jacobsen, A.T. (1981). Reduced Staffing: At What Cost?, Fire Service Today, Pg. 15.
- Fahy R (2005). U.S. Firefighter Fatalities Due to Sudden Cardiac Death 1995-2004. NFPA Journal. 99(4): 44-47.
- Hall, John R. Jr. (2006). U.S Unintentional Fire Death Rates by State. National Fire Protection Association, Quincy, MA.
- Huggett, C. (1980). Estimation of the Rate of Heat Release by Means of Oxygen Consumption. J. of Fire and Flammability, Vol. 12, pp. 61-65.
- International Association of Fire Fighters/John's Hopkins University. (1991). "Analysis of Fire Fighter Injuries and Minimum Staffing Per Piece of Apparatus in Cities With Populations of 150,000 or More," December 1991.
- ISO (2007). ISO 13571: Life-threatening Components of Fire — Guidelines for the Estimation of Time Available for Escape Using Fire Data, International Standards Organization, Geneva.
- Janssens, M. L. (1991). Measuring Rate of Heat Release by Oxygen Consumption., Fire Technology, Vol. 27, pp. 234-249.
- Jones, W. W. (2000). Forney, G. P.; Peacock, R. D.; Reneke, P. A. Technical Reference for CFAST: An Engineering Tool for Estimating Fire and Smoke Transport. National Institute of Standards and Technology, Gaithersburg, MD. NIST TN 1431; 190 p. March 2000.
- Karter, M.J. Jr. (2008). U.S. Fire Loss for 2007. NFPA Journal, September/October 2008.
- McGrattan, K. B. (2006). Fire Dynamics Simulator (Version 4): Technical Reference Guide. NIST Gaithersburg, MD. NIST SP 1018; NIST Special Publication 1018; 109 p. March 2006.
- McManis Associates and John T. O'Hagan and Associates (1984). "Dallas Fire Department Staffing Level Study," June 1984; pp. I-2 & II-1 through II-7.
- Menker, W.K. (1994). Predicting Effectiveness of Manual Suppression, MS Thesis, Worcester Polytechnic Institute.
- Metro Chiefs/International Association of Fire Chiefs (1992) "Metro Fire Chiefs - Minimum Staffing Position," May 1992.
- Mittleman MA, Maclure M, Tofler GH, Sherwood JB, Goldberg RJ, Muller JE (1993). Triggering of acute myocardial infarction by heavy physical exertion. N Engl J Med 329(23):1677–1683.
- Morrison, R. C. (1990). Manning Levels for Engine and Ladder Companies in Small Fire Departments National Fire Academy, Emmitsburg, MD.
- NFA (1981). Fire Engines are Becoming Expensive Taxi Cabs: Inadequate Manning. National Fire Academy, United States Fire Administration, Emmitsburg, MD.
- NFPA (2007). NFPA 1403: Standard on Live Fire Training Evolutions. National Fire Protection Association, Quincy, MA.
- NFPA (2004). NFPA 1710: Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments. National Fire Protection Association, Quincy, MA.
- NFPA (2008). Fire Protection Handbook, 20th Edition. National Fire Protection Association, Quincy, MA.

- Office of the Fire Marshal of Ontario. (1993). Fire Ground Staffing and Delivery Systems Within a Comprehensive Fire Safety Effectiveness Model. Ministry of the Solicitor General, Toronto, Ontario, Canada.
- Omega Engineering, Inc. (2004). The Temperature Handbook. 5th Edition.
- Parker, W. J. (1984). Calculations of the Heat Release Rate by Oxygen-Consumption for Various Applications., Journal of Fire Sciences, Vol. 4, pp. 380-395.
- Phoenix, AZ Fire Department," Fire Department Evaluation System (FIREDAP)," December 1991; p. 1.
- Purser, D. (2002). "Toxicity Assessment of Combustion Products." In The SFPE Handbook of Fire Protection Engineering, 3rd Edition. DiNenno (Editor). National Fire Protection Association, Quincy, MA.
- Rand Institute. (1978). Fire Severity and Response Distance: Initial Findings. Santa Monica, CA.Roberts, B.
- Romet TT, Frim J (1987). Physiological responses to firefighting activities. Eur J Appl Physiol 56: 633-638.
- Sardqvist, S; Holmsted, G., Correlation Between Firefighting Operation and Fire Area: Analysis of Statistics, Fire Technology, Vol. 36, No. 2, Pg. 109, 2000
- Smith DL, Petruzzello SJ, Kramer JM, Warner SE, Bone BG, Misner JE (1995). Selected physiological and psychobiological responses of physical activity in different configurations of firefighting gear. Ergonomics 38(10): 2065-2077
- Smith, D. Effect of Deployment of Resources on Cardiovascular Strain of Firefighters." DHS, 2009.
- Thornton, W. (1917). The Relation of Oxygen to the Heat of Combustion of Organic Compounds., Philosophical Magazine and J. of Science, Vol. 33.
- TriData Corporation. The Economic Consequences of Firefighter Injuries and Their Prevention, Final Report. National Institute of Standards and Technology, U.S. Department of Commerce, Gaithersburg, MD. 2005.
- USFA (2002). Firefighter Fatality Retrospective Study. United States Fire Administration
- USFA (2008). Fatal Fires, Vol. 5-Issue 1, March 2005. USFA, Firefighter Fatalities in the United States in 2007. June 2008. Prepared by C2 Technologies, Inc., for U.S. Fire Administration, Contract Number EME-2003-CO-0282.
- USNRC (2007). Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications. Volume 2: Experimental Uncertainty. Washington, DC : United States Nuclear Regulatory Commission. 1824.

APPENDIX A: Laboratory Experiments

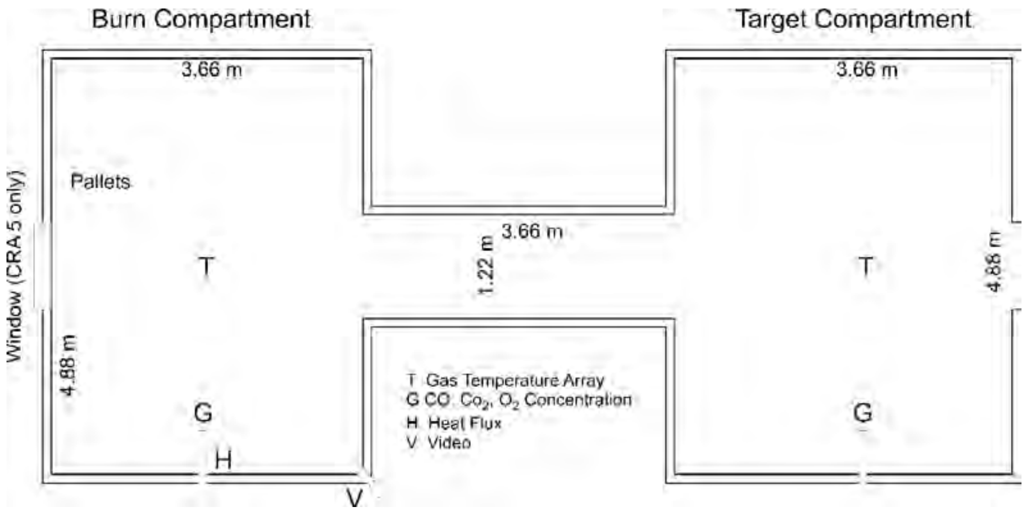


Figure A-1. Compartment Configuration and Instrumentation for Pallet Tests

The fire suppression and resource deployment experiments consisted of four distinct parts: laboratory experiments, time-to-task experiments, room and contents experiments and fire modeling. The purpose of the laboratory experiments was to assure a fire in the field experiments that would consistently meet *NFPA 1403* requirements for live fire training exercises. The laboratory experiments enabled investigators to characterize the burning behavior of the wood pallets as a function of:

- number of pallets and the subsequent peak heat release rate
- compartment effects on burning of wood pallets
- effect of window ventilation on the fire
- effect on fire growth rate of the loading configuration of excelsior (slender wood shavings typically used as packing material)

Design and Construction

Figure A-1 shows the experimental configuration for the compartment pallet burns. Two identically sized compartments (3.66 m x 4.88 m x 2.44 m) were connected by a hallway (4 m x 1 m x 2.4 m). At each end of the hallway, a single door connected the hallway to each of the compartments. In the burn compartment, a single window (3 m x 2 m) was covered with noncombustible board that was opened for some experiments and closed for others. At the end of test, it was opened to extinguish the remaining burning material and to remove any debris prior to the next test. In the second compartment, a single doorway connected the compartment to the rest of the test laboratory. It was kept open throughout the tests allowing the exhaust to flow into the main collection hood for measurement of heat release rate.

The structure was constructed of two layer of gypsum wallboard over steel studs. The floor of the structure was lined with two layers of gypsum wallboard directly over the concrete floor of the test facility. In the burn compartment, an additional lining of cement board was placed over the gypsum walls and ceiling surfaces near the fire source to minimize fire damage to the structure after multiple fire experiments. A doorway 0.91 m wide by 1.92 m tall connected the burn compartment to the hallway and an opening 1 m by 2 m connected the hallway to the target compartment. Ceiling height was 2.41 m throughout the structure, except for the slight variation in the burn room.

Fuel Source

The fuel source for all of the tests was recycled hardwood pallets constructed of several lengths of hardwood boards nominally 83 mm wide by 12.7 mm thick. Lengths of the individual boards ranged from nominally 1 m to 1.3 m. The finished size of a single pallet was approximately 1 m by 1.3 m by 0.11 m. **Figure A-2** shows the fuel source for one of the tests including six stacked pallets and excelsior ignition source. For an ignition source, excelsior was placed within the pallets, with the amount and location depending on the ignition scenario. Figure A-3 shows the pallets prior to a slow and a fast ignition scenario fire. Table A-1 details the total mass of pallets and excelsior for each of the free burn and compartment tests.

Experimental Conditions

The experiments were conducted in two series. In the first series, heat release measurements were made under free burn conditions beneath a 6 m by 6 m hood used to collect combustion gases and provide the heat release rate (HRR) measurement. A second series of tests was conducted with the fire in a compartmented structure to assess environmental conditions within the structure during the fires and determine the effect of the compartment enclosure on the fire growth. Table A-1 presents a summary of the tests conducted.

Figure A-2. Pallets and Excelsior Ignition Source Used as a Fuel Source

Table A-1. Tests Conducted and Ambient Conditions at Beginning of Each Test

Test	Test Type	Number of Pallets	Ignition Scenario	Total Pallet Mass (kg)	Excelsior Mass (kg)
PAL 1	Free burn	4	Fast	79.3	8.1
PAL 2	Free burn	6	Fast	118.8	15.1
PAL 3	Free burn	8	Fast	146.7	16.2
PAL 4	Free burn	4	Slow	51.0	1.65
PAL 5	Free burn	6	Slow	160.3	0.85
CRA 1	Compartment	6	Slow	114.0	0.83
CRA 2	Compartment	4	Slow	69.7	
CRA 3	Compartment	4	Fast	71.1	0.8
CRA 4	Compartment	4	Slow	73.9	0.83
CRA 5	Compartment	4	Slow	73.8	0.85

Notes: PAL stands for "pallet" and CRA ("Community Risk Assessment") is the designator for the configuration of pallets burned in the compartment. Efforts were made to use the same amount of excelsior mass for CRA 2 (~0.8 kg), but the value was not measured.

Figure A-3. Fuel and Excelsior Source for Slow (top) and Fast (bottom) Ignition Scenarios

Measurements Conducted

Heat release rate (HRR) was measured in all tests. HRR measurements were conducted under the 3 m by 3 m calorimeter at the NIST Large Fire Research Laboratory. The HRR measurement was based on the oxygen consumption calorimetry principle first proposed by Thornton (Thornton 1917) and developed further by Huggett (Huggett 1980) and Parker (Parker 1984). This method assumes that a known amount of heat is released for each gram of oxygen consumed by a fire. The measurement of exhaust flow velocity and gas volume fractions (O_2, CO_2 and CO) were used to determine the HRR based on the formulation derived by Parker (Parker 1984) and Janssens (Janssens 1981). The combined expanded relative uncertainty of the HRR measurements was estimated at ± 14 %, based on a propagation of uncertainty analysis (Bryant 2004).

For the compartment fire tests, gas temperature measurements were made in the burn compartment and in the target compartment connected by a hallway to the burn compartment using 24 gauge bare-bead chromel-alumel (type K) thermocouples positioned in vertical array. Thermocouples were located at the center of each compartment at locations 0.03 m, 0.30 m, 0.61 m, 0.91 m, 1.22 m, 1.52 m, 1.83 m, and 2.13 m from the ceiling. The expanded uncertainty associated with a type K thermocouple is approximately ± 4.4° C. (Omega 2004)

Gas species were continuously monitored in the burn compartment at a level 0.91 m from the ceiling at a location centered on the side wall of the compartment, 0.91 m from the wall. Oxygen was measured using paramagnetic analyzers. Carbon monoxide and carbon dioxide were measured using non-dispersive infrared (NDIR) analyzers. All analyzers were calibrated with nitrogen and a known concentration of gas prior to each test for a zero and span concentration calibration. The expanded relative uncertainty of each of the span gas molar fractions is estimated to be ± 1 %.

Total heat flux was measured on the side wall of the enclosure at a location centered on the side wall, 0.61 m from the ceiling level. The heat flux gauges were 6.4 mm diameter Schmidt-Boelter type, water cooled gauges with embedded type-K thermocouples (see Figure A-4). The manufacturer reports a ± 3 % expanded uncertainty in the response calibration (the slope in $kW/m^2/mV$). Calibrations at the NIST facility have varied within an additional ± 3 % of manufacturer's calibration. For this study, an uncertainty of ± 6 % is estimated.

Figure A-4: Heat Flux Gauge with Radiation Shielding

Test	Test Type	Number of Pallets	Ignition Scenario	Peak HRR (kW)	Time to Peak HRR (s)
PAL 1	Free burn	4	Fast	2144	205
PAL 2	Free burn	6	Fast	2961	320
PAL 3	Free burn	8	Fast	3551	301
PAL 4	Free burn	4	Slow	1889	385
PAL 5	Free burn	6	Slow	2410	986
CRA 1	Compartment	6	Slow	1705	1102
CRA 2	Compartment	4	Slow	1583	649
CRA 3	Compartment	4	Fast	1959	159
CRA 4	Compartment	4	Slow	1620	775
CRA 5	Compartment	4	Slow	1390	927

Table A-2. Peak Heat Release Rate During Several Pallet Tests in Free-burn and in a Compartment

Results

Table A-2 shows the peak HRR and time to peak HRR for the free burn tests and for the compartment tests. Figure A-5 includes images from the free burn experiments near the time of peak HRR for each of the experiments. Figure A-6 illustrates the progression of the fire from the exit doorway looking down the hallway to the burn compartment for one of the tests. Figure A-7 to Figure A-10 present graphs of the heat release rate for all of the tests. Figure A-11 through Figure A-15 shows the gas temperature, major gas species concentrations, and heat flux in the burn compartment and target compartment in the five compartment tests.

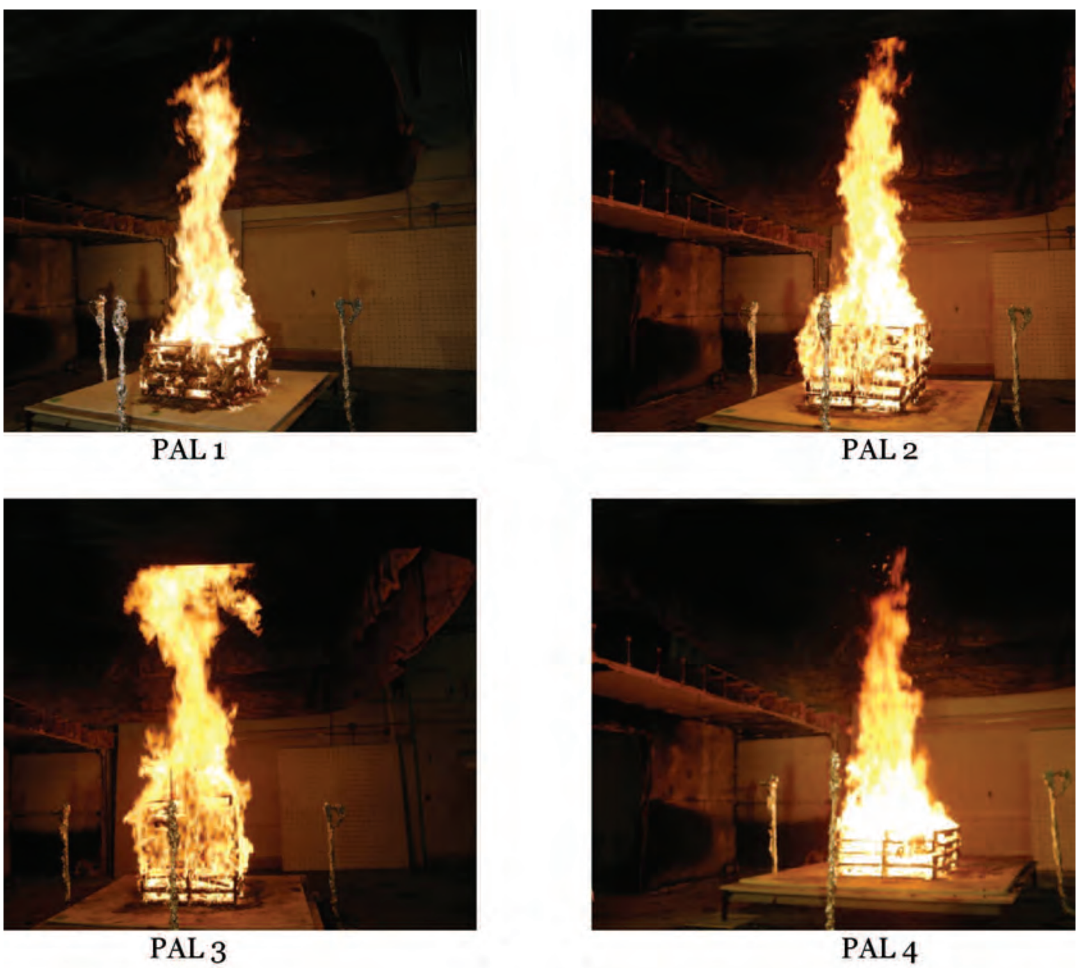


Figure A-5. Free-Burn Experiments Near Time of Peak Burning

Figure A-6. Example Fire Progression from Test CRA 1

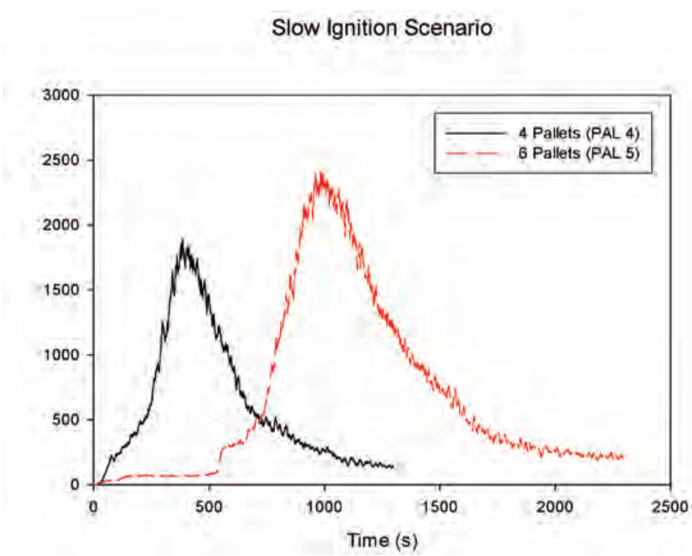


Figure A-7. HRR, Slow Ignition, Free Burn Scenario

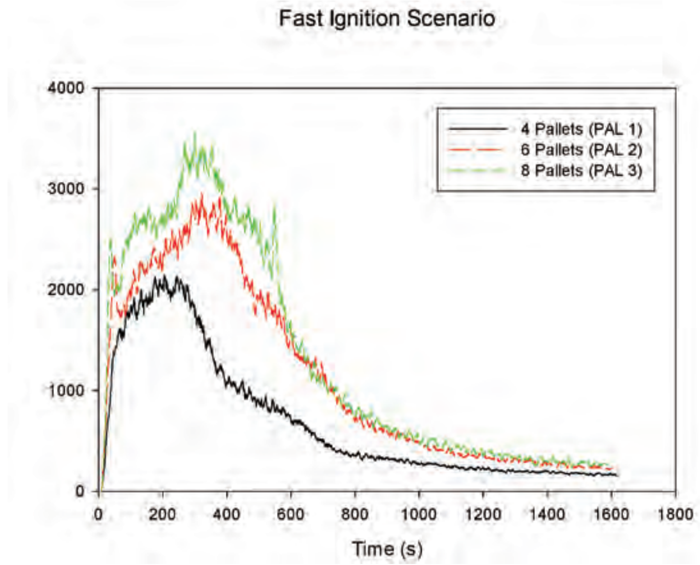


Figure A-8. HRR, Fast Igntion, Free Burn Scenario

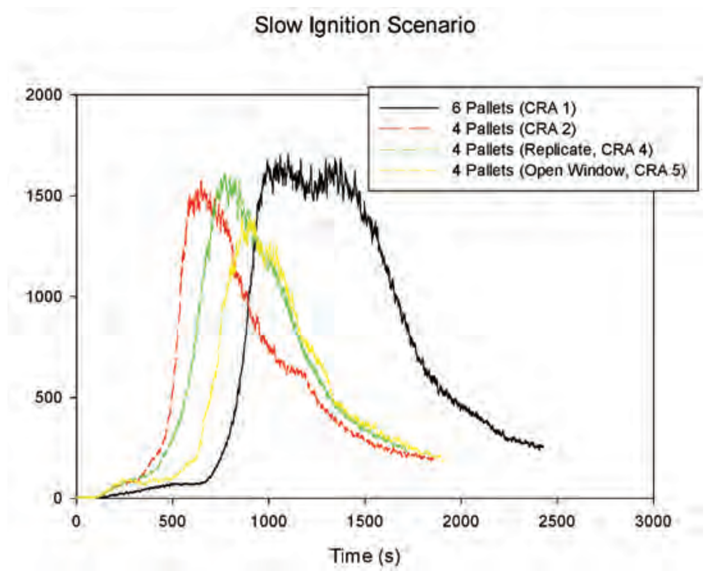


Figure A-9. HRR, Slow Ignition, Compartment Test

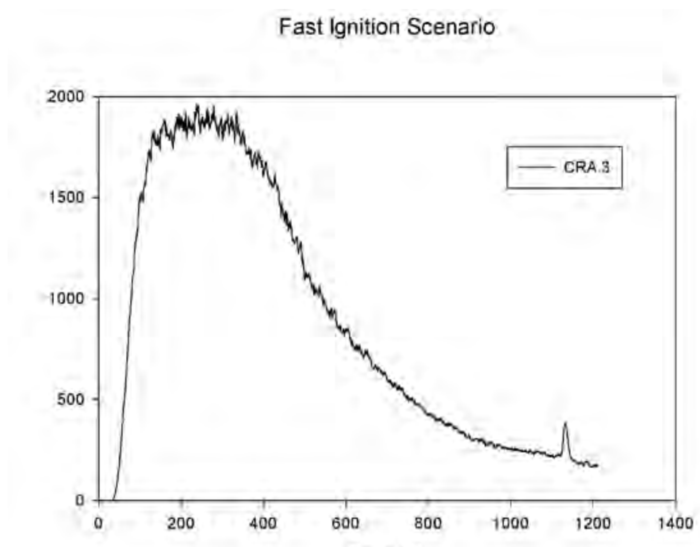


Figure A-10. HRR, Fast Ignition, Compartment Test

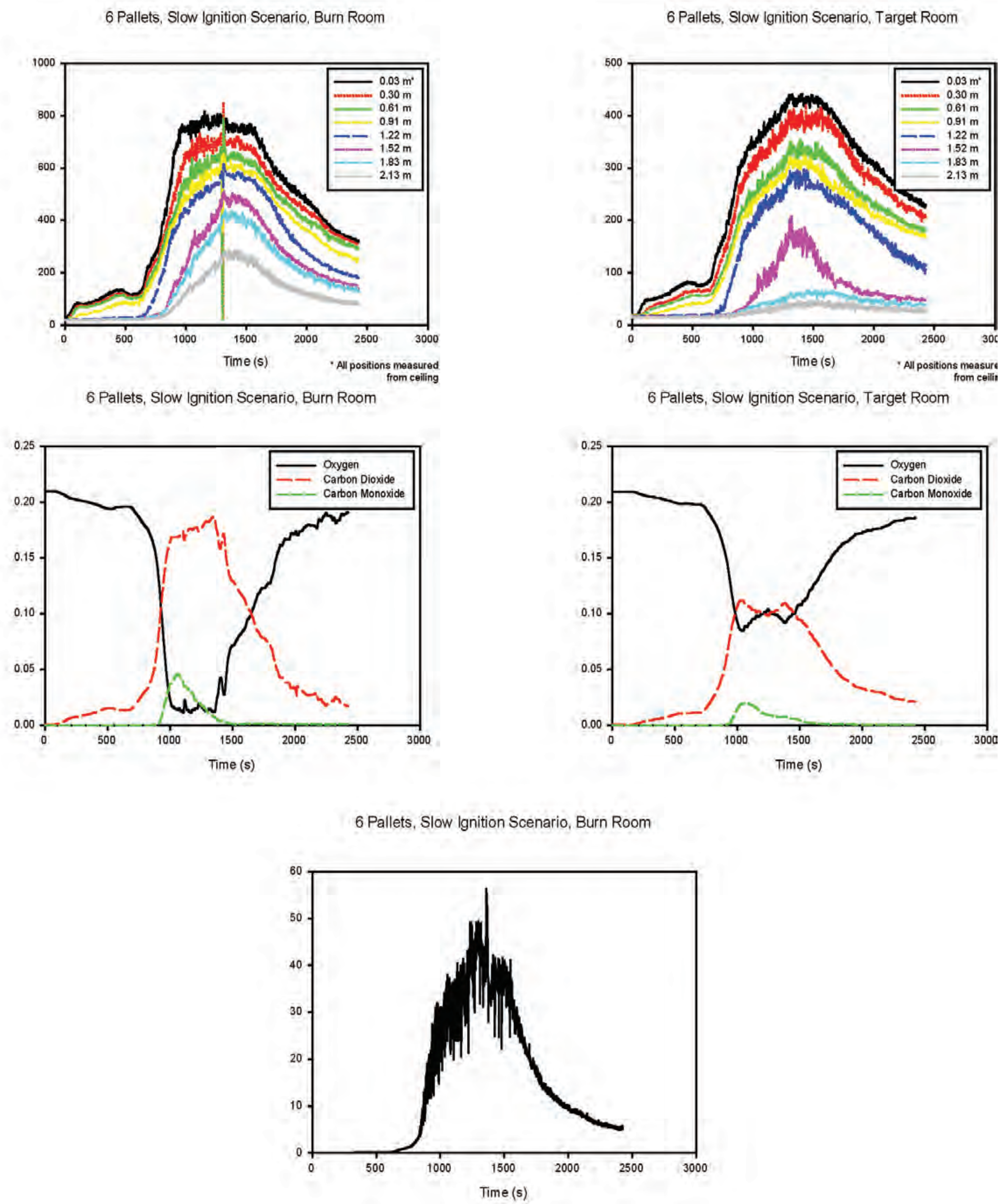


Figure A-11. Temperature, Gas Concentration, and Heat Flux During Test CRA 1, 6 Pallets, Slow Ignition Scenario

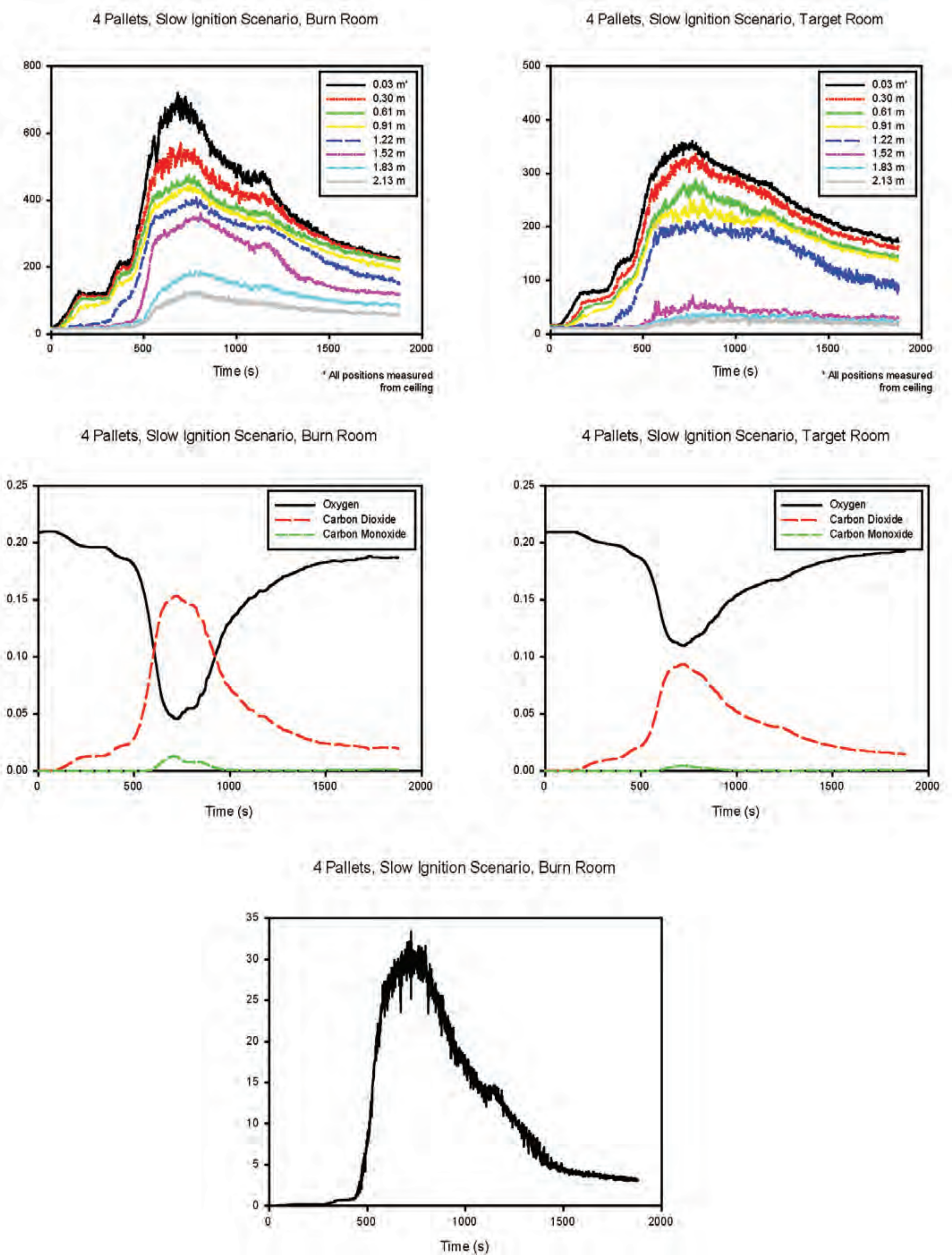
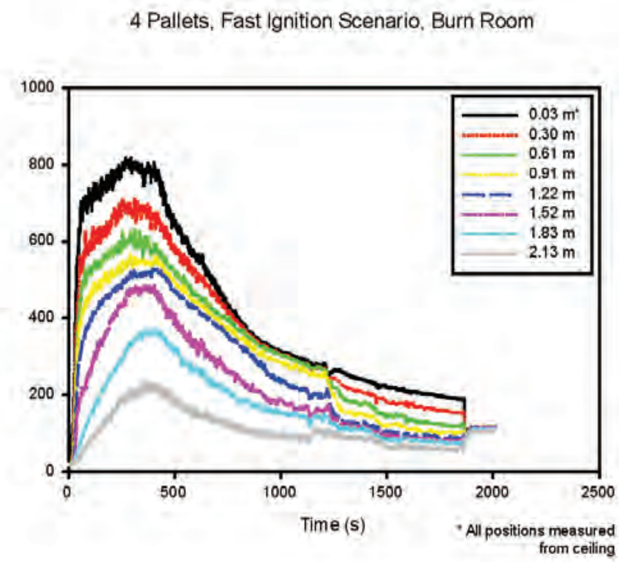
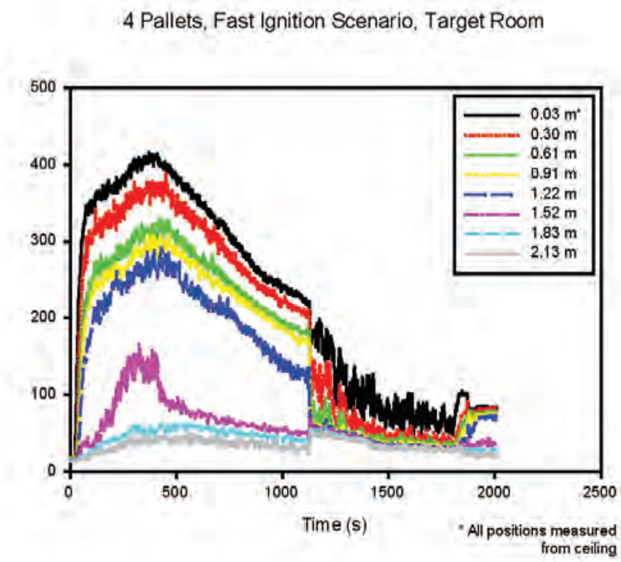
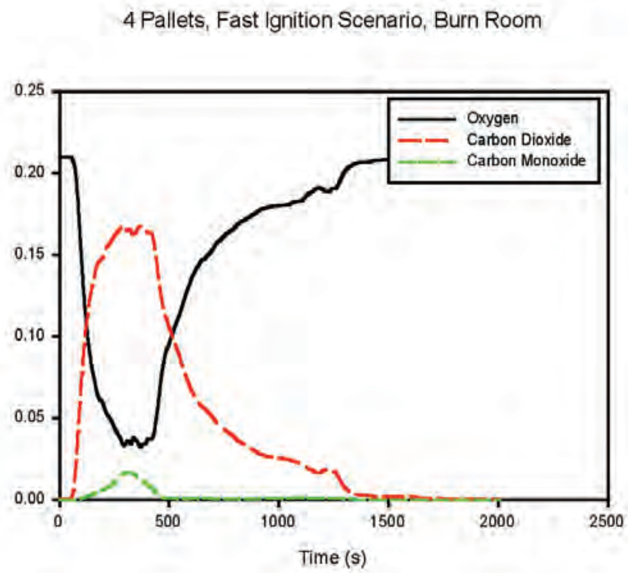
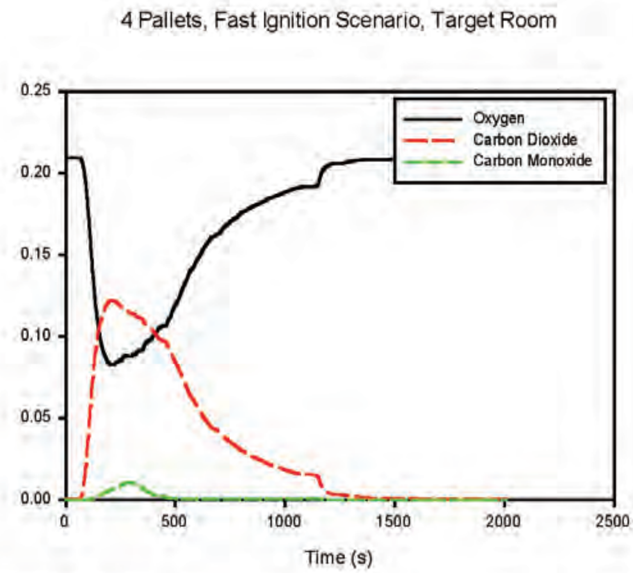


Figure A-12. Temperature, Gas Concentration, and Heat Flux During Test CRA 2, 4 Pallets, Slow Ignition Scenario









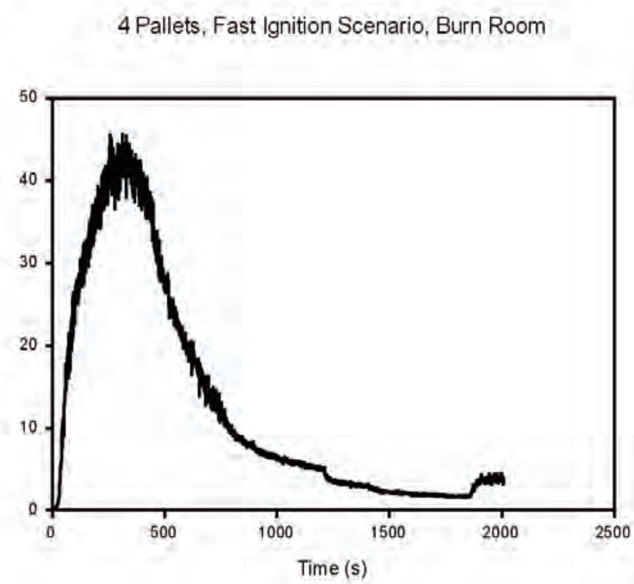
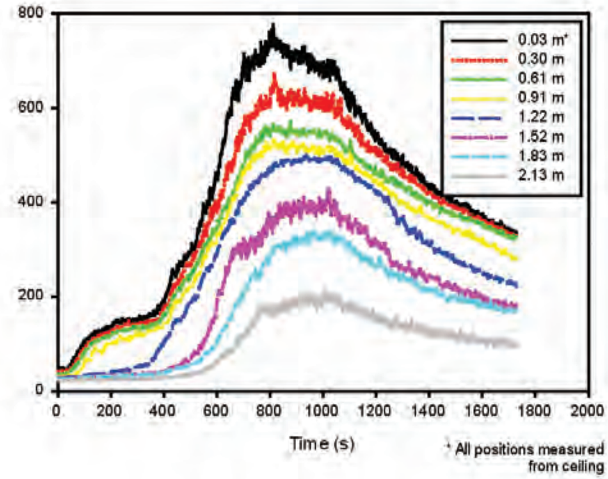
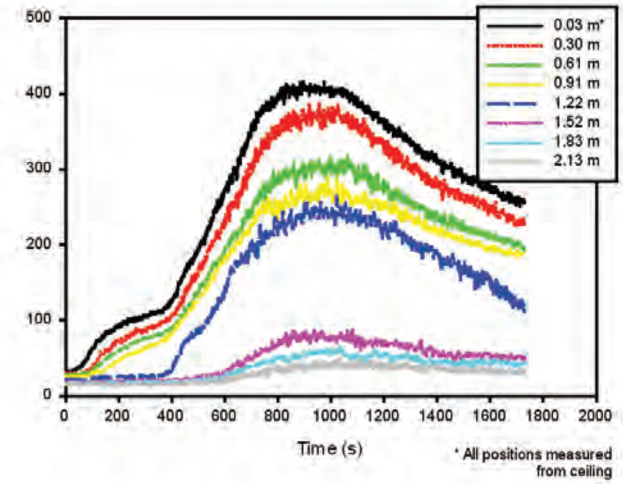


Figure A-13. Temperature, Gas Concentration, and Heat Flux During Test CRA 3, 4 Pallets, Fast Ignition Scenario

4 Pallets, Slow Ignition Scenario, Burn Room
(Replicate)



4 Pallets, Slow Ignition Scenario, Target Room
(Replicate)



4 Pallets, Slow Ignition Scenario, Burn Room
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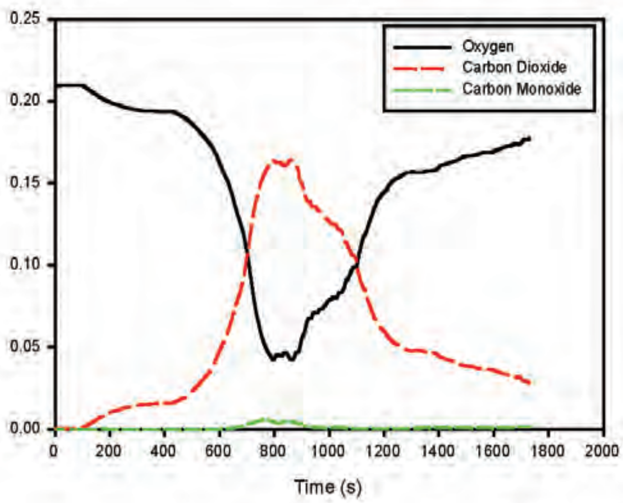
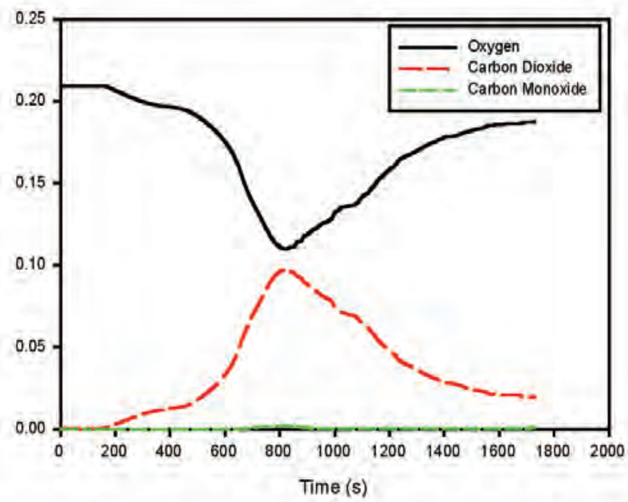


4 Pallets, Slow Ignition Scenario, Target Room
(Replicate)



4 Pallets, Slow Ignition Scenario, Burn Room
(Replicate)

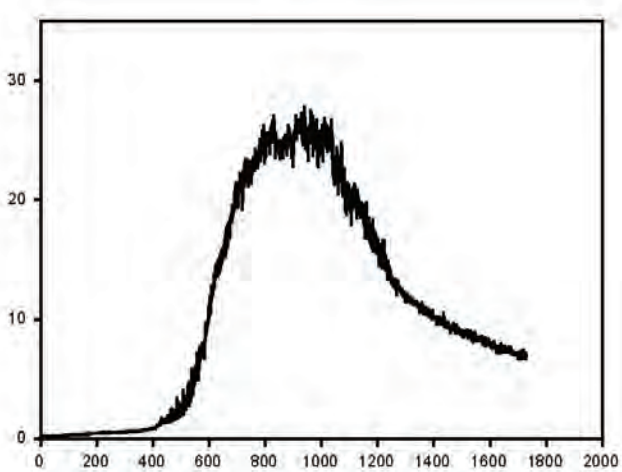


Figure A-14. Temperature, Gas Concentration, and Heat Flux During Test CRA 4, 4 Pallets, Slow Ignition Scenario (Replicate)

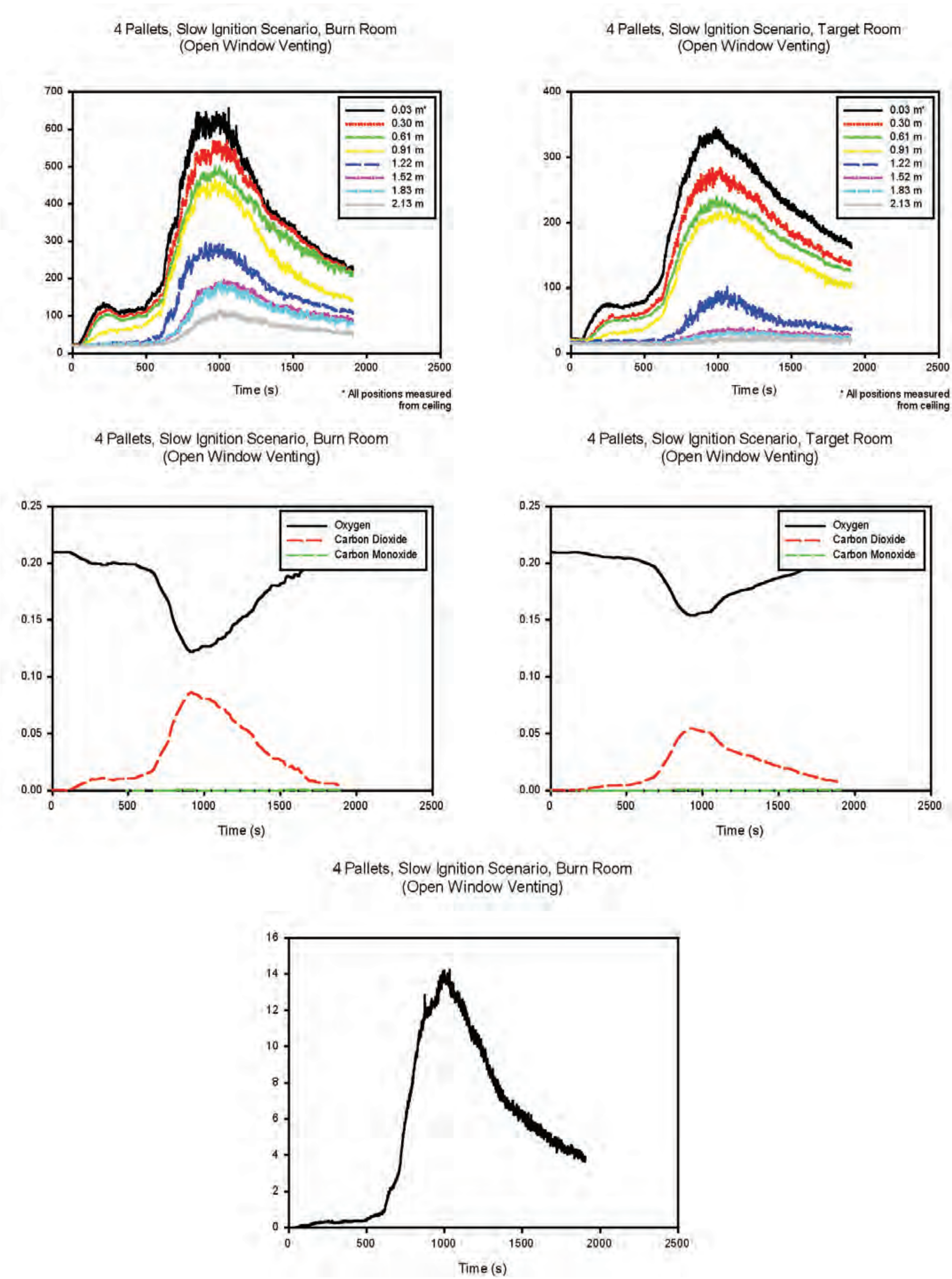
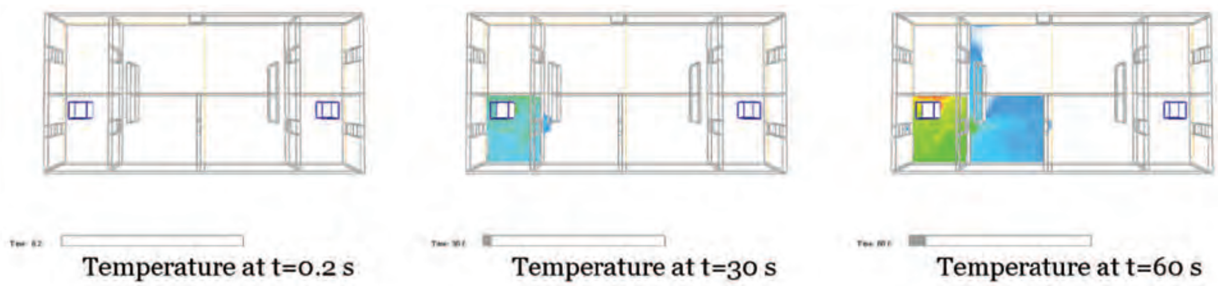


Figure A-15. Temperature, Gas Concentration, and Heat Flux During Test CRA 5, 4 Pallets, Slow Ignition Scenario (Open Window Venting)

APPENDIX B: Designing Fuel Packages for Field Experiments

Based upon the results of the laboratory experiments, the project team determined that four pallets would provide both a realistic fire scenario, as well as a repeatable and well-characterized fuel source. Varying the placement and quantity of excelsior provided significant variance in the rate of fire growth. Prior to finalization of the fuel package and construction specifications, modeling was used to ensure that the combination of fuel and residential geometry would result in untenable conditions throughout the structure without subjecting the firefighters to unsafe testing conditions. Therefore, CFAST (the consolidated fire and smoke transport model (Jones 2000)) and FDS (fire dynamics simulator model (McGrattan 2006)) were used to predict the temperatures and toxic species within the structure as a function of the experimentally determined heat release rates. The results summarized below confirmed that the building geometry and fuel package produced adequate variation in tenability conditions in the residential structure and ensured that the room of origin would not reach flashover conditions (a key provision of *NFPA 1403*). Meeting these conditions provided the foundation for experiments to meet the two primary objectives of fire department response: preservation of life and property.



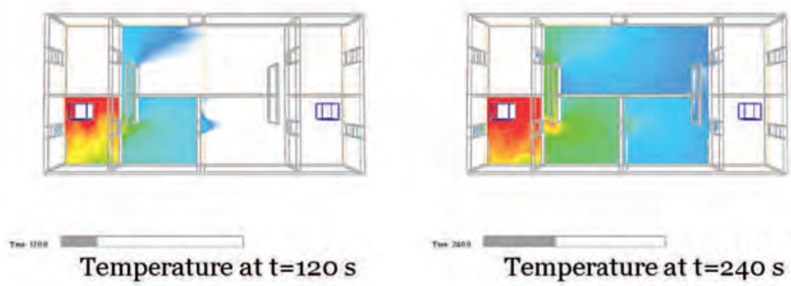


Figure B-1 and B-2 show the thermal and smoke conditions in the residential structure at different time periods using the fast growth, four pallet fuel package.

The results of the fire modeling indicated development of untenable conditions in the field experiments between 5 and 15 minutes, depending upon several factors: fire growth rate, ventilation conditions, the total leakage of heat into the building and through leakage paths, and firefighter intervention. This time frame allowed for differentiation of the effectiveness of various fire department deployment models.

Figure B-1: Time-dependent temperature contours in field structure with fast growth fire

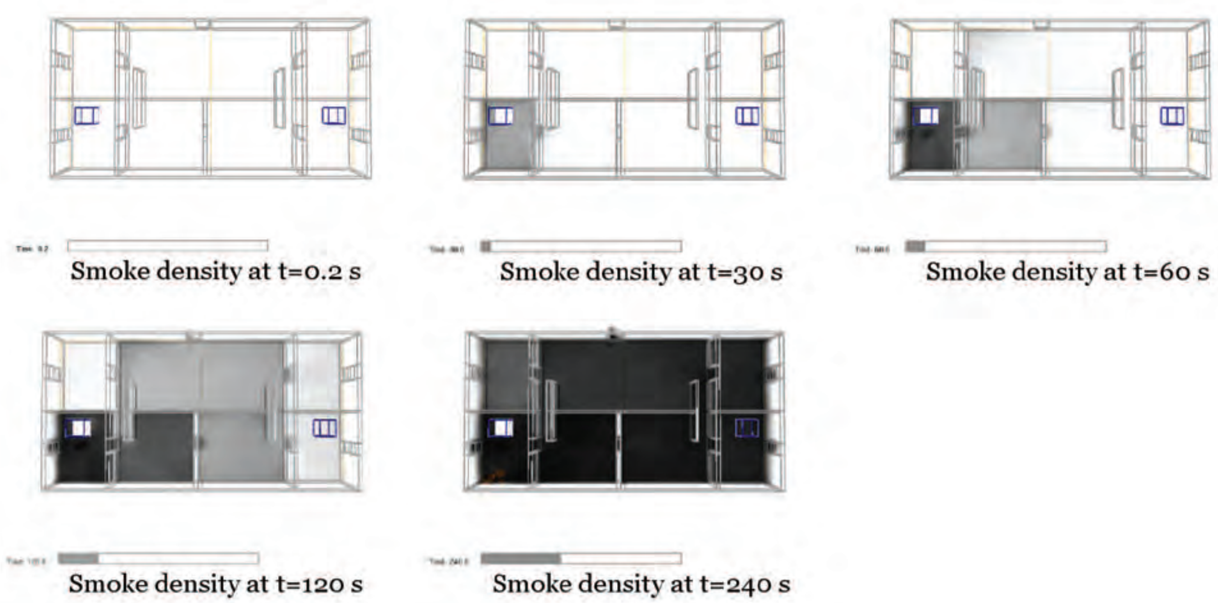


Figure B-2: Time-dependent smoke density contours in field structure with fast growth fire

APPENDIX C: Temporary Burn Prop Construction and Instrumentation

Through the generosity of the Montgomery County (MD), an open space was provided to construct a temporary burn prop at the Montgomery County Fire and Rescue Training Facility in Rockville, MD. The area had ready access to water and electrical utilities. A licensed general contractor was retained, including a structural engineer for the design of critical ceiling members, and the burn prop was constructed over a several month period in late 2008.

The burn prop consisted of two 2,000 ft.^{2} (186 m^2) floors totaling 4,000 ft.^{2} (372 m^2). An exterior view of two sides of the burn prop is shown in Figure C-1.

Additional partitions were installed by NIST staff to create a floor plan representative of a two-story, 186 m^2 (2,000 ft.^{2}) single family residence. Note that the structure does not have a basement and includes no exposures. The overall dimensions are consistent with the general specifications of a typical low hazard residential structure that many fire departments respond to on a regular basis, as described in *NFPA 1710*.

Further details about typical single family home designs are not provided in the standard. Therefore, a floor plan representative of a typical single family home was created by the project team. Details and floor plan dimensions are shown in Figure C-2.

Figure C-1: View of two sides of the burn prop

The black lines indicate load-bearing reinforced concrete walls and red lines indicate the gypsum over steel stud partition walls. The ceiling height, not shown in Figure C-2, is 94 in. (2.4 m) throughout the entire structure except in the burn compartments, where the ceiling height is 93 in. (2.4 m). The purpose of the partition walls was to symmetrically divide the structure about the short axis in order to allow one side of the test structure to cool down and dry-out after a fire test with suppression while conducting experiments on the other side.

The concrete walls original to the burn prop were 8 in. (204 mm) thick steel reinforced poured concrete and the floors on the first level and second levels were 4 in. (102 mm) thick poured concrete. The support structure for the second floor and the roof consisted of corrugated metal pan welded to open web steel joists. The dimensions of the joists are shown in Figure C-3. The ceiling was constructed from ½ in. (13 mm) thick cement board fastened to the bottom chord of the steel joists. Partition walls were constructed from 5/8 in. (17 mm) thick gypsum panels attached to 20 gauge steel studs fastened to steel track, spaced 16 in. (407 mm) on center.

Additional construction was implemented in the burn compartments to address thermal loading and hose stream impingement concerns. Spray-on fireproofing was applied to the steel joists prior to fastening the ceiling, as shown in Figure C-4. The ceilings were constructed with three layers of ½ in. (13 mm) cement board, as opposed to one layer construction in the rest of the building. Each layer was fastened in a different direction so that seams of adjacent layers ran orthogonally. The difference in ceiling heights previously

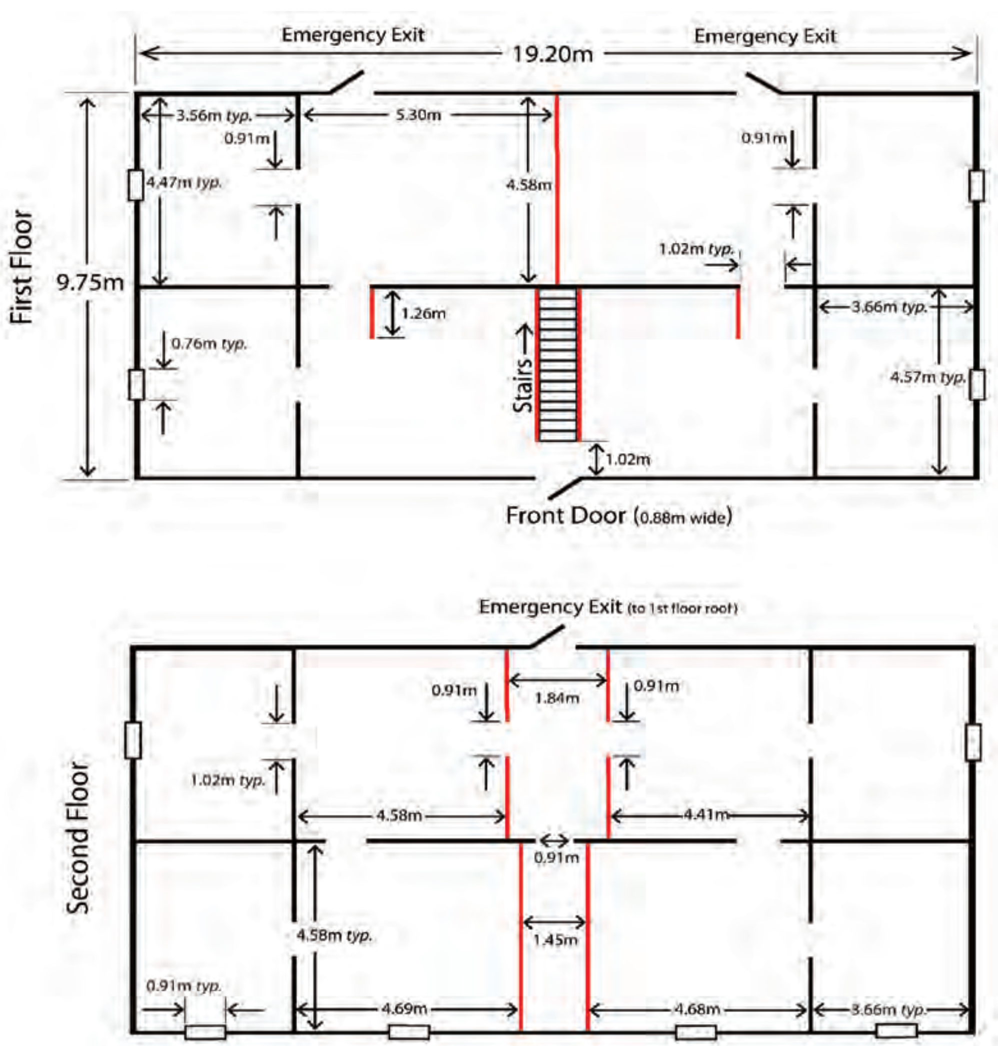


Figure C-2: Dimensions of the Burn Prop Floor Plan

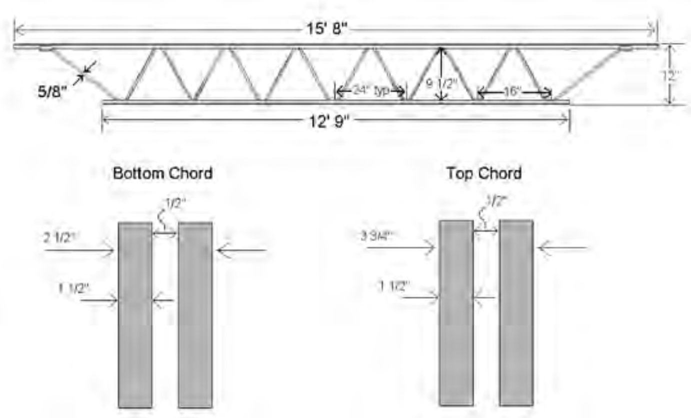


Figure C-3: Structural Steel Dimensions

mentioned is the result of the two additional sheets of cement board. The burn compartment walls were constructed from a single layer of ½ in. (13 mm) cement board over a single layer of 5/8 in. (16 mm) gypsum board, attached to 7/8 in. (22 mm) offset metal furring strips. Particular care was taken so that all ceiling and partition wall seams were filled with chemically-setting type joint compound to prevent leakage into the interstitial space between the ceiling and the floor above. After construction of the ceiling was complete, a dry-standpipe deluge system was installed with one head in each burn room to provide emergency suppression. During an experiment, a 2.5 in. (104 mm) ball valve fitting was attached and charged from a nearby hydrant. Figure C-5 was taken during the process of replacing "worn out" ceiling panels and shows the additional construction implemented in the burn room as well as the deluge sprinkler head.

Windows and exterior doors were constructed to be non-combustible. Windows were fabricated from 0.25 in. (10 mm) thick steel plate and the exterior doors were of prefabricated hollow-core steel design. The windows on the first floor were 30 in. (0.76 m) width x 36 in. (0.91 m) height and 36 in. (0.91 m) width x 40 in. (1.02 m) height on the second floor. Exterior doors were 35.8 in. (0.88 m) width x 80.5 in. (2.03 m) height. There were no doors attached to the doorways inside the structure. Figure C-6 shows the construction of the burn prop windows as well as the NFPA 1403-compliant latch mechanism. Figure C-7 is a picture of the interior of the burn prop taken just outside the burn compartment, showing the construction of the ceiling, interior doorway construction, gypsum wing wall and the joint compound used to seal seams in the ceiling and walls.

Instrumentation

After construction, the instrumentation to measure the propagation of products of combustion was installed throughout the burn prop. The instrumentation plan was designed to measure gas temperature, gas concentrations, heat flux, visual obscuration, video, and time during the experiments. The data were recorded at intervals of 1 s on a computer based data acquisition system. A schematic plan view of the instrumentation arrangement is shown in Figure C-8.

Table C-1 gives the locations of all of the instruments. Measurements taken prior to the compartment fire experiments were length, wood moisture content, fuel mass and weather conditions (relative humidity, temperature, wind speed and direction). Gas temperatures were measured with two different constructs of type K (Chromel-Alumel) thermocouples. All thermocouples outside the burn compartments were fabricated from 30 gauge glass-wrapped thermocouple wire. Vertical arrays of three thermocouples were placed near the front door on the north side and south sides of the stairwell on the first floor. On the second floor, vertical arrays of eight thermocouples were placed near the center of each target room. Inside the burn compartments, seven 3.2 mm (0.125 in.) exposed junction thermocouples and 0.76 m (30 in.) SUPER OMEGACLAD XL® sheathed thermocouple probes were arranged in a floor-to-ceiling array. Figure C-9 shows the vertical array in the burn

Figure C-4: Fireproofing added to structural steel

Figure C-5: Additional construction of burn room walls and ceiling and deluge sprinkler head.

Figure C-6: Window & Latch Construction

Figure C-7: Interior View of Burn Prop

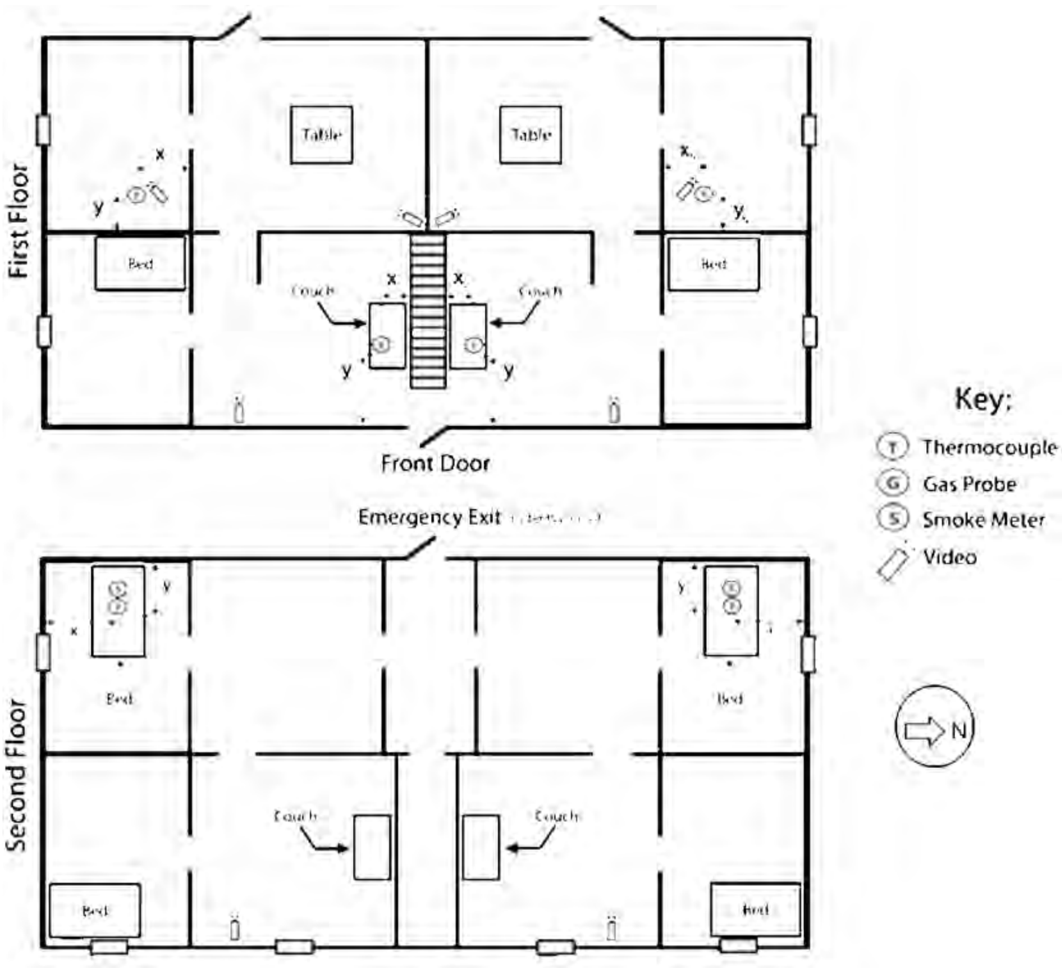


Figure C-8: Instrumentation & Furniture Prop Layout

compartment. Type K thermocouple probes were chosen because of their ability to withstand high temperature, moisture and physical abuse resulting from physical contact with hose streams and firefighters. To protect the extension wire and connectors from the effects of heat and water, through-holes were drilled in the burn compartment walls and the sheaths were passed through from the adjacent compartment. To prevent leakage through the holes, all void spaces were tightly packed with mineral wool. Inside the burn compartment the end of each probe was passed through an angle iron stand, and fastened to the floor and ceiling to provide additional protection from physical contact with firefighters and to ensure that the measurement location remained fixed throughout the experiments. In consideration of the risk associated with heating the open web steel joists, additional thermocouples were placed above each burn compartment to monitor the temperature of the interstitial space.

Table C-1: Detailed locations of instruments within respective rooms

Floor	Instrument	X_S [m]	Y_S [m]	Z_S [m]	X_N [m]	Y_N [m]	Z_N [m]	X_C [m]	Y_C [m]	Z_C [m]
1	**Thermocouple**	0.76	0.51	0.3, 0.61, 0.91, 1.22, 1.52, 1.83, 2.13	0.76	0.51	0.3, 0.61, 0.91, 1.22, 1.52, 1.83, 2.13	Find	Find	0.91, 1.52, 2.41
	HF Gauge 1		N/A		0.91	0.91	0.17			
	HF Gauge 2				0.5	0.66	1			
2	**Thermocouple**	1.83	0.91	0.3, 0.61, 0.91, 1.22, 1.52, 1.83, 2.13, 2.41	1.83	0.91	0.3, 0.61, 0.91, 1.22, 1.52, 1.83, 2.13, 2.41		N/A	
	Smoke Meter	1.7	0.49	1.52	1.64	0.43	1.5			
	Gas Probe	1.83	0.91	1.7	1.83	0.91	1.52			

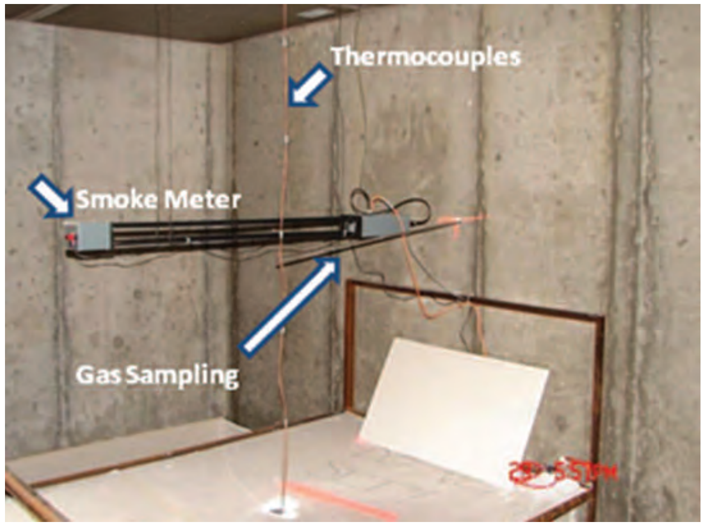


Figure C-9: Burn Room Thermocouple Array **Figure C-10: Target Room Instrument Cluster**

Gas concentrations were sampled at the same location in each target room. Both gas probes were plumbed to the same analyzer and isolated using a switch valve; gas was only sampled at one location during any given test. The gas sampling points were located in the center of the West wall (C Side) of both rooms, 1.5 m (5 ft.) above the floor. The sampling tubes were connected to a diaphragm pump which pulled the gas samples through stainless steel probes into a sample conditioning system designed to eliminate moisture in the gas sample. The dry gas sample was then piped to the gas analyzer setup. In all of the experiments, oxygen was measured using a paramagnetic analyzer and carbon monoxide and carbon dioxide were measured using a non-dispersive infrared (NDIR) analyzer. One floor-to-ceiling thermocouple array was also co-located with each sample port inlet.

Schmidt-Boelter heat flux gauges were placed in the North burn room. One gauge was located 1.0 m (3.3 ft.) above the floor and was oriented towards the fire origin (waste basket). This heat flux gauge was placed to characterize the radiative heat flux at the face piece level that would be experienced by a firefighter inside the room. A second flux gauge was placed on the floor in order to characterize the radiative heat flux from the upper layer and to make an estimate of how close the room was to flashing over with respect to time from ignition (using the common criteria of flashover occurring at ~20kW/m^2 at the floor level). The heat flux gauges were co-located with the thermocouple probe array.

Figure C-11: Non-combustible "Prop" Table

All length measurements were made using a steel measuring tape. Wood moisture content measurements were taken using a non-insulated-pin type wood moisture meter. Fuel mass was measured prior to each experiment using a platform-style heavy duty industrial scale. Mass was not measured after each experiment because of the absorption of fire suppression water. Publicly accessible Davis Vantage Pro2 weather instrumentation (available via http://www.wunderground.com) located approximately two miles from the experimentation site was used to collect weather data in five minute intervals for the each day that the experiments were conducted. Figure C-10 is a photograph of the West wall of the North target room, showing the thermocouple array, the smoke obscuration meter, and a gas sampling probe used during the phase two experiments. The layout is identical to that in the South target room.

Non-combustible "prop" furniture was fabricated from angle iron stock and gypsum wallboard. The purpose of the furniture was twofold. The furniture was placed inside the burn prop to simulate realistic obstacles which obscure the search paths and hose stream advancement. The second use for the furniture was so that measurement instrumentation could be strategically placed within the frame of the furniture. This served to protect instrumentation from physical damage as a result of contact with firefighters and their tools. Figure C-11 shows an example of a table placed outside the burn room.

All instruments were wired to a centralized data collection room, shown in Figure C-12, which was attached as a separate space on one side of the building. This ensured physical separation for the data collection personnel from the effects of the fire, while minimizing the wire and tube lengths to the data logging equipment. Note that the roof of the instrument room was designed to serve as an additional means of escape for personnel from the second floor of the burn prop through a metal door. A railing was installed in order to minimize the fall risk in the event that the emergency exit was required.

Outside

Inside

Figure C-12: Instrumentation Room

Table C-2: Dimensions and Mass of Furniture for Room and Contents Tests

Furniture	Width [m]	Depth [m]	Height [m]	Mass [kg]	Material
Couch	1.8	0.8	0.9	58.1	See D-3
Dresser	1.8	0.5	0.6	72.3	Laminated Particle Board
Nightstand	0.5	0.6	0.61	22.7	Laminated Particle Board
Chair	0.5	0.7	0.6	9.2	Wood, Fabric, and Polyurethane Foam
	Back cushion = 0.1m, Bottom cushion = 0.07m				
Blanket	1.8	-	2.4	1.3	100 % Cotton
Body Pillow	0.5	-	1.4	1.3	100 % cotton cover, polyester fill
Trash Can	0.4	0.3	0.4	1.3	Polypropylene
Towel	0.8	-	1.4	0.4	100 % Cotton
Wallboard	1.2	0.003	2.4	9.0	MDF

Table C-3: Materials in Couch

Body:	Resinated dyed fiber (unknown material) 3 %
	PU foam pad 46%
	Waste fiber batting (unknown material) 26 %
	Polyester fiber batting 25 %
Cushions:	PU foam pad 86 %
	Polyester fiber batting 14 %

Time-to-Task Data Collection Chart

Date ______________ Start Time __________ End Time (all task complete) __________

Timer Name ____

Task	Start Time	Completion Time	Duration
Stop at Hydrant-- Wrap Hose			
Position Engine 1			
Conduct Size-up - 360° lap - Transmit report - establish command			
Engage Pump			
Position attack line (stop time – at front door)			
Establish 2-in-2-out			
Charge Hydrant – supply attack Engine			
Establish RIT			
Gain/Force Entry			
Advance Line (stop time –water on fire)			
Deploy Back up line (stop time at front door)			
Advance Back up line/protect stairwell (start time at front door – Stop at stairwell)			
Conduct Primary Search			
Ground Ladders in Place			
Horizontal Ventilation (ground)			
Horizontal Ventilation (2nd story)			
Control Utilities (interior)			
Control Utilities (exterior)			
Conduct Secondary Search			
Check for Fire Extension (walls)			
Check for Fire Extension (ceiling)			
Mechanical Ventilation			

Company Protocols: Crew Size of 2

(10 total personnel on scene)

PLUS 4 RIC – 1403 = total 14 needed

Tasks/Company	Engine 1/2	Truck 1/2	Engine 2/2	Battalion Chief/ Aide	Engine 3/2
Arrive on Scene - Arrive/ stop at hydrant - Position engine ———————— - Layout report - On-scene report - Conduct size-up – 360° lap – incident action plan – offensive – detail incident (situation report) - Transmit size-up to responding units - Transfer command to chief	Driver Officer -	-Arrive - 360° lap		- Arrives - Assumes Command - Evaluates Resources - Establishes Command post - Evaluates exposure problems - Directs hose positioning - Coordinates Units - Transmits Progress reports - Changes strategy - Orders, records, and transmits results of primary and secondary searches - Declares fire under control	
Establish Supply line - Hydrant-Drop line (wrap) - Position engine - Pump engaged - 4" straight lay - ---------------- - Supply attack engine	Driver/O Driver/O Driver/O	Position Truck	-Dry Lay – 2nd engine takes hydrant - Charged hydrant – Supply attack engine Driver		
Position attack line - Flake - Charge - Bleed - ---------------- - Advance	Officer – (Not interior—just front door) Officer	Officer			
Establish - 2 in – 2 out (Initial RIT)		O/D			
Establish RIT (Dedicated)		O/D (performs all RIT duties)			

Tasks/Company	Engine 1/2	Truck 1/2	Engine 2/2	Battalion Chief/ Aide	Engine 3/2
Gain/ Force Entry		O/D			
Advance Line - scan search fire room - suppression	Officer (if officer commits then he must pass command)		Officer		
Deploy Back-up Line and protect stairwell					O/D
Complete Primary Search (in combo with Fire Attack) Search Fire Floor Search other Floors					O/D
Ventilation (vent for fire or vent for life) - Horizontal - Ventilation		Driver/Officer			
Ground Laddering – 2nd story windows, front and side, for firefighter means of egress and for vertical ventilation – 24'/28' and roof ladder in case of vertical vent.		Driver /Officer			
Control Utilities (Interior and exterior)					Driver/Officer
Conduct Secondary Search - Search Fire Floors - Search other Floors Check for Fire Extension Open ceiling walls near fire on fire floor Check floor above for fire extension - wall breech - ceiling breech	Officer Officer		Officer Officer		 O/D
Mechanical Ventilation		Driver/Officer			

Company Protocols: Crew Size of 3

(14 total personnel on scene)

PLUS 4 RIC – 1403 = total 18 needed

Tasks/Company	Engine 1/3	Truck 1/3	Engine 2/3	Battalion Chief/ Aide	Engine 3/2
Arrive on Scene - Arrive/ stop at hydrant - Position engine ________________ - Layout report - On-scene report - Conduct size-up – 360º lap – incident action plan – offensive – detail incident (situation report) - Transmit size-up to responding units - Transfer command to chief	 Driver Officer -	-Arrive - 360 degree lap		- Arrives - Assumes Command - Evaluates Resources - Establishes Command post - Evaluates exposure problems - Directs hose positioning - Coordinates Units - Transmits Progress reports - Changes strategy - Orders, records, and transmits results of primary and secondary searches - Declares fire under control	
Establish Supply line - Hydrant-Drop line (wrap) - Position engine - Pump engaged - 4" straight lay - ---------------- - Supply attack engine	Driver Driver Driver	Position Truck	Dry Lay – 2nd engine takes hydrant Charged hydrant – Supply attack engine Driver		
Position attack line - Flake - Charge - Bleed - Advance	D/RB				
Establish - 2 in – 2 out (Initial RIT)		O/RB			
Establish RIT (Dedicated)			O/RB— advance by foot to get to point of entry – performs all RIT duties		

Tasks/Company	Engine 1/3	Truck 1/3	Engine 2/3	Battalion Chief/ Aide	Engine 3/3
Gain/ Force Entry		O/RB			
Advance Line - scan search fire room - suppression	O/RB (if officer commits then he must pass command)				
Deploy Back-up Line and protect stairwell					O/RB
Complete Primary Search (in combo with Fire Attack) Search Fire Floor Search other Floors		O/ RB -			
Ventilation (vent for fire or vent for life) - Horizontal - Ventilation		Driver			Driver
Ground Laddering – 2nd story windows, front and side, for firefighter means of egress and for vertical ventilation – 24'/28' and roof ladder in case of vertical vent.		Driver			Driver
Control Utilities (Interior and exterior)		Driver (exterior) O/RB (Interior)			Driver (exterior)
Conduct Secondary Search - Search Fire Floors - Search other Floors					O/RB
Check for Fire Extension Open ceiling walls near fire on fire floor Check floor above for fire extension - wall breech - ceiling breech	O/RB	O/RB			
Mechanical Ventilation		Driver			Driver

Company Protocols: Crew Size of 4

Total on scene = 18

PLUS 4 RIC – 1403 = total 22 needed

Tasks/Company	Engine 1/4	Truck 1/4	Engine 2/4	Battalion Chief/ Aide	Engine 3/4
Arrive on Scene - Arrive/ stop at hydrant - Position engine ——————— - Layout report - On-scene report - Conduct size-up – 360º lap – incident action plan – offensive – detail incident (situation report) - Transmit size-up to responding units - Transfer command to chief	Driver Officer -	-Arrive - 360 degree lap		- Arrives - Assumes Command - Evaluates Resources - Establishes Command post - Evaluates exposure problems - Directs hose positioning - Coordinates Units - Transmits Progress reports - Changes strategy - Orders, records, and transmits results of primary and secondary searches - Declares fire under control	
Establish Supply line - Hydrant-Drop line (wrap) - Position engine - Pump engaged - 4" straight lay - ---------------- - Supply attack engine (1 3/4")	Driver Driver Driver	Position Truck	-Dry Lay – 2nd engine takes hydrant Charged hydrant – Supply attack engine Driver		
Position attack line - Flake - Charge - Bleed - Advance	RB/Nozzle LB/Flake Both advance line for fire attack				
Establish - 2 in – 2 out (Initial RIT)		D/LB			
Establish RIT (Dedicated)			O/LB/RB— advance by foot to get to point of entry – performs all RIT duties		

Tasks/Company	Engine 1/4	Truck 1/4		Battalion Chief/ Aide	Engine 3/4
Gain/ Force Entry		O/RB			
Advance Line - scan search fire room - suppression	RB/LB Officer – not on line (if officer commits then he must pass command)				
Deploy Back-up Line and protect stairwell					O/RB
Complete Primary Search (in combo with Fire Attack) Search Fire Floor Search other Floors		Officer and RB -			
Ventilation - Horizontal - Ventilation		Driver and LB			
Ground Laddering – 2nd story windows, front and side, for firefighter means of egress and for vertical ventilation – 24'/28' and roof ladder in case of vertical vent.		Driver /LB			
Control Utilities (Interior and exterior) Conduct Secondary Search - Search Fire Floors - Search other Floors		Driver/LB (control exterior) O/RB (control interior)			D/LB
Check for Fire Extension Open ceiling walls near fire on fire floor Check floor above for fire extension - wall breech - ceiling breech	O/RB	O/RB			
Mechanical Ventilation		D/LB			

Company Protocols: Crew Size of 5

D/O/LB/RB/CB Total on scene = 22

PLUS 4 RIC – 1403 = total 26 needed

Tasks/Company	Engine 1/5	Truck 1/5	Engine 2/5	Battalion Chief/ Aide	Engine 3/4
Arrive on Scene - Arrive/ stop at hydrant - Position engine ________________ - Layout report - On-scene report - Locate Fire - Conduct size-up – 360º lap – incident action plan – offensive – detail incident (situation report) - Transmit size-up to responding units - Transfer command to chief	Driver Officer -	-Arrive - 360 degree Size up.		- Arrives - Assumes Command - Evaluates Resources - Establishes Command post - Evaluates exposure problems - Directs hose positioning - Coordinates Units - Transmits Progress reports - Changes strategy - Orders, records, and transmits results of primary and secondary searches - Declares fire under control	
Establish Supply line - Hydrant-Drop line (wrap) - Position engine - Pump engaged - 4" straight lay - ---------------- - Supply attack engine (1 3/4")	Driver Driver Driver	Position Truck	-Dry Lay – 2nd engine takes hydrant Charged hydrant – Supply attack engine Driver		
Position attack line - Flake - Charge - Bleed - Advance	RB/Nozzle LB/Flake CB/ Control --------------- Advance line for fire attack ---------------- The Officer responsibility is to supervise hose stretch /monitor safety and continually survey the scene				
Establish - 2 in – 2 out (Initial RIT)		D/LB			

Tasks/Company	Engine 1/5	Truck 1/5	Engine 2/5	Battalion Chief/ Aide	Engine 3/5
Establish RIT (Dedicated)			O/LB/RB— advance by foot to get to point of entry – performs all RIT duties		
Gain/ Force Entry		O/RB/CB			
Advance Line - scan search fire room - suppression	RB/LB/CB Officer – not on line (if officer commits then he must pass command)				
Insures first line flowing water— Deploy Back-up Line and protect stairwell (1 ¾")					O/RB/CB
Complete Primary Search (in combo with Fire Attack) Search Fire Floor – Search other floors-		Officer and RB/CB			
Ventilation (vent for fire or vent for life) - Horizontal - Vertical		Driver and LB			
Ground Laddering – 2nd story windows, front and side, for firefighter means of egress and for vertical ventilation – 24'/28' and roof ladder in case of vertical vent.		Driver /LB			
Control Utilities after search, force entry, venting and fire extinguished (Interior and exterior)		Driver/LB (control exterior) O/RB/CB (control interior)			
Conduct Secondary Search -Fire Floor -Primary and secondary search of entire floor above		D/LB			D/LB O/RB/CB
Check for Fire Extension Open ceiling walls near fire on fire floor Check floor above for fire extension wall breech ceiling breech-	O/RB				O/RB/CB
Mechanical Ventilation					

Appendix E: Statistical Analysis of Time to Task Test Data

Identifying Statistically Significant Differences in Crew Size and Stagger on a Number of Task Timings Using Regression Analyses of Times (Start, End and Duration) on Crew Size and Stagger

	Crew Size			Stagger	Crew Size	Stagger
Task-Based Measure of Time	**3 vs. 2**	**4 vs. 3**	**5 vs. 4**		**5/4 vs. 3/2**	
Total time	X*	X			X	
Conduct size up (start)			X		X	
Conduct size up (end)					X	
Conduct size up (duration)						
Position attack line (start)	X				X	
Position attack line (duration)		X			X	
Establish 2 in 2 out (end)		X		X	X	X
Establish RIT (end)	na	na	na	na	na	na
Gain forced entry (start)		X			X	
Advance line (start)	X	X			X	
Advance line (end)	X		X		X	
Deploy backup line (start)					X	X
Deploy backup line (end)				X		X
Advance backup line (start)				X		X
Advance backup line (end)				X		X
Conduct primary search (start)	X	X			X	
Ground ladders in place (end)		X	x	X	X	o
Ground ladders in place (duration)			X	X	X	X
Horizontal ventilation Story 2 window 3 (Start)		X			X	
Horizontal ventilation Story 2 window 3 (End)		X			X	
Horizontal ventilation Story 2 window 2 (Start)		X			X	
Horizontal ventilation Story 2 window 2 (End)		X			X	
Horizontal ventilation Story 2 window 1 (Start)		X			X	
Horizontal ventilation Story 2 window 1 (End)		X			X	
Horizontal ventilation Story 1 window 2 (Start)	o	X			X	
Horizontal ventilation Story 1 window 2 (End)		X			X	
Control utilities (interior) (Start)	X	X			X	
Conduct Secondary Search (Start)	X				X	
Check for Fire Ext (walls) (Start)	X	X			X	
Check for Fire Ext (ceiling) (Start)		X				
Stretch time**	X		o		X	

* An 'X' denotes statistical significance at the 0.05 level; a 'o' denotes significance at the 0.10 level.

Appendix F: All Regression Coefficients

Regression Models of Time to Task (in Seconds) as a Function of Crew Size and Stagger (Standard Errors are in Parentheses underneath coefficients)

		Coefficients				
Measure of Task Time	**Time measured**	**Crew size of 3**	**Crew size of 4**	**Crew size of 5**	**Close Stagger**	**Constant**
Total time		-100.5	**-408.33**	**-402.17**	**-40.83**	**1374.42**
		(50.29)	(50.29)	(50.29)	(35.56)	(39.77)
Conduct size up	Start	**2.5**	**-5.167**	**-18.17**	**-1.25**	**335**
		(5.97)	(5.97)	(5.97)	(4.22)	(4.72)
Conduct size up	Complete	**-5.167**	**-13.17**	**-38.33**	**-12**	**416**
		(13.60)	(13.60)	(13.60)	(9.62)	(10.75)
Conduct size up	Duration	**-7.667**	**-8**	**-20.17**	**-10.75**	**81.04**
		(12.10)	(12.10)	(12.10)	(8.56)	(9.57)
Position attack line	Start	**-63.5**	**-63.5**	**-69.67**	**-11.17**	**408.1**
		(14.09)	(14.09)	(14.09)	(9.96)	(11.14)
Position attack line	Duration	**-16**	**-63.67**	**-61.67**	**5.167**	**160.6**
		(13.79)	(13.79)	(13.79)	(9.75)	(10.90)
Establish 2in - 2 out	Complete	**-6.7E-15**	**-90**	**-90**	**-30**	**355**
		(9.73)	(9.73)	(9.73)	(6.88)	(7.69)
Establish RIT	Complete	**70**	**70**	**70**	**-60**	**435**
		0.00	0.00	0.00	0.00	0.00
Gain forced entry	Start	**-23.5**	**-54**	**-80.83**	**-20.83**	**528.6**
		(19.66)	(19.66)	(19.66)	(13.90)	(15.54)
Advance line	Start	**-54**	**-97.83**	**-123.5**	**-17.5**	**586.3**
		(18.83)	(18.83)	(18.83)	(13.31)	(14.88)
Advance line	Complete	**-61**	**-95.5**	**-134.7**	**-19.08**	**625.5**
		(20.35)	(20.35)	(20.35)	(14.39)	(16.08)
Deploy backup line	Start	**-26**	**-42.67**	**-53.5**	**-96.75**	**641.5**
		(17.11)	(17.11)	(17.11)	(12.10)	(13.53)
Deploy backup line	Complete	**-15.83**	**-56.17**	**-17.5**	**-53.75**	**728.9**
		(33.49)	(33.49)	(33.49)	(23.68)	(26.48)
Advance backup line	Start	**-33**	**-66.83**	**-34.83**	**-63**	**779.7**
		(29.65)	(29.65)	(29.65)	(20.97)	(23.44)
advancebackupline2	Complete	**-34.5**	**-68.17**	**-36.17**	**-63.75**	**784.4**
		(29.73)	(29.73)	(29.73)	(21.02)	(23.50)
conductprimarysearch1	Start	**-147**	**-215.8**	**-211.5**	**0.1667**	**736.1**
		(25.08)	(25.08)	(25.08)	(17.74)	(19.83)
Ground ladders in place	Complete	**-38**	**-196.5**	**-317.8**	**-69.83**	**1168**
		(48.38)	(48.38)	(48.38)	(34.21)	(38.24)
Ground ladders in place	Duration	**-33.83**	**-83.67**	**-185.7**	**-72.08**	**617**
		(48.12)	(48.12)	(48.12)	(34.03)	(38.04)
Horizontal ventilation, second story, window 3	Start	**-53.67**	**-217.8**	**-211**	**-26.59**	**759.1**
		(30.75)	(30.75)	(30.75)	(21.75)	(24.31)
Horizontal ventilation, second story, window 3	Complete	**-64.83**	**-316**	**-353**	**-33.58**	**1088**
		(49.74)	(49.74)	(49.74)	(35.17)	(39.32)
Horizontal ventilation, second story, window 2	Start	**-51.67**	**-265.8**	**-261.2**	**-18.83**	**885.1**
		(37.20)	(37.20)	(37.20)	(26.30)	(29.41)

All Regression Coefficients (CONTINUED)

Regression Models of Time to Task (in Seconds) as a Function of Crew Size and Stagger (Standard Errors are in Parentheses underneath coefficients)

Horizontal ventilation, second story, window 2	Complete	**-53.5**	**-259.8**	**-262.3**	**-13.33**	**931.3**
		(39.97)	(39.97)	(39.97)	(28.26)	(31.60)
Horizontal ventilation, second story, window 1	Start	**-70**	**-316.3**	**-348.8**	**-31.08**	**1038**
		(48.37)	(48.37)	(48.37)	(34.20)	(38.24)
Horizontal ventilation, second story, window 1	Complete	**-51.83**	**-219**	**-214.8**	**-24**	**805.7**
		(33.71)	(33.71)	(33.71)	(23.83)	(26.65)
Horizontal ventilation, first story, window 2	Start	**-87.17**	**-386.3**	**-428.5**	**-44.67**	**1200**
		(45.13)	(45.13)	(45.13)	(31.91)	(35.68)
Horizontal ventilation, first story, window 2	Complete	**-88.5**	**-391.5**	**-423.3**	**-44.17**	**1224**
		(47.02)	(47.02)	(47.02)	(33.25)	(37.17)
Control utilities interior	Start	**-136.5**	**-287.8**	**-300**	**-6.333**	**946.3**
		(45.57)	(45.57)	(45.57)	(32.22)	(36.02)
Control utilities exterior	Start	**6.667**	**-281.8**	**-312.8**	**-38.17**	**1063**
		(70.21)	(70.21)	(70.21)	(49.65)	(55.51)
Conduct secondary search	Start	**-92.5**	**-143**	**-152.7**	**-28.25**	**846**
		(38.97)	(38.97)	(38.97)	(27.56)	(30.81)
Check for fire extension walls	Start	**-453.8**	**-535.3**	**-608.7**	**-38.25**	**1155**
		(38.28)	(38.28)	(38.28)	(27.07)	(30.26)
Check for fire extension ceiling	Start	**-206.3**	**-349.7**	**-292.7**	**-2.833**	**1086**
		(48.29)	(48.29)	(48.29)	(34.14)	(38.17)

Regression Models of Time to Task (in Seconds) as a Function of Combined Crew Size and Stagger (Standard Errors appear in Parentheses)

Measure of Task Time*	Time measured	Coefficients: Crew size of 4/5 vs. 3/2	Coefficients: Close Stagger	Coefficients: Constant
Total time		**-355**	**-40.83**	**1324.00**
		(37.23)	(37.23)	(32.24)
Conduct size up	Start	**-12.92**	**-1.25**	**336.2**
		(4.50)	(4.50)	(3.90)
Conduct size up	Complete	**-23.17**	**-12**	**413.4**
		(9.97)	(9.97)	(8.64)
Conduct size up	Duration	**-10.25**	**-10.75**	**77.21**
		(8.44)	(8.44)	(7.31)
Position attack line	Start	**-34.83**	**-11.17**	**376.3**
		(13.66)	(13.66)	(11.83)
Position attack line	Duration	**-54.67**	**5.167**	**152.6**
		(9.60)	(9.60)	(8.31)
Establish 2in - 2 out	Complete	**-90**	**-30**	**355**
		(6.55)	(6.55)	(5.67)
Establish RIT	Complete	**35**	**-60**	**470**
		(10.80)	(10.80)	(9.35)
Gain forced entry	Start	**-55.67**	**-20.83**	**516.8**
		(14.32)	(14.32)	(12.40)
Advance line	Start	**-83.67**	**-17.5**	**559.3**
		(15.67)	(15.67)	(13.57)
Advance line	Complete	**-84.58**	**-19.08**	**595**
		(17.67)	(17.67)	(15.31)
Deploy backup line	Start	**-35.08**	**-96.75**	**628.5**
		(12.30)	(12.30)	(10.65)
Deploy backup line	Complete	**-28.92**	**-53.75**	**721**
		(23.43)	(23.43)	(20.29)
Advance backup line	Start	**-34.33**	**-63**	**763.2**
		(21.17)	(21.17)	(18.33)
advancebackupline2	Complete	**-34.92**	**-63.75**	**767.1**
		(21.27)	(21.27)	(18.42)
conductprimarysearch1	Start	**-140.2**	**0.1667**	**662.6**
		(28.28)	(28.28)	(24.49)
Ground ladders in place	Complete	**-238.2**	**-69.83**	**1149**
		(37.99)	(37.99)	(32.90)
Ground ladders in place	Duration	**-117.7**	**-72.08**	**600.1**
		(36.37)	(36.37)	(31.49)
Horizontal ventilation, second story, window 3	Start	**-187.6**	**-26.59**	**732.3**
		(22.31)	(22.31)	(19.32)
Horizontal ventilation, second story, window 3	Complete	**-302.1**	**-33.58**	**1056**
		(35.38)	(35.38)	(30.64)

Regression Models of Time to Task (in Seconds) as a Function of Combined Crew Size and Stagger (CONTINUED) (Standard Errors appear in Parentheses)

Horizontal ventilation, second story, window 2	Start	**-237.7**	**-18.83**	**859.3**
		(26.27)	(26.27)	(22.75)
Horizontal ventilation, second story, window 2	Complete	**-234.3**	**-13.33**	**904.6**
		(28.12)	(28.12)	(24.36)
Horizontal ventilation, second story, window 1	Start	**-297.6**	**-31.08**	**1003**
		(34.64)	(34.64)	(30.00)
Horizontal ventilation, second story, window 1	Complete	**-191**	**-24**	**779.8**
		(24.05)	(24.05)	(20.83)
Horizontal ventilation, first story, window 2	Start	**-363.8**	**-44.67**	**1156**
		(33.83)	(33.83)	(29.30)
Horizontal ventilation, first story, window 2	Complete	**-363.2**	**-44.17**	**1180**
		(34.80)	(34.80)	(30.14)
Control utilities interior	Start	**-225.7**	**-6.333**	**878.1**
		(37.23)	(37.23)	(32.25)
Control utilities exterior	Start	**-300.7**	**-38.17**	**1066**
		(47.48)	(47.48)	(41.12)
Conduct secondary search	Start	**-101.6**	**-28.25**	**799.7**
		(29.88)	(29.88)	(25.88)
Check for fire extension walls	Start	**-345.1**	**-38.25**	**927.9**
		(75.46)	(75.46)	(65.35)
Check for fire extension ceiling	Start	**-218**	**-2.833**	**983.1**
		(46.32)	(46.32)	(40.12)
Stretch time = advance line minus position engine	Duration	**-75.7**	**-17.2**	**273.3**
		(16.68)	(16.68)	(14.44)

*** Standard errors are in parentheses below coefficient value**

		Crew size of 3	Crew size of 4	Crew size of 5	Close Stagger	Constant
Stretch time = advance line minus position engine	Duration	**-57.3**	**-86.7**	**-122.0**	**-17.2**	**301.9**
		(19.39)	(19.39)	(19.39)	(13.71)	(15.33)

APPENDIX G: Measurement Uncertainty

The measurements of length, temperature, mass, moisture content, smoke obscuration, and time taken in these experiments have unique components of uncertainty that must be evaluated in order to determine the fidelity of the data. These components of uncertainty can be grouped into two categories: Type A and Type B. Type A uncertainties are those evaluated by statistical methods, such as calculating the standard deviation of the mean of a set of measurements. Type B uncertainties are based on scientific judgment using all available and relevant information. Using relevant information, the upper and lower limits of the expected value are estimated so that the probability that the measurement falls within these limits is essentially 100 %. After all the component uncertainties of a measurement have been identified and evaluated it is necessary to use them to compute the combined standard uncertainty using the law of propagation of uncertainty (the "root sum of squares"). Although this expresses the uncertainty of a given measurement, it is more useful in a fire model validation exercise to define an interval for which the measurement will fall within a certain level of statistical confidence. This is known as the expanded uncertainty. The current international practice is to multiply the combined standard uncertainty by a factor of two (k=2), giving a confidence of 95 %.

Length measurements of room dimensions, openings and instrument locations were taken using a steel measuring tape with a resolution of 0.02 in (0.5 mm). However, measurement error due to uneven and unlevel surfaces results in an estimated uncertainty of ± 0.5 % for length measurements taken on the scale of room dimensions. The estimated total expanded uncertainty for length measurements is ± 1.0 %.

The standard uncertainty of the thermocouple wire itself is 1.1°C or 0.4 % of the measured value, whichever is greater (Omega 2004). The estimated total expanded uncertainty associated with type K thermocouples is approximately ± 15 %. Previous work done at NIST has shown that the uncertainty of the environment surrounding thermocouples in a full-scale fire experiment has a significantly greater uncertainty (Blevins 1999) than the uncertainty inherent with thermocouple design. Furthermore, while a vertical thermocouple array gives a good approximation of the temperature gradient with respect to height, temperatures cannot be expected to be uniform across a plane at any height because of the dynamic environment in a compartment fire. Inaccuracies of thermocouple measurements in a fire environment can be caused by:

- Radiative heating or cooling of the thermocouple bead
- Soot deposition on the thermocouple bead which change its mass, emissivity, and thermal conductivity
- Heat conduction along thermocouple wires
- Flow velocity over the thermocouple bead

To reduce these effects, particularly radiative heating and cooling, thermocouples with smaller diameter beads were chosen. This is particularly important for thermocouples below the interface because the radiative transfer between the surrounding room surfaces will be significantly less uniform than if the thermocouple were in the hot gas layer. It is suggested in [Pitts] that it may be possible to correct for radiative transfer given enough sufficient knowledge about thermocouple properties and the environment. However, measurements of local velocity and the radiative environment were not taken. Additionally, the probes were located away from the burn compartment walls in order to avoid the effects of walls and corners.

The gas measurement instruments and sampling system used in this series of experiments have been demonstrated to have an expanded (k = 2) relative uncertainty of ± 1 % when compared with span gas volume fractions (Matheson). Given the limited set of sampling points in these experiments, an estimated uncertainty of ± 10 % is being applied to the results.

The potential for soot deposition on the face of the water-cooled total heat flux gauges contributes significant uncertainty to the heat flux measurements. Calibration of heat flux gauges was completed at lower fluxes and then extrapolated to higher values and this resulted in a higher uncertainty in the flux measurement. Combining all of component uncertainties for total heat flux resulted in a total expanded uncertainty of -24 % to +13 % for the flux measurements.

Prior to experimentation, ten of the wooden pallets used in the fuel packages were randomly selected for measurement. Two measurements were taken, moisture content and mass. Moisture content was measured using a pin-type moisture meter with a moisture measurement range of 6 % to 40% and an accuracy of <0.5 % of the measured value between 6 % and 12 % moisture content. Mass measurements were made with an industrial bench scale having a range of 0kg to 100 kg, a resolution of 0.1 kg and an uncertainty of ± 0.1 kg.

All timing staff were equipped with the same model of digital stopwatch with a resolution of 0.01 seconds and an uncertainty of ± 3 seconds per 24 hours; the uncertainty of the timing mechanism in the stopwatches is small enough over the duration of an experiment that it can be neglected. There are three components of uncertainty when using people to time fire fighting tasks. First, timers may have a bias depending on whether they record the time in anticipation of, or reaction to an event. A second component exists because multiple timers were used to record all tasks. The third component is the mode of the stimulus to which the staff is reacting: audible (firefighters announcing task updates over the radio) or visual (timing staff sees a task start or stop).

Milestone events in these experiments were recorded both audibly and visually. A test series described in the *NIST Recommended Practice Guide for Stopwatch and Timer Calibrations* found the reaction times for the two modes of stimulus to be approximately the same, so this component can be neglected. Because of the lack of knowledge regarding the mean bias of the timers, a rectangular distribution was assumed and the worst case reaction time bias of 120 ms was used, giving a standard deviation of 69 ms. The standard deviation of the reaction time was assumed to be the worst case of 230 ms. The estimated total expanded uncertainty of task times measured in these experiments is 240 ms.

An additional component of uncertainty exists for the time measurement of the application of water on the fire. In order to measure this time, timing staff were required to listen for radio confirmation that suppressing water had been applied by the interior attack crew. This process required a member of the interior crew to find and manipulate their microphone, wait for the radio to access a repeater, and transmit the message. Because of the lack of knowledge about the distributions of time it takes for each part of this process, all parts are lumped into a single estimate of uncertainty and a rectangular distribution is assumed. This is most reasonably estimated to be 2.5 seconds with a standard deviation of ±2.89 seconds and an expanded uncertainty of ± 5.78 seconds.

Weather measurement uncertainty was referenced to the published user's manual for the instrumentation used. The weather instrumentation has calibration certificates that are traceable to NIST standards. A summary of experimental measurement uncertainty is given in Table G-1.

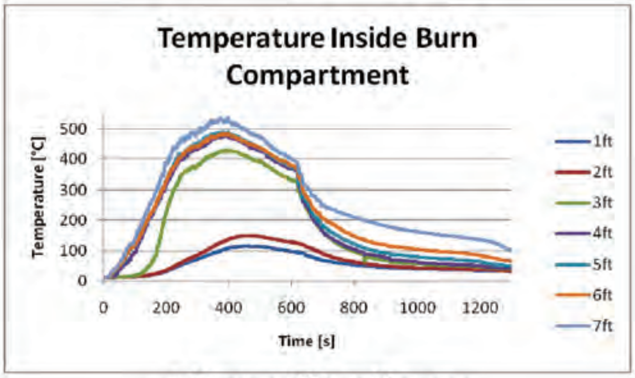
Table G-1: Summary of Measurement Uncertainty

Measurement	Component Standard Uncertainty	Combined Standard Uncertainty	Total Expanded Uncertainty
Length Measurements			
Instrumentation Locations	± 1 %	± 3 %	± 6 %
Building Dimensions	± 1 %		
Repeatability[1]	± 2 %		
Random[1]	± 2 %		
Gas Temperature – Lower Layer			
Calibration	± 1 %	± 8 %	± 15 %
Radiative Cooling	- 5 % to + 0 %		
Radiative Heating	0 % to + 5 %		
Repeatability[1]	± 5 %		
Random[1]	± 3 %		
Wood Moisture Content			
	± 0.5 %	± 0.5 %	± 1%
Wood Pallet Mass			
	± 0.2%	± 0.1%	± 0.1%
Weather			
Relative Humidity	± 3%		
Barometric Pressure	± 0.03" Hg		
Wind Speed	± 5%		
Wind Direction	± 5%		
Outside Temperature	±0.5°C		
Time			
Timer Bias	± 0.069s	± 2.90s	
Reaction Time	± 0.230s		± 5.80 s
Radio Operation	± 2.890s		
Notes: 1. Random and repeatability evaluated as Type A, other components as Type B.			

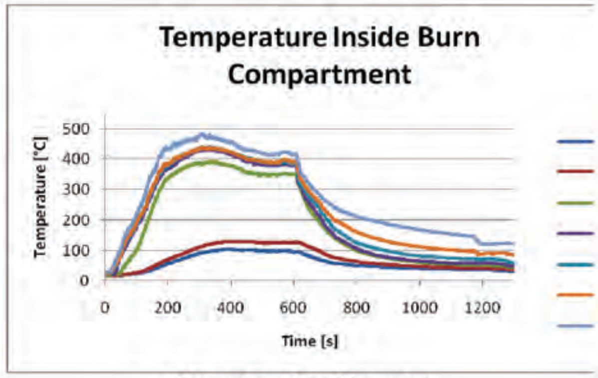
APPENDIX H: Charts of Gas and Temperature Data

Examples of Gas and Temperature Data for Time-to-Task Tests

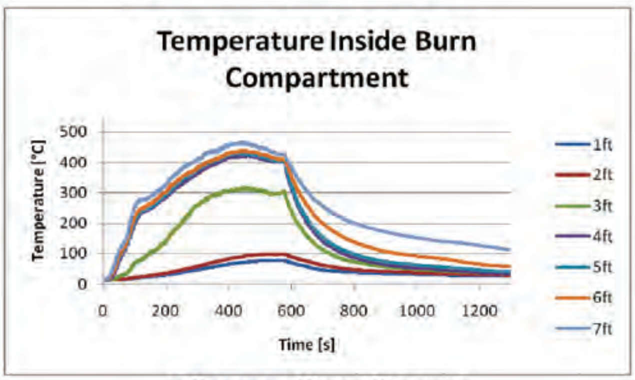
Burn Room Data



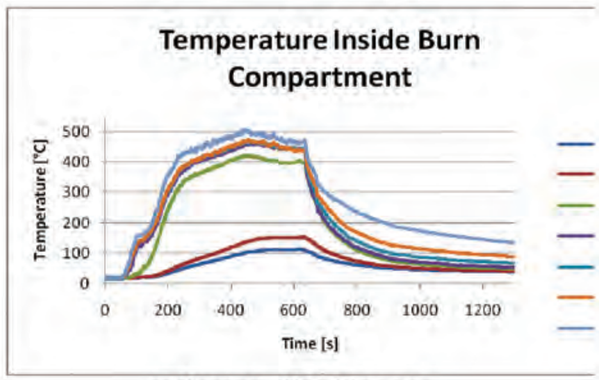
2 Person, Close Stagger



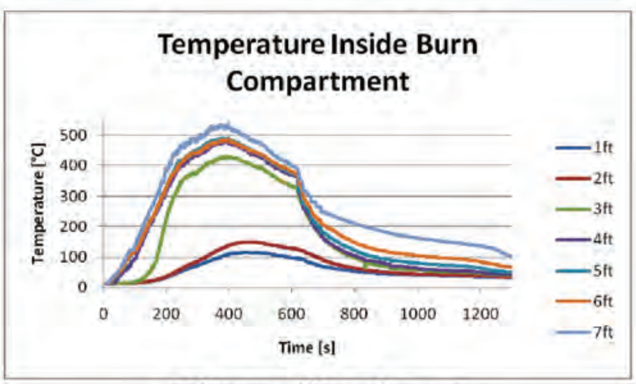
2 Person, Far Stagger



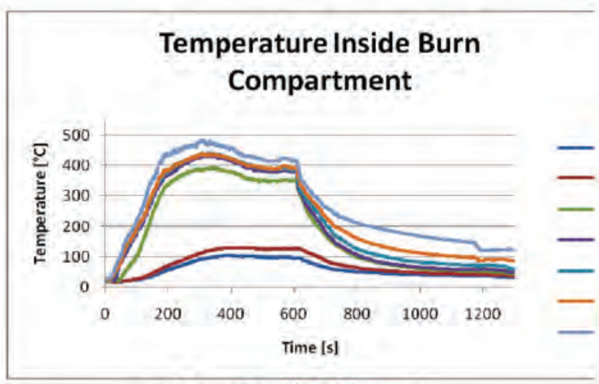
3 Person, Close Stagger



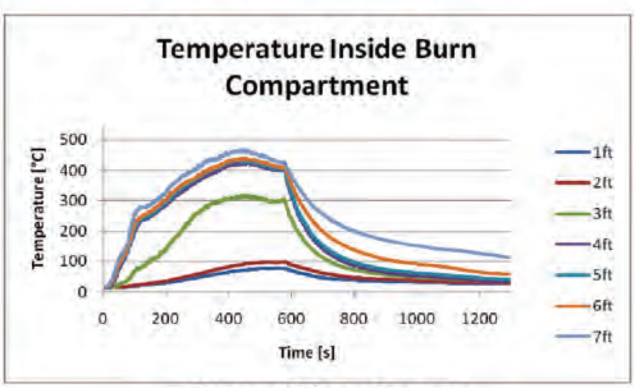
3 Person, Far Stagger



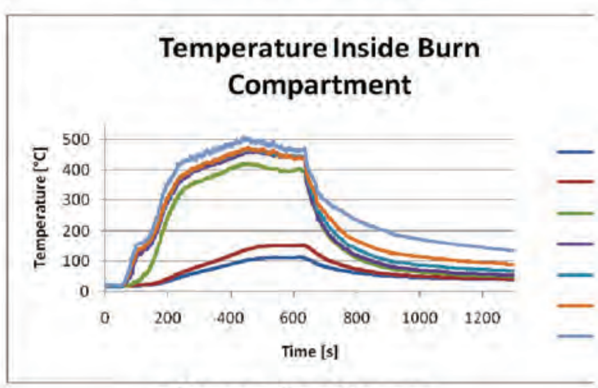
2 Person, Close Stagger



2 Person, Far Stagger

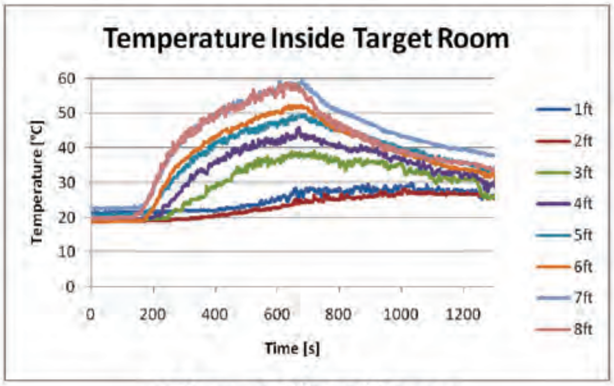


3 Person, Close Stagger

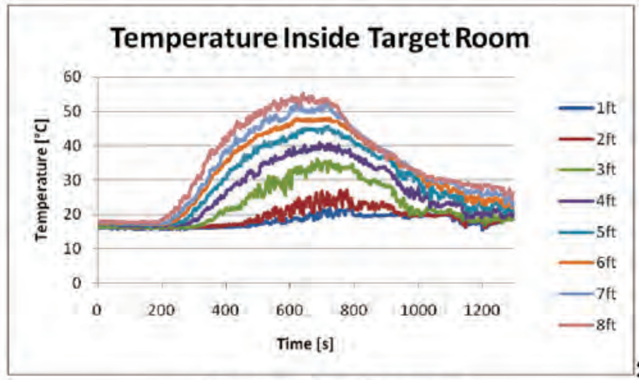


3 Person, Far Stagger

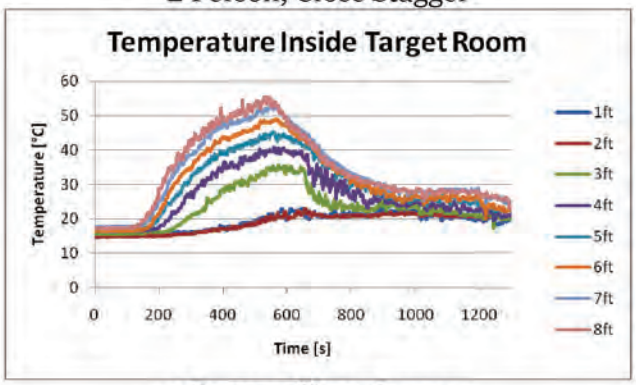
Target Room Data



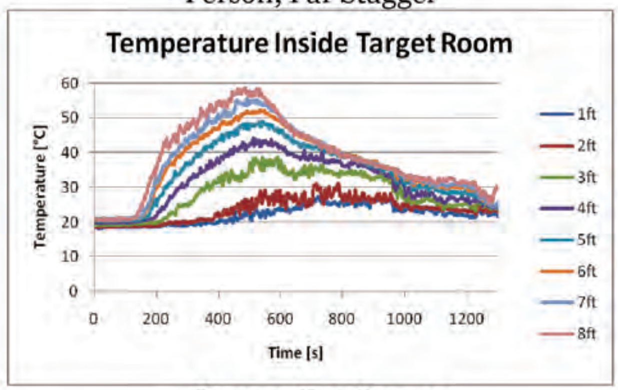
2 Person, Close Stagger



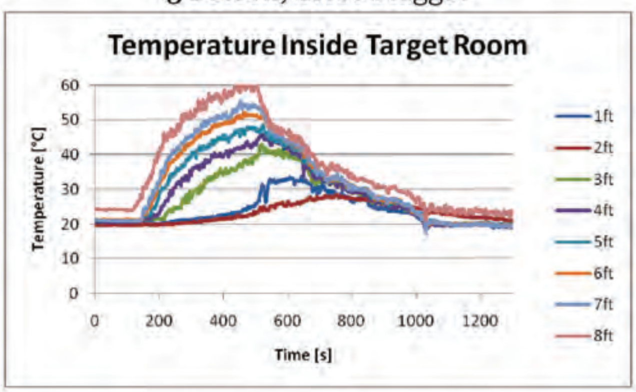
2 Person, Far Stagger

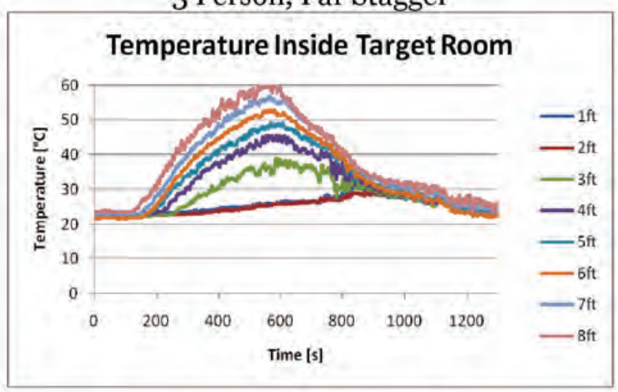


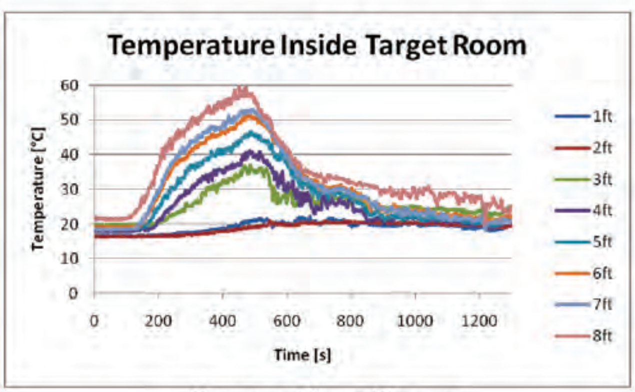
3 Person, Close Stagger



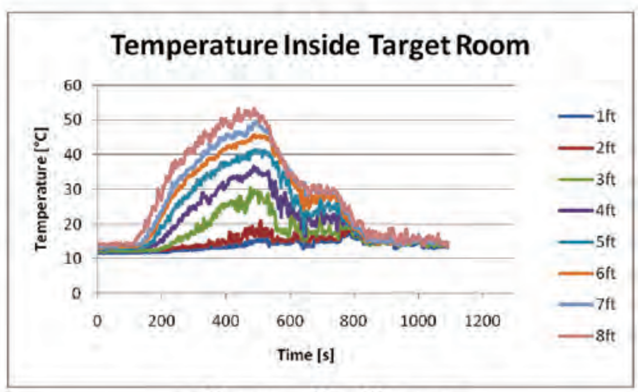
3 Person, Far Stagger





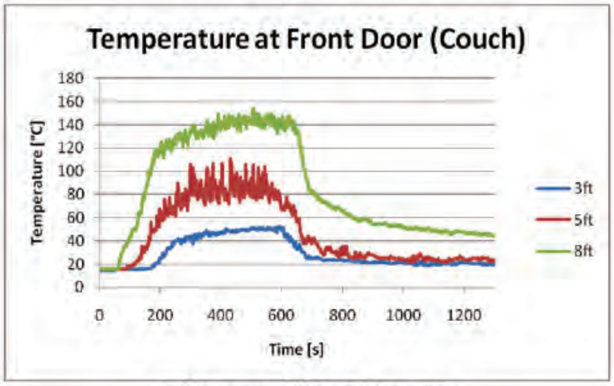


5 Person, Close Stagger

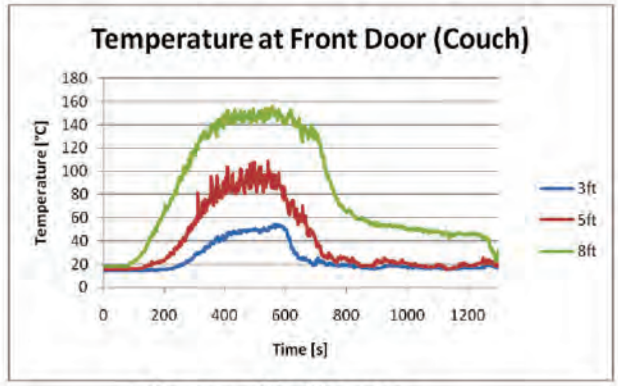


5 Person, Far Stagger

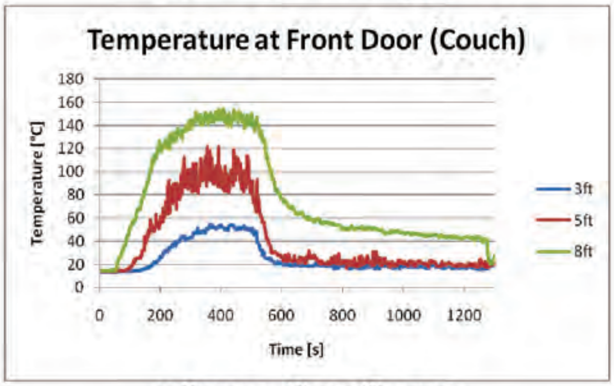
Temperature Near Front Door (Couch)



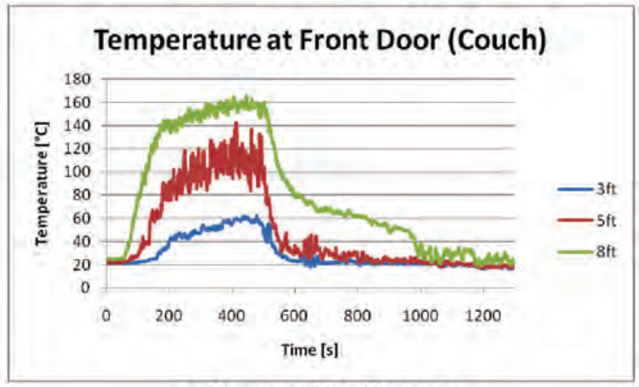
2 Person, Close Stagger



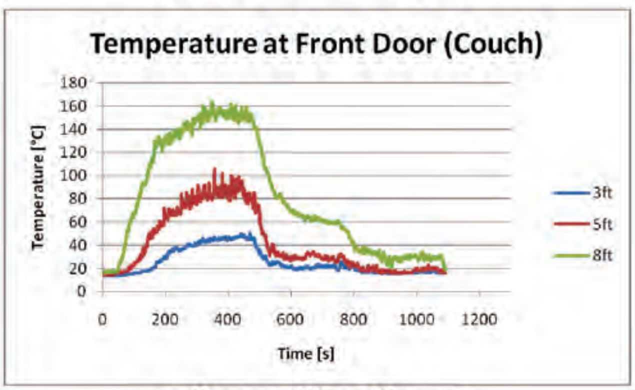
2 Person, Far Stagger



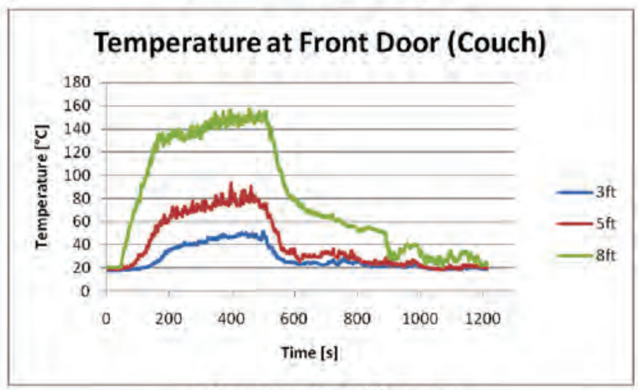
3 Person, Close Stagger



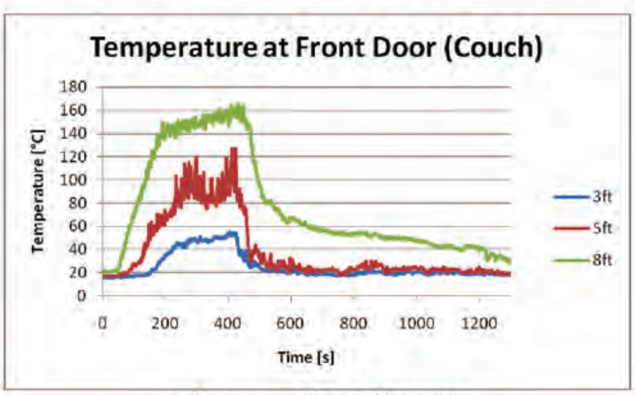
3 Person, Far Stagger



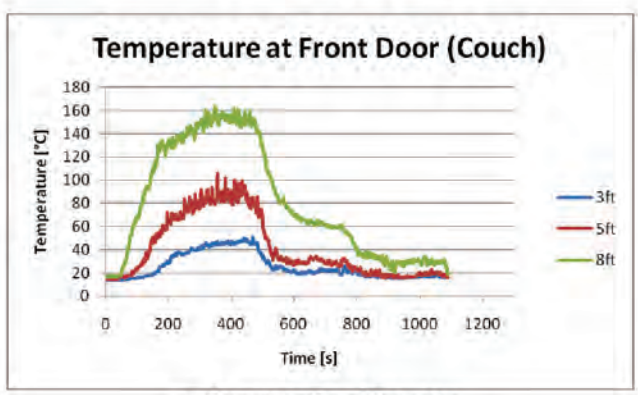
4 Person, Close Stagger



4 Person, Far Stagger



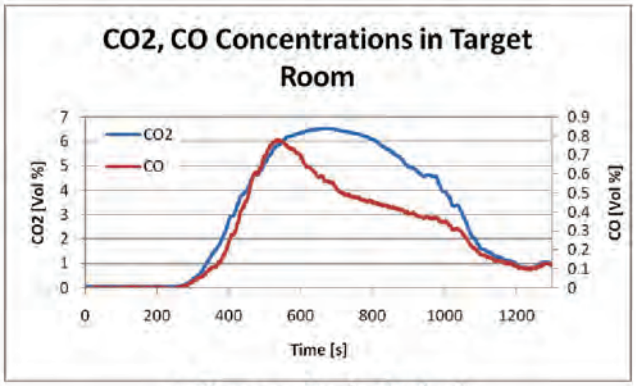
5 Person, Close Stagger



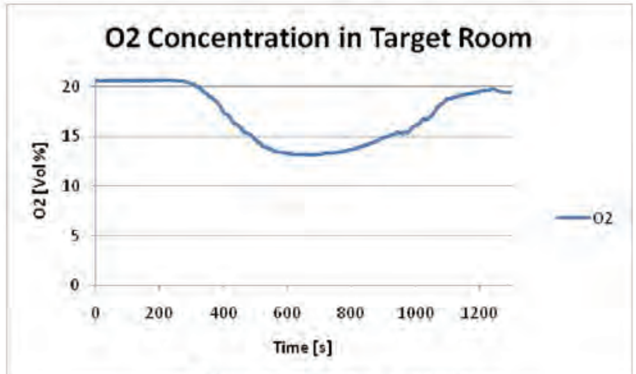
5 Person, Far Stagger

Gas and Temperature Data for Room and Contents Tests

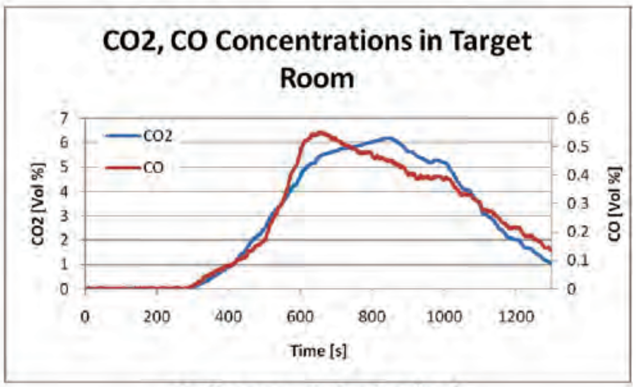
Examples of Gas Data in Target Room



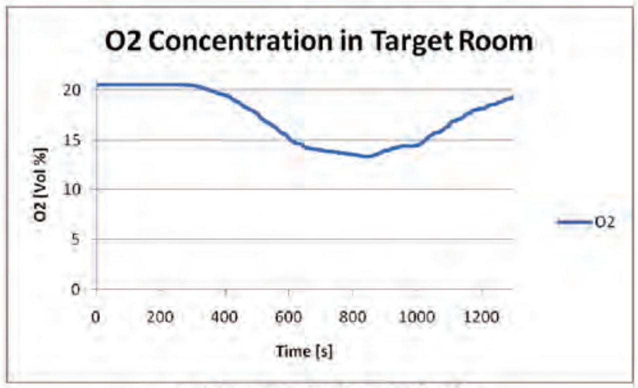
2-Person, Early Arrival



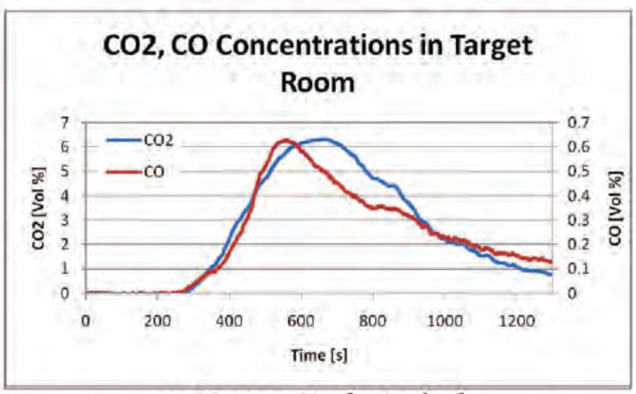
2-Person, Early Arrival



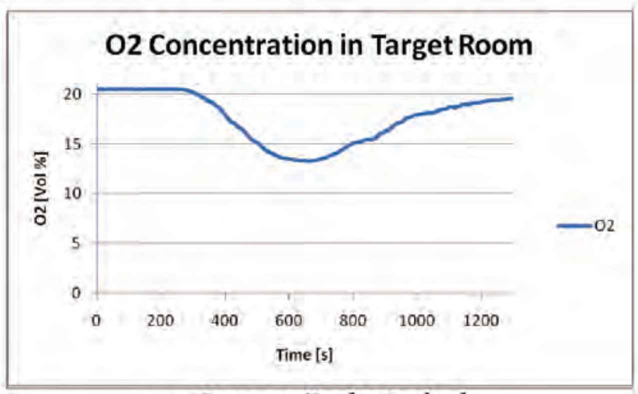
2-Person, Late Arrival



2-Person, Late Arrival



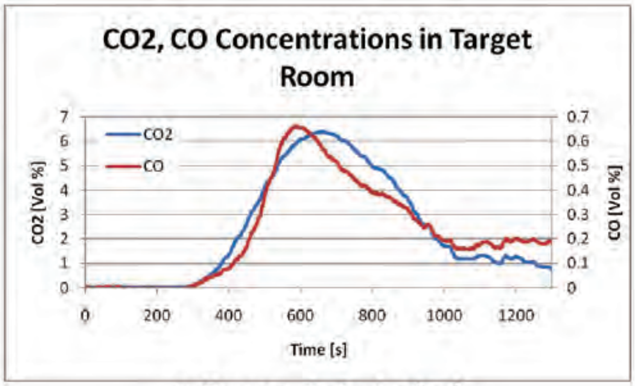
3-Person, Early Arrival



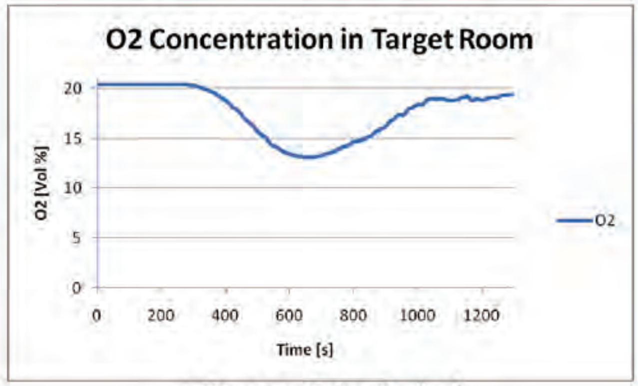
3-Person, Early Arrival

Gas and Temperature Data for Room and Contents Tests

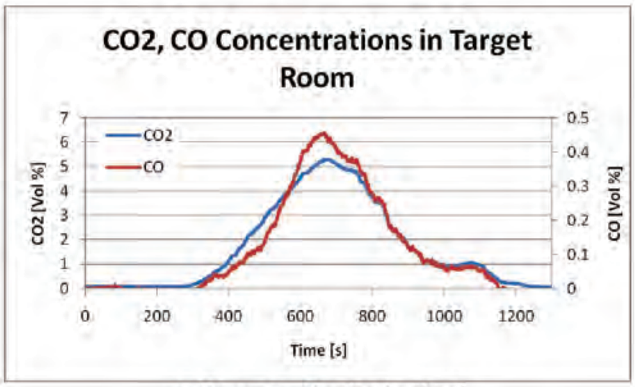
Examples of Gas Data in Target Room



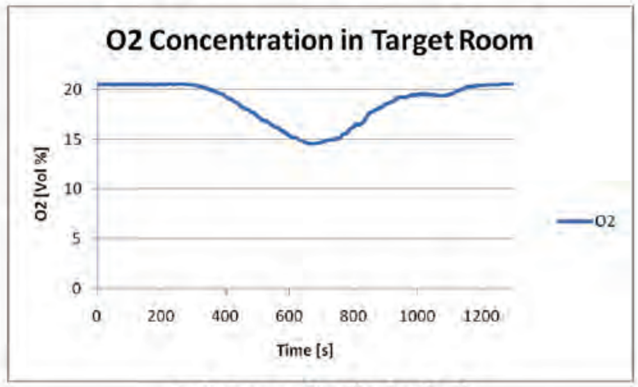
3-Person, Late Arrival



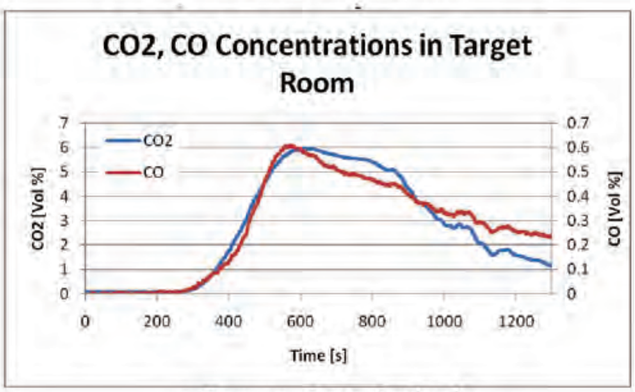
3-Person, Late Arrival



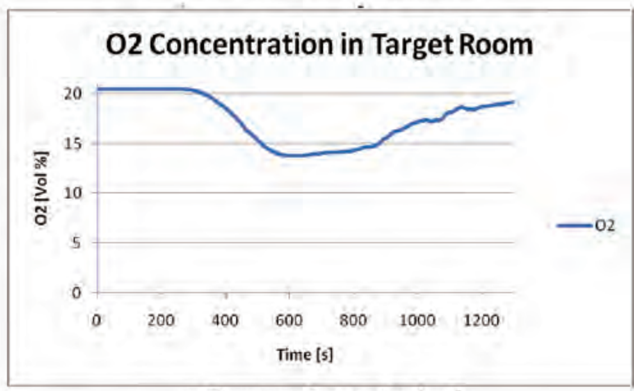
4-Person, Early Arrival



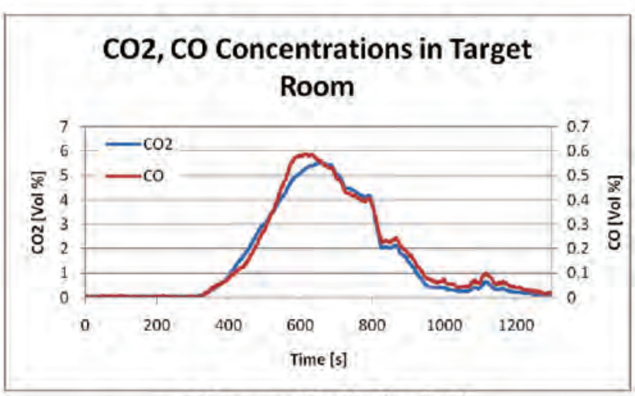
4-Person, Early Arrival



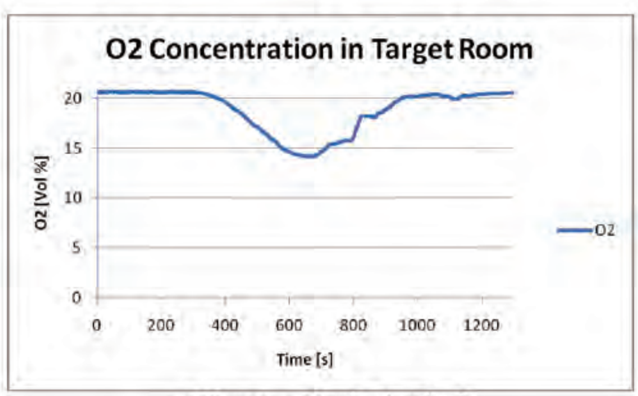
4-Person, Late Arrival



4-Person, Late Arrival

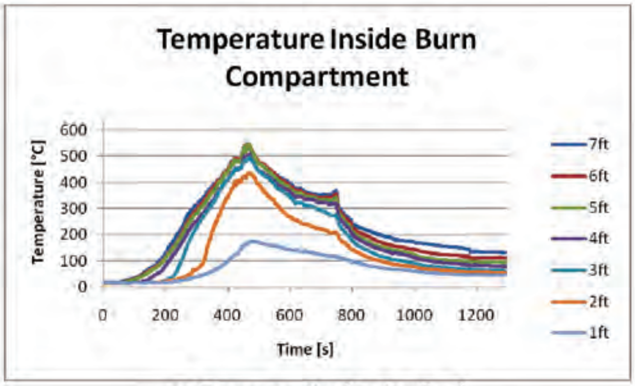


5-Person, Early Arrival

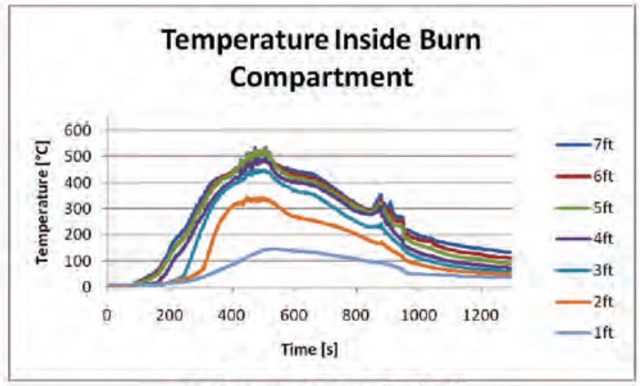


5-Person, Early Arrival

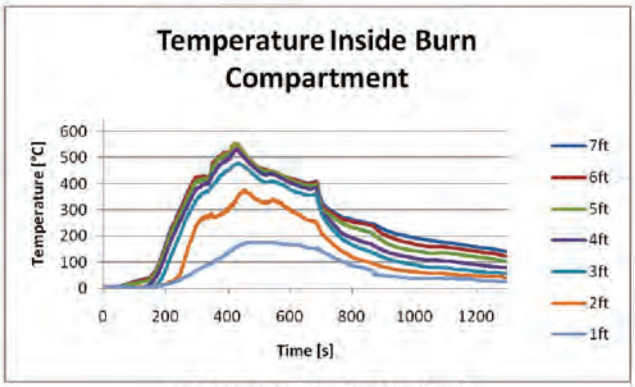
Temperatures in Burn Room



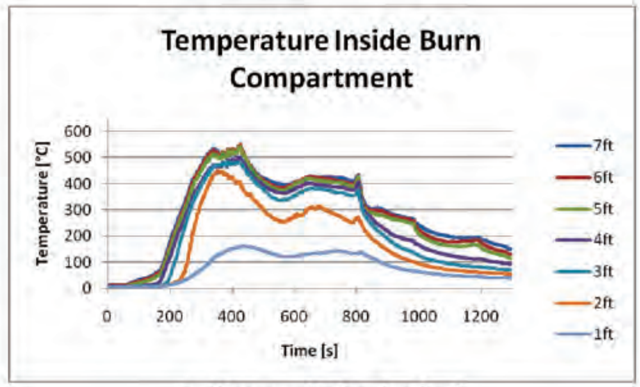
2-Person, Early Arrival



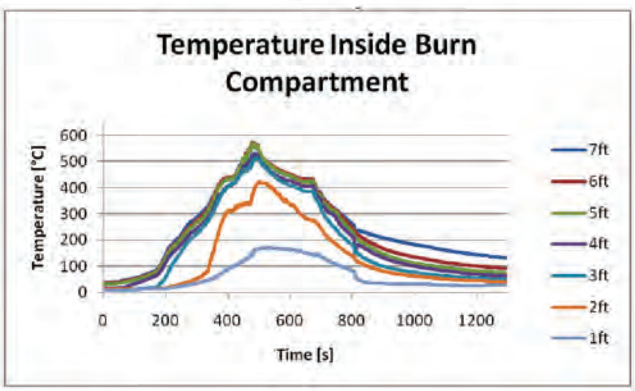
2-Person, Late Arrival



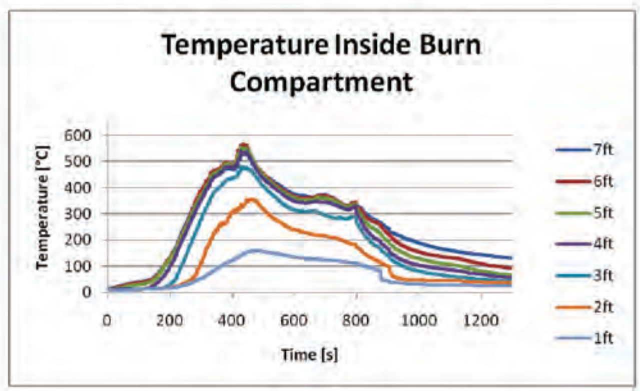
3-Person, Early Arrival



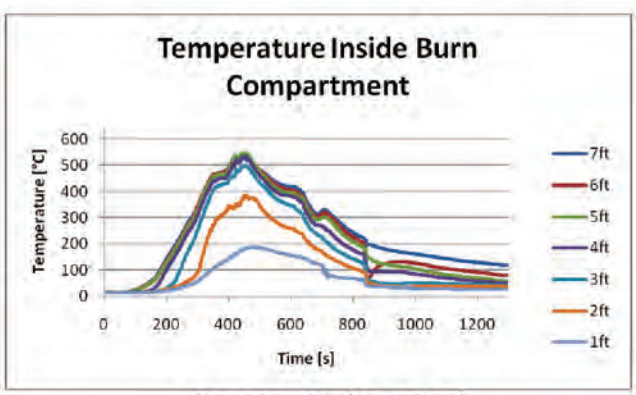
3-Person, Late Arrival



4-Person, Early Arrival

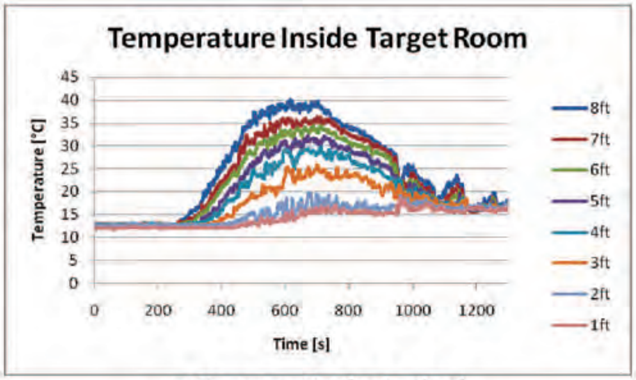


4-Person, Late Arrival

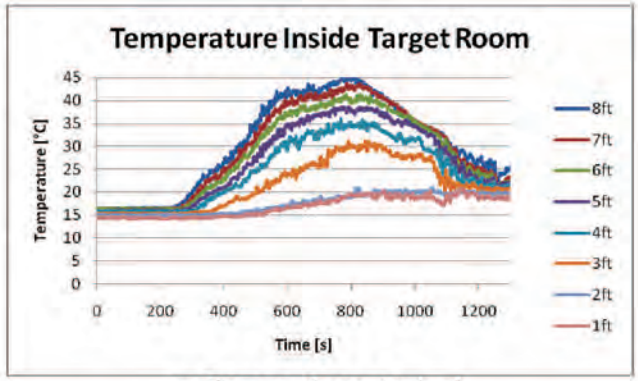


5-Person, Early Arrival

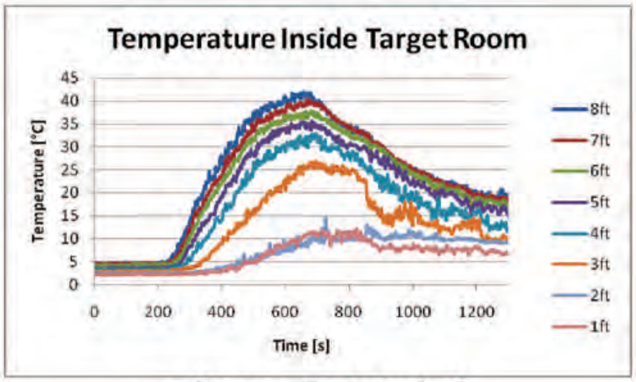
Temperatures in Target Room



2-Person, Early Arrival



2-Person, Late Arrival



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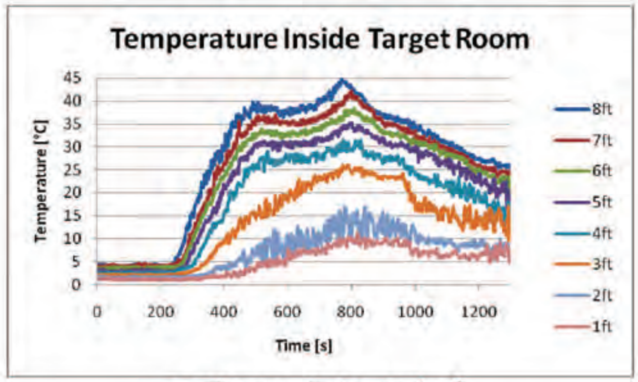
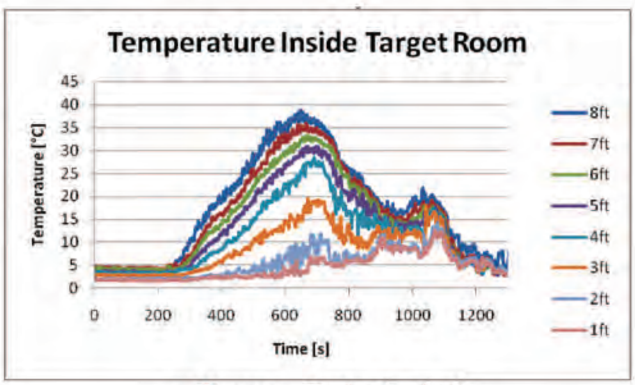
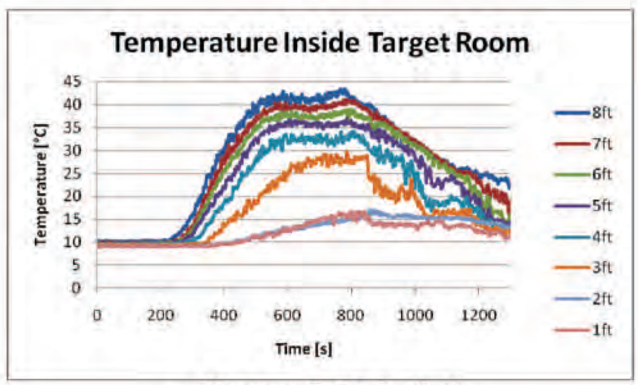


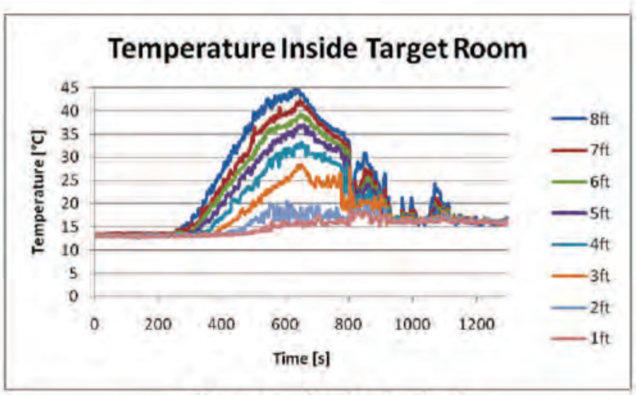
3-Person, Late Arrival



4-Person, Early Arrival

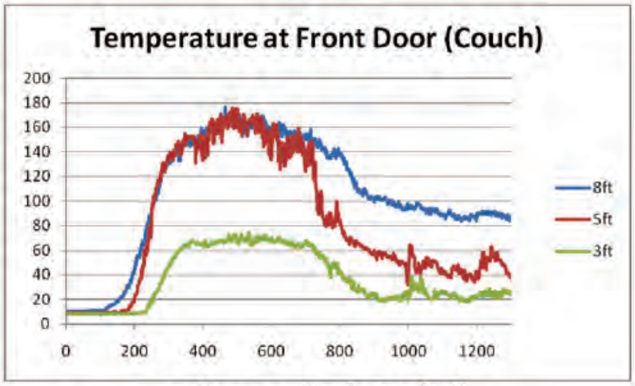


4-Person, Late Arrival

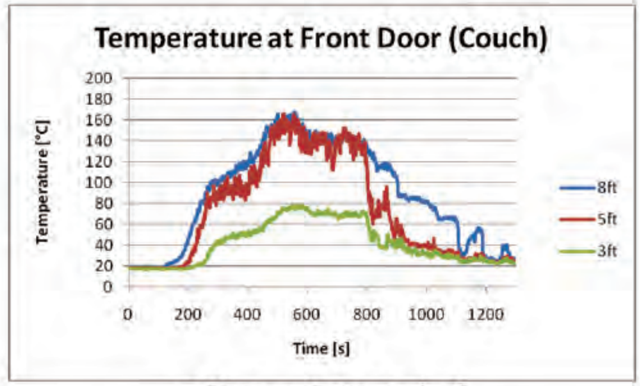


5-Person, Early Arrival

Temperatures Near Front Door (Couch)



2-Person, Early Arrival



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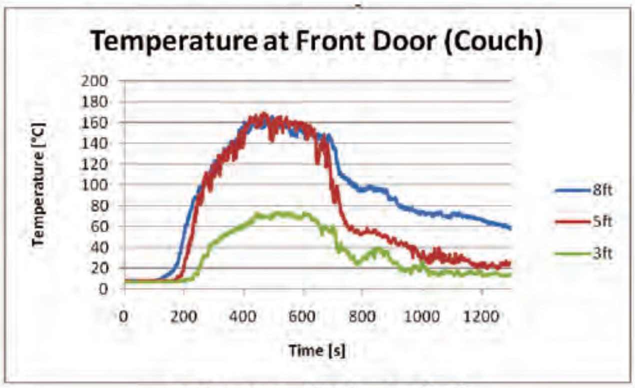
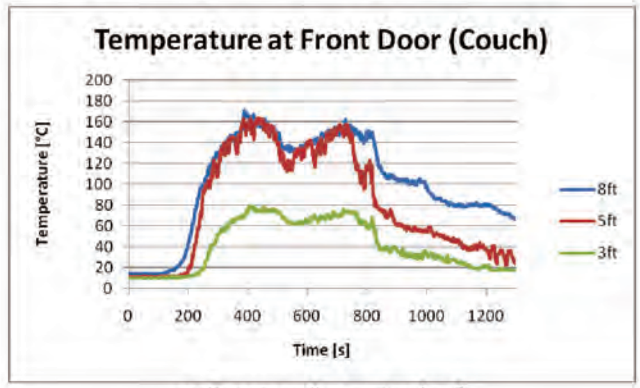


3-Person, Early Arrival



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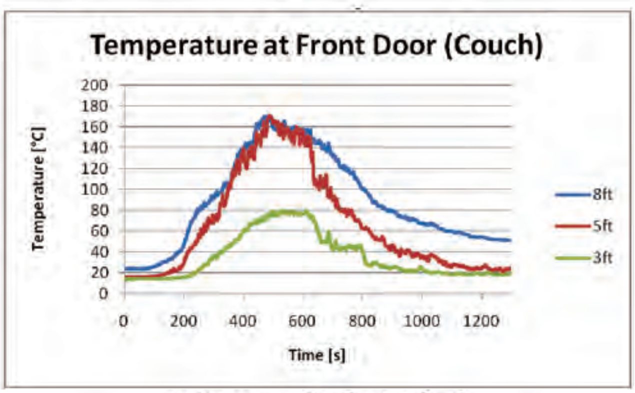
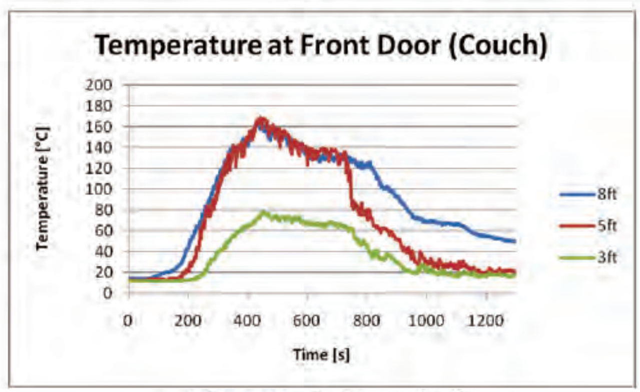


4-Person, Early Arrival



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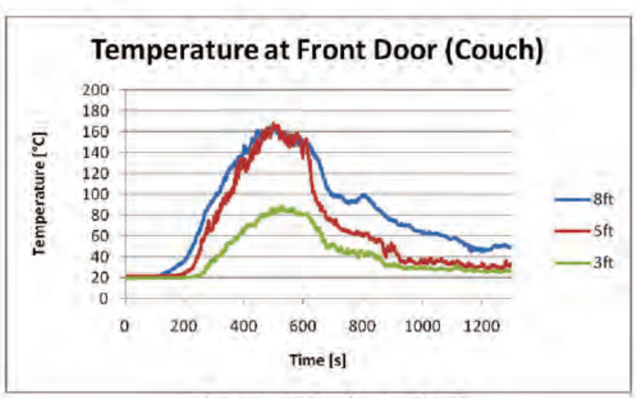

5-Person, Early Arrival

NOTES:

FIRE FIGHTER SAFETY AND DEPLOYMENT STUDY

Report on

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Kathy Notarianni

National Institute of Standards and Technology
U.S. Department of Commerce

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FIRE FIGHTER
SAFETY AND
DEPLOYMENT
STUDY

Produced with the Cooperation of
Montgomery County, Maryland
Fire and Rescue, Department
Chief Richard Bowers

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Abstract

The fire service has become the first line medical responder for all types of medical emergencies in the majority of the United States. Fire departments typically deliver first-on-scene, out-of-hospital care services, regardless of whether or not they provide transport. The design of fire department-based Emergency Medical Services (EMS) systems varies across communities. Some departments deploy only Basic Life Support (BLS) units and personnel, some deploy a mix of BLS and Advanced Life Support (ALS) units and personnel, and a few departments operate solely at an ALS level. Additionally, the number of total personnel dispatched on an EMS call also differs. This number is dependent on factors such as the type of system resources, the nature of the EMS incident, and the number of simultaneous and concurrent incidents.

For the first time, this study investigates the effects of varying crew configurations for first responders, the apparatus assignment of ALS personnel, and the number of ALS personnel on scene on the task completion times for ALS level incidents. This study is also unique because of the array of stakeholders and the caliber of technical experts involved. Throughout the experiments, all industry standards and safety protocols were followed and robust research methods were used. The results and conclusions will directly inform the NFPA 1710[1] and NFPA 1720 Technical Committees, who are responsible for developing industry operational and deployment standards.

This report presents the results of more than 102 field experiments designed to quantify the effects of various fire department-based EMS deployment configurations for three different scenarios—-1) patient access and removal from the incident scene, 2) a victim of systemic trauma due to a long distance fall and 3) a patient with chest pain leading to a cardiac arrest. In addition to systematically controlling for arrival times of units, first responder crew size was varied to consider two-, three-, and four-person staffing. ALS personnel configuration for both the first responder unit and ambulance transport unit were also varied for purposes of the experiments. In each deployment, personnel performed a series of defined tasks consistent with the scenario being evaluated. Report results quantify the effectiveness of crew size, ALS configuration, and the number of ALS personnel on the start, duration, and completion time of all tasks delineated in the three scenarios. Conclusions are drawn from statistically significant results.

Executive Summary

Increasing demands on the fire service, including the rising number of EMS responses, point to the need for scientifically-based studies on the effect of first responder crew size, Advanced Life Support configuration, and the number of Advanced Life Support (ALS) personnel on scene on the safety of responders, as well as the operational efficiency and effectiveness of fire departments responding to emergency medical incidents. To address this need, a research partnership of the Commission on Fire Accreditation International (CFAI), International Association of Fire Chiefs (IAFC), International Association of Fire Fighters (IAFF), National Institute of Standards and Technology (NIST), and Worcester Polytechnic Institute (WPI) was formed to conduct a multiphase study of firefighter safety and the deployment of resources. A portion of that study, as reported here, includes an assessment of time-to-tasks for EMS incidents.

Beginning in FY 2005, funding was provided through the Department of Homeland Security (DHS)/ Federal Emergency Management Agency (FEMA) Grant Program Directorate for Assistance to Firefighters Grant Program-Fire Prevention and Safety Grants. In addition to the EMS field experiments described in this report, the multiple phases of the overall research effort include development of a conceptual model for community risk assessment and deployment of resources, implementation of a generalizable department incident survey, and delivery of a software tool to quantify the effects of deployment decisions on resultant firefighter and civilian injuries and on property losses.

The first phase of the project was an extensive survey of more than 400 career and combination (both career and volunteer) fire departments in the United States with the objective of optimizing a fire service leader's capability to deploy resources to prevent or mitigate adverse events that occur in risk- and hazard-filled environments. The results of this survey are not documented in this report, which is limited to the EMS experimental phase. The survey results will constitute significant input into the development of a future software tool to quantify the effects of community risks and associated deployment decisions on resultant firefighter and civilian illnesses and injuries.

The National Fire Protection Association estimates that 10,380 EMS workers were exposed to infectious diseases in 2008 (Karter, 2009). Another study noted that almost 10 % of Emergency Medical Technicians (EMTs) and Paramedics miss work at any given time due to job-related illness or injury (Studnek et al, 2007). Another study noted that injury rates for EMS workers are higher than rates reported by the Department of Labor (DOL) for any other industry in 2000 (Maguire et al, 2005) and another study noted that EMS providers have a high risk for occupational injury, with approximately 25 % of workers reporting at least one work-related injury in the previous six months. Many of these injuries were the result of falls or lifting patients (Heick, 2009). Funding and additional research are critical to further defining the high risks to firefighters during EMS responses and developing interventions to mitigate this serious problem.

In order to address the primary research questions using realistic scenarios, the research was divided into three distinct, yet interconnected parts.

- Part 1 — Time-to-task experiments related to gaining access to a patient and removing the patient from the incident scene.
- Part 2 — Time-to-task experiments related to the care of a victim with multi-system trauma.
- Part 3 — Time-to-task experiments related to the care of a victim with chest pain and witnessed cardiac arrest.

These parts included the most basic elements of an overall EMS response, which are — access the patient, conduct patient assessment, deliver on scene patient care, package the patient, and remove the patient from the scene to a transport-capable vehicle.

Scope

The EMS portion of the Firefighter Safety and Deployment of Resources Study was designed solely to assess the personnel number and configuration aspect of an EMS incident for responder safety, effectiveness, and efficiency. This study does not address the efficacy of any patient care intervention. This study does however quantify first responder crew size, i.e., the number and placement of ALS trained personnel resources on the time-to-task measures for EMS interventions. Upon recommendation of technical experts, the investigators selected trauma and cardiac scenarios to be used in the experiments as these events are resource intensive and will likely reveal relevant differences in regard to the research questions. The applicability of the conclusions from this report to a large-scale hazardous or multiple-casualty event has not been assessed and should not be extrapolated from this report.

EMS protocols pertaining to the treatment and transport of patients vary by departments. For the purpose of this study, apparatus arrival times and on scene tasks were standardized by technical experts. Individual performance times were recorded for each task. Response data from more than 300 United States Fire Departments show that when dispatched simultaneously, a first responder arrives prior to an ambulance in approximately 80 % of EMS responses, (IAFC/IAFF, 2005). Therefore, arrival times of the first responder engine and the ambulance were staggered. Additionally, in real-world situations, as in this study, many of the tasks can be performed simultaneously based on the number and training level of responding personnel. Attempts to generalize the results from these experiments to individual departments must take into account response and patient care protocols and equipment that may vary from those used in the experiments.

Primary Findings

The objective of the experiments was to determine how first responder crew size, ALS provider placement, and the number of ALS providers is associated with the effectiveness of EMS providers. EMS crew effectiveness was measured by task intervention times in three scenarios including patient access and removal, trauma, and cardiac arrest. The results were evaluated from the perspective of firefighter and paramedic safety and scene efficiency rather than as a series of distinct tasks. More than 100 full-scale EMS experiments were conducted for this study.

Hundreds of firefighters and paramedics are injured annually on EMS responses. Most injuries occur during tasks that require *lifting or abnormal movement* by rescuers. Such tasks include lifting heavy objects (including human bodies both conscious and unconscious), manipulating injured body parts and carrying heavy equipment. Several tasks included in the experiments fall into this category, including splinting extremities, spinal immobilization (back boarding) and patient packaging. Similar to the lifting or heavy workload tasks, larger crews were able to complete the labor intensive tasks using multiple crew members on a single task to assure safe procedures were used reducing the likelihood of injury or exposure.

A number of tasks are also *labor intensive*. These tasks can be completed more efficiently when handled by multiple responders. Several tasks in the experiments are in this category. These include checking vital signs, splinting extremities, intubation with spinal restriction, establishing I.V. access, spinal immobilization, and patient packaging. During the experiments larger crews completed these tasks more efficiently by distributing the work load among more people thereby reducing the likelihood of injury.

Finally, there are opportunities on an EMS scene to reduce scene time by completing tasks simultaneously rather than sequentially thus increasing operational efficiency. For the experiments, crews were required to complete all tasks in each scenario regardless of their crew size or configuration. Therefore, patterns in task start times and overall scene times reveal operational efficiencies. When enough hands are available at the scene to complete tasks simultaneously, this leads to overall time reductions relative to smaller crews that are forced to complete tasks sequentially.

Patient Access and Removal

With regard to accessing the patient, crews with three or four first responders reached the patient around half a minute faster than smaller crews with two first responders. With regard to completing patient removal, larger first responder crews in conjunction with a two-person ambulance were more time efficient. The removal tasks require heavy lifting and are labor intensive. The tasks also involve descending stairs while carrying a patient, carrying all equipment down stairs, and getting patient and equipment out multiple doors, onto a stretcher and into an ambulance.

The patient removal results show substantial differences associated with crew size. Crews with three- or four-person first responders complete removal between 1.2 – 1.5 minutes faster than smaller crews with two first responders. All crews with first responders complete removal substantially faster (by 2.6 - 4.1 minutes) than the ambulance-only crew.

These results suggest that time efficiency in access and removal can be achieved by deploying three- or four-person crews on the first responding engine (relative to a first responder crew of two). To the extent that each second counts in an EMS response, these staffing features deserve consideration. Though these results establish a technical basis for the effectiveness of first responder crews and specific ALS crew configurations, other factors contributing to policy decisions are not addressed.

Trauma

Overall, field experiments reveal that four-person first responder crews completed a trauma response faster than smaller crews. Towards the latter part of the task response sequence, four-person crews start tasks significantly sooner than smaller crews of two or three persons.

Additionally, crews with one ALS provider on the engine and one on the ambulance completed all tasks faster and started later tasks sooner than crews with two ALS providers on the ambulance. This suggests that getting ALS personnel to the site sooner matters.

A review of the patterns of significant results for task start times reinforced these findings and suggests that (in general) small non-significant reductions in task timings accrue through the task sequence to produce significantly shorter start times for the last third of the trauma tasks.

Finally, when assessing crews for their ability to increase on-scene operational efficiency by completing tasks simultaneously, crews with an ALS provider on the engine and one ALS provider on the ambulance completed all required tasks 2.3 minutes (2 minutes 15 seconds) faster than crews with a BLS engine and two ALS providers on the ambulance. Additionally, first responders with four-person first responder crews completed all required tasks 1.7 minutes (1 minute 45 seconds) faster than three-person crews and 3.4 minutes (3 minutes and 25 seconds) faster than two-person crews.

Cardiac

The overall results for cardiac echo those of trauma. Regardless of ALS configuration, crews responding with four first responders completed all cardiac tasks (from at-patient to packaging) more quickly than smaller first responder crew sizes. Moreover, in the critical period following cardiac arrest, crews responding with four first responders also completed all tasks more quickly than smaller crew sizes. As noted in the trauma scenario, crew size matters in the cardiac response.

Considering ALS placement, crews responding with one ALS provider on both the engine and ambulance completed all scene tasks (from at-patient to packaging) more quickly than a crew with a BLS engine and two ALS providers on the ambulance. This suggests that ALS placement can make a difference in response efficiency. One curious finding was that crews responding with a BLS engine and an ambulance with two ALS providers completed the tasks that follow cardiac arrest 50 seconds *sooner* than crews with an ALS provider on both the engine and ambulance. As noted, this counter-intuitive difference in the results may be attributable to the delay of the patient arrest time based on the arrival of the 12-Lead ECG monitor with the two-person ALS Ambulance crew. The 12-Lead ECG task *end time* was the arrest *start time*. In this scenario, there were instantaneously two ALS providers present at the arrest rather than the one ALS provider placing the 12-Lead ECG device in the ALS engine /ALS Ambulance crew.

A review of the patterns of significant findings across task start times showed mixed results. An ALS on an engine showed an advantage (sooner task starting times) over an ALS on an ambulance for a few tasks located earlier in the cardiac response sequence (specifically, ALS Vitals 12-Lead through IV access). A first responder with four-person crew also showed shorter start times for a few early tasks in the cardiac response sequence (initial airway, breathing and circulation (ABCs), and the ALS Vitals 12-Lead and expose chest sequence). More importantly, a sequential time advantage appears for the last three tasks of the sequence (analyze shock #2 through package patient).

Finally, when assessing crews for their ability to increase on-scene operational efficiency by completing tasks simultaneously, crews with an ALS provider on the engine and one ALS provider on the ambulance completed all required tasks 45 seconds faster than crews with a BLS engine and two ALS providers on the ambulance. Regardless of ALS configuration, crews responding with four first responders completed all cardiac tasks from the 'at patient time' to completion of packaging 70 seconds faster than first responder crews with three persons, and 2 minutes and 40 seconds faster than first responder crews with two persons. Additionally, *after the patient arrested*, an assessment of time to complete remaining tasks revealed that first responders with four-person crews completed all required tasks 50 seconds faster than three-person crews and 1.4 minutes (1 minute 25 seconds) faster than two-person crews.

Summary

While resource deployment is addressed in the context of three basic scenarios, it is recognized that public policy decisions regarding the cost-benefit of specific deployment decisions are a function of many factors including geography, resource availability, community expectations as well as population demographics that drive EMS call volume. While this report contributes significant knowledge to community and fire service leaders in regard to effective resource deployment for local EMS systems, other factors contributing to policy decisions are not addressed. The results, however, do establish a technical basis for the effectiveness of first responder crews and ALS configuration with at least one ALS level provider on first responder crews. The results also provide valid measures of total crew size efficiency in completing on-scene tasks some of which involve heavy lifting and tasks that require multiple responders to complete.

These experimental findings suggest that ALS provider placement and crew size can have an impact on some task start times in trauma and cardiac scenarios, especially in the latter tasks leading to patient packaging. To the extent that creating time efficiency is important for patient outcomes, including an ALS trained provider on an engine and using engine crew sizes of four are worth considering. The same holds for responder safety – for access and removal and other tasks in the response sequence, the availability of additional hands can serve to reduce the risks of lifting injuries or injuries that result from fatigue (e.g., avoid having small crews repeatedly having to ascend and descend stairs).

Background

In recent years, the provision of emergency medical services has progressed from an amenity to a citizen-required service. Today more than 90 % of career and combination fire departments deliver emergency medical care services, making fire departments the largest group of providers of prehospital EMS in North America. Fire department operations are geared to rapid response, whether it is for EMS, resuce, or fire suppression. In many jurisdictions, EMS responses equate to over 75 % of a fire departments call volume. EMS deployment decisions are therefore a critical driving factor for any department considering both short and long term resource deployment decisions.

The National Fire Protection Association estimates that 10,380 EMS workers were exposed to infectious diseases in 2008 (Karter, 2009). Another study noted that almost 10 % of EMTs and Paramedics miss work at any given time due to job-related illness or injury (Studnek et al, 2007). Another study noted that injury rates for EMS workers are higher than rates reported by the Department of Labor (DOL) for any other industry in 2000 (Maguire et al, 2005) and another study noted that EMS providers have a high risk for occupational injury, with approximately 25 % of workers reporting at least one work-related injury in the previous 6 months. Many of these injuries were the result of falls or lifting patients (Heick, 2009). Funding and additional research are critical to further quantifying the high risks to firefighters during EMS responses and developing interventions to mitigate this serious problem.

Much discussion and past research has focused on ambulance transport services, largely ignoring the impact of critical interventions that can be provided prior to ambulance transport unit arrival. Ambulances are important for the transport of patients needing more definitive medical care (Pratt, 2007). However, based on the number and the geographic distribution of apparatus stationed for "all hazards" response, a more rapid response is typically provided by fire department baseline units carrying medical supplies and EMS trained personnel (IAFC/IAFF, 2005). As fire departments continue to enhance their roles in EMS, it becomes important to examine how different deployment configurations and initiation of specific medical interventions may change the long-term outcome for the patient. Consequently, community planners and decision-makers need tools to optimally align resources with their service commitment for adequate emergency medical care for citizens.

Problem

Despite the role played by the fire service in the provision of emergency medical services, there are no scientifically based tools available to community and fire service leaders to assess the effects of EMS crew size and deployment on firefighter safety. More and more individuals, including the indigent, the working uninsured, and the underinsured, rely on prehospital medical care, which continuously increases the need for EMS resources in fire departments. The continued lack of comprehensive community health services and comprehensive health care reform means addressing this issue is a critical step in the evolution of the fire service and public safety.

Presently, community and fire service leaders have a qualitative understanding of the effect of certain resource allocations. For example, an increase in the number of fire houses, medically equipped apparatus, and EMS trained personnel would lead to a decrease in the time citizens spend waiting for EMS resources to arrive. Consequently a decrease in the number of fire houses, medically equipped apparatus, and EMS trained personnel would likely lead to an increase in the time before critical medical interventions can be provided. However, decision-makers lack a sound basis for quantifying the overall impact of enhanced emergency medical resources and the number of EMS-trained personnel on the timely provision of life-saving procedures.

Studies on adequate deployment of resources are needed to enable fire departments, cities, counties, and fire districts to design an acceptable level of resource deployment based upon community risks and service provision commitment. These studies will assist with strategic planning and municipal and state budget processes. Additionally, as resource studies refine data collection methods and measures, both subsequent research and improvements to resource deployment models will have a sound scientific basis.

Literature Review

Within the past four decades, the range and structure of services provided by firefighters have broadened and changed dynamically as an ever-increasing amount of department resources are used to respond to emergency medical calls. Expanded activities and increased expectations bring advantages, as well as challenges for both communities and fire departments in terms of providing optimal protection during emergency situations, while quantitatively assessing objective systems performance.

Studies documenting engine and ladder response times and crew performance in diverse live and simulated fire hazard environments, show a relationship between apparatus staffing levels and a range of important performance variables and outcome measurements such as response time, time-to-task completion, fire growth status at the time of attack, and occupant toxicity levels (Averill et al, 2010). Recent analyses of EMS crew staffing configuration have suggested that both the number of personnel dispatched per unit and the level of emergency medical certification of that crew may influence similar standards of measurement in the realm of medical response by multi-role firefighters. (Brown et al, 1996)

The rapid evolution of emergency service delivery and the growth of fire-based EMS systems correspond with an increase in literature that has detailed both the need for careful outcomes evaluation and continued innovation in terms of establishing performance variables that accurately assess the effectiveness of prehospital care provided by emergency medical technicians (EMTs). Investigators from government, professional organizations, and academia have described the progress made in the field of prehospital care and the challenges that EMT's and multi-role firefighters face in an expanding body of literature (Moore, 2002).

Publications to date have continually reached towards ascertaining the performance measures, operational protocols, and dispatch configurations that optimize outcomes across diverse communities. Many of the currently established EMS benchmarks and obstacles identified in recent literature hold particular importance for multi-role firefighters. Far-reaching studies of EMS response have demonstrated how response time, scene time, transport time, crew size, equipment, and the level of crew staffing and certification levels have influenced patient survival (Cummins et al, 1991). While studies have continued to demonstrate the impact of these factors with increasingly sophisticated methods, the need to improve understanding of EMS delivery persists. Existing standards of care need to be reevaluated so current systems can adjust and progress in response to ongoing research findings.

Historically, total response time has been measured from the time a responding unit leaves a fire station until the time the unit arrives at the incident. However, anecdotal evidence suggests that total response time should include the time to locate and access the patient (time to patient side). Previous studies have shown a substantial time difference between the time the first responder arrives on-scene and the time of patient access. One study noted that the patient access time interval represented 24 % of the total EMS response time interval among calls originating less than three floors above or three floors below ground and 32 % of those located three or more stories above ground. (Morrison et al, 2005)

Early literature on out-of-hospital cardiac arrest (OHCA) sought to uncover the effects of patient characteristics and location of initial collapse on survival to hospital discharge, with researchers then beginning to quantify the importance of response time. A paper by researchers from the EMS Division of King County, Washington and University of Washington Departments of Medicine and Biostatistics found significantly higher survival rates for patients who arrested outside the home, noting that of those 781 patients, most were more frequently younger, male, and more likely to be witnessed at the time of collapse and had received bystander cardiopulmonary resuscitation (CPR). (Litwin et al, 1987)

A growing number of defibrillation effectiveness studies began to demonstrate that response time, EMT training and practice, and population density influenced the effectiveness of this type of EMS delivery. (Olson, 1989; Kellerman, 1992; Hallstrom, 2004; DeMaio, 2005) For an urban environment exceeding three million, at least one study noted that over a period of one year, survival rates were lower in urban environments than those reported for smaller cities, but reaffirmed that the single factor most likely contributing to poor overall survival was a relatively long interval between collapse and defibrillation. In their conclusions, the authors recommended the use of standardized terms and methodology and stressed that "detailed analysis of each component of the emergency medical services systems will aid in making improvements to maximize survival of out-of-hospital cardiac arrest." (Becker, 1991)

Researchers studying patient outcomes following traumatic brain injury (TBI) were employing the specific anatomic, physiologic, and age characteristics of patients to formulate methods that would evaluate the effectiveness of trauma care. The "Trauma and Injury Severity Scores" (TRISS) method was one such system that generated scores for patients based upon systolic blood pressure, capillary refill, respiratory rate, and respiratory expansion. These scores provided a means of accurate analysis for EMS performance for cases of TBI, just as situational characteristics for OHCA, such as location of collapse, collapsing rhythm, and time to initial call were being used to gauge the effectiveness of emergency medical interventions for patients in distinct crisis scenarios. For instance, the correlation between age and predicted mortality for patients with comparable Trauma and Injury Severity Scores in an early study of the TRISS method suggested that a significantly narrower margin of effectiveness exists for seriously injured patients age 55 years or older. (Boyd, 1987)

Fire departments have long grappled with the most appropriate dispatch and notification configurations for EMS systems in different communities. Analyses have focused on comparisons of "one-tier" versus "two-tier" notification systems. "One-tier" systems require ALS units to respond to and transport all calls. In

[2] "Multi-role" is a term given to firefighters cross-trained in a number of related emergency services fields, such as EMS, hazardous materials response, and technical rescue.

a "two-tier" system, ALS units are allowed to delegate varying degrees of responsibility for response and transport to BLS units. Two studies appearing in the *Annals of Emergency Medicine* in the same year examined the response capacity and performance measures for a broad sample of urban EMS systems with regard to dispatching protocols and notification systems. (Sweeney, 1998; Chu, 1998) Reviewing previously published studies on 39 emergency medical services programs from 29 different locations from 1967 to 1988, researchers focusing specifically on cardiac arrest and resuscitation outcomes noted survival rates to be higher for two-tiered systems where both a paramedic and either an EMT or EMT-D were dispatched to calls, as compared to survival rates for one-tier systems where dispatches were exclusive for an EMT, EMT-D, or paramedic. This analysis also showed rates of survival to hospital discharge to be slightly higher for patients with a collapse rhythm of ventricular fibrillation, which suggested that the earlier CPR initiation possible in two-tier configurations was a primary means to the higher survival rates in these systems (Eisenberg et al., 1990).

In an article that plotted responses to an EMS system configuration survey against Code 3 ("lights and sirens") response times to emergency calls, investigators identified three different types of "two-tier" configurations. In the first two-tier system, ALS units responded to all calls but once on-scene could turn a patient over to a BLS unit for transport. In the second two-tier model, ALS units did not respond to all calls and BLS units could be sent for noncritical calls. In the final two-tier configuration, a non-transport ALS unit was dispatched with a transporting BLS unit with ALS personnel joining BLS personnel for transport on all ALS calls. After reviewing survey responses from EMS systems in 25 mid-sized cities with populations of 400,000 to 900,000, researchers suggested that a two-tier response system that permitted dispatch of BLS units for noncritical calls would allow a given number of ALS units to serve a much larger population while still maintaining rapid Code 3 response times (Braun et al, 1990).

The emergence of the "chain of survival" concept in the prehospital treatment of cardiac arrest merged the effectiveness of specific EMS interventions for individual patient characteristics and the level of qualification of staffing on emergency apparatus as standards of measurement within a system-wide scheme of performance evaluation. In a statement explaining the chain of survival and detailing its components, researchers argued that time to recognition of OHCA, EMS system activation, initiation of CPR, defibrillation, intubation, and intravenous administration of medications were successive, distinct factors that directly influenced outcomes of sudden cardiac arrest and should therefore be used inclusively as measurements of overall performance for EMS systems. The authors presented a thorough review of past literature and noted that while a small number of urban EMS systems approached the then-current practical limit for survivability from sudden cardiac arrest, most EMS systems in the U.S. and other countries had defects in their chain, as demonstrated by a near universal preponderance of poor resuscitation rates. This paper was notable for describing the research supporting each "link" in the chain or performance measurement of EMS system effectiveness and recommending specific actions to improve each area, thereby strengthening the chain of survival. Moreover, researchers suggested that communities implementing two-tier, double response systems might show optimal improvements in survival rates, as reports on EMT-D systems showed small response times but restricted intervention methods while ALS-only systems recorded longer response times with more advanced treatment options (Cummins et al, 1991).

Time-to-task measurements that have more recently been formulated into the "chain of survival" model for sudden cardiac arrest have been widely accepted as measurements of fire crews' performance. The continuous patient care and vigilant monitoring of vitals advocated in most EMS models are duties that multi-role firefighters are distinctly well-equipped to perform, especially in emergency situations requiring both fire suppression and emergency medical response. Critical thinking, strategic teamwork, and ongoing, immediate priority assessments during emergency situations are all skills taught and regularly instilled by training and routine evaluation for multi-role firefighters.

In light of the existing literature, there remain unanswered questions about the relationship between resource deployment levels, in terms of first responder crew size and EMS training levels, and the associated task performance during EMS incidents. For the first time, this study investigates the effects of varying crew configurations for first responders, the apparatus assignment of ALS personnel, and the number of ALS personnel on scene on the task completion for ALS level incidents. This study is also unique because of the array of stakeholders and technical advisors involved. All industry standards and safety protocols were followed, and robust research methods were used. The results and conclusions will directly inform the NFPA 1710 Technical Committee, who is responsible for developing industry standards associated with the deployment of fire suppression operations, emergency medical operations, and special operations to the public by career fire departments.

Purpose and Scope of the Study

This project systematically studies deployment of fire department-based EMS resources and the subsequent effect on the ability to provide an efficient and effective response. It will enable fire departments and city/county managers to make sound decisions regarding optimal resource allocation to meet service commitments using the results of scientifically based research. Specifically, the EMS field experiments provide quantitative data on the effects on varying crew size configurations, ALS personnel placement, and the number of ALS personnel available on ALS level incidents.

The first phase of the multiphase project was an extensive survey of more than 400 career and combination fire departments in the United States with the objective of optimizing a fire service leader's capability to deploy resources to prevent or mitigate adverse events that occur in risk- and hazard-filled environments. The results of this survey are not documented in this report, which is limited to the experimental phase of the project, but they will constitute significant input into future applications of the data presented in this document.

In order to address the primary research questions using realistic scenarios, the research was divided into three distinct, yet interconnected parts.

- Part 1- Time-to-task experiments related to gaining access to a patient and removing the patient from the incident scene.
- Part 2- Time-to-task experiments related to the care of a victim with multi-system trauma.
- Part 3- Time-to-task experiments related to the care of a victim with chest pain and witnessed cardiac arrest.

These parts included the most basic elements of an overall EMS response and included time for personnel to access the patient, conduct patient assessment, deliver on-scene patient care, package the patient, and remove the patient from the scene to a transport-capable vehicle.

The EMS portion of the Firefighter Safety and Deployment of Resources Study was designed to assess the labor aspect of an EMS incident necessary to ensure safe, effective, and efficient operations. While studies have shown a relationship between response time and efficiency of patient care intervention, this project has no direct measures. This study does however quantify the effects of first responder crew size and ALS trained personnel resources on time-to-task for EMS interventions. The applicability of the conclusions from this report to a large-scale hazardous or multiple-casualty event has not been assessed and should not be extrapolated from this report.

EMS protocols pertaining to the treatment and transport of patients vary by departments. For the purpose of this study, tasks were standardized by technical experts and individual times were recorded for each task. In real-world situations, as in this study, many of these can be performed simultaneously based on the number and training level of responding personnel. Attempts to generalize the results from these experiments to individual departments must take into account protocols and equipment that vary from those used in the experiments.

A Brief Overview of the EMS Response

Considering the setting and the circumstances of emergency medical care delivery, the prehospital 9-1-1 emergency care patient should be considered a distinct type of patient in the continuum of health care. These patients not only have medical needs, but they may also need simultaneous physical rescue, protection from the elements and the creation of a safe physical environment, as well as management of non-medical surrounding sociologic concerns (Pratt et al., 2007). Interdependent and coordinated activities of all personnel are required to meet the priority objectives.

NFPA 1710: *Standard on Fire Department Operations, Emergency Medical Operations, and Special Operations to the public by Career Fire Departments* specifies that the number of on-duty EMS providers must be sufficient relative to the level of EMS provided by the fire department, and be based on the minimum levels needed to provide patient care and member safety.[3] NFPA Standard 1710 also recommends that personnel deployed to ALS emergency responses include a minimum of two members trained at the emergency medical technician-basic level and two members trained at the emergency medical technician-paramedic level, arriving at the scene within the established time frame of two hundred and forty seconds (four minutes) or less for BLS units and four hundred and eighty seconds (eight minutes) or less for ALS units provided that a first-responder with Automated External Defibrillator (AED) or BLS unit arrived in two hundred forty seconds (four minutes) or less travel time, or at the minimum levels established by the authority having jurisdiction.[4]

During each EMS experiment, a first responder unit and an ambulance transport unit was dispatched to the scene. Crew size for the first responder unit and ALS configuration for both the first responder unit and ambulance transport unit were varied for purposes of the experiments. There were three specific scenarios to which personnel responded.

- Patient access and removal from incident site
- Systemic trauma/fall victim
- Chest pain/cardiac arrest

Important time intervals typically not measured by EMS systems are "time to patient access" and the "time to patient removal" intervals. These intervals include the time it takes personnel with equipment to locate and access the patient and the time it takes personnel to remove the patient and equipment from the incident scene to the ambulance for transport. These intervals are critically important to calculating overall scene time, particularly in scenarios where the patient is not immediately accessible (high-rise buildings, commercial complexes, schools, etc.).

The Star of Life

The elements comprising an EMS incident are symbolized by the Star of Life.[5] The six branches of the star are symbols of the six main tasks executed by rescuers throughout an emergency medical event.

Figure 1: The Star of Life

The six branches of the star include the elements listed below.

- Detection: Citizens must first recognize that an emergency exists and know how to contact the emergency response system in their community. This can be done using several different methods such as dialing 9-1-1, dialing a seven digit local emergency number, using amateur radios, or call boxes.

- Reporting: Upon accessing a call center, callers are asked for specific information so that the proper resources can be sent. In an ideal system, certified Emergency Medical Dispatchers (EMDs) ask a pre-defined set of questions. In this phase, dispatchers also become a link between the scene and the responding units and can provide additional information as it becomes available.

- Response: This branch identifies the response of emergency crews to the scene. The response may include an engine with firefighters trained as EMT's followed by an ambulance carrying additional firefighter/EMT's or it may be a fire engine first responder crew followed by an ambulance carrying single role EMS personnel.

- On scene care: Definitive care is provided on the scene by the emergency response personnel. Standing orders and radio or cellular contact with an emergency physician has broadened the range of on scene care that can be provided by EMS responders. A long algorithm of procedures and drugs may be used before the patient is removed from the scene.

- Care in Transit: Emergency personnel transport the patient to the closest appropriate medical care facility for definitive care. During transport, patient care/treatment is continued.

- Transfer to Definitive care: Emergency crews transfer the patient to the appropriate specialized care facility. Transfer includes providing a detailed written report of the patient assessment and care provided on-scene and in-transit.

[3] NFPA 1710, Section 5.3.3.2.1: On duty EMS units shall be staffed with the minimum personnel necessary for emergency medical care relative to the level of EMS provided by the fire department.

[4] NFPA 1710, Section 5.3.3.3.4: Personnel deployed to ALS emergency responses shall include a minimum of two members trained at the emergency medical technician-paramedic level and two members trained at the emergency medical technician-basic level arriving on scene within the established travel time.

[5] Designed by Leo R. Schwartz, Chief of the EMS Branch, National Highway Traffic Safety Administration (NHTSA) in 1977.

EMS Response to Time Critical Events

In a statement explaining the chain of survival and detailing its components, researchers argued that time to recognition of OHCA, EMS system activation, initiation of CPR, defibrillation, intubation, and intravenous administration of medications were successive, distinct factors that directly influenced outcomes of sudden cardiac arrest and should therefore be used inclusively as measurements of overall performance for EMS systems. This paper was notable for describing the research supporting each "link" in the chain or performance measurement of EMS system effectiveness and recommending specific actions to improve each area, thereby strengthening the chain of survival (Cummins et al., 1991).

A typical EMS event, regardless of the nature of the incident, follows a basic script. The first arriving unit performs a scene size-up and initial life safety assessment. The crew then gathers the appropriate equipment from the unit based upon patient injury, illness and location, and accesses and treats the patient.

In an analysis of data from more than 300 U.S. Fire Departments, first responder units arrived prior to ambulances in approximately 80 % of responses (IAFC/IAFF 2005). This response capability is likely attributed to the strategic locations of fire stations housing the engines and the fact that engines are often more densely located than ambulance transport units. In some cases, as is the case with motor vehicles accidents with entrapment and some structural collapse incidents, initial responding personnel may need to perform patient treatment and stabilization while performing patient rescue. For these types of incidents, it is necessary to have additional personnel on scene to assist with patient care and removal from the incident scene.

However, even without these major impediments, additional crew members assist with patient care and movement. In the experiments, crew members were used to assist with patient treatment, packaging, removing the patient from the incident location to the ambulance transport unit, repositioning the ambulance transport unit, and other tasks that streamlined the on-scene activity.

The Relation of Time-to-Task Completion and Risk

Delayed response, combined with inadequate personnel resources exacerbates the likelihood of negative patient outcomes. While rapid response is critical to patient survival, the personnel who respond must also be highly competent in patient assessment and stabilizing treatment delivery.

Figure 2 illustrates a hypothetical sequence of events for response to a cardiac arrest (heart attack). A rapid response to an EMS incident is effective only if the personnel arriving on the scene can initiate appropriate emergency medical interventions. This requires adequate numbers of personnel, as well as appropriate equipment and prior training. Early advanced cardiac life support (ACLS) provided by paramedics at the scene is another critical link in the management of cardiac arrest. According to industry standards EMS systems should have sufficient staffing to provide a minimum of two rescuers trained in ACLS to respond to the emergency. However, because of the difficulties in treating cardiac arrest in the field, additional responders should be present (AHA, 2005).

The delivery of prehospital care is complex requiring both interpersonal and clinical skills. Firefighter/Paramedics must be able to communicate with patients, bystanders, on scene safety personnel, and hospital personnel. A lack of cooperation in any of these interactions could have a detrimental effect on the patient.

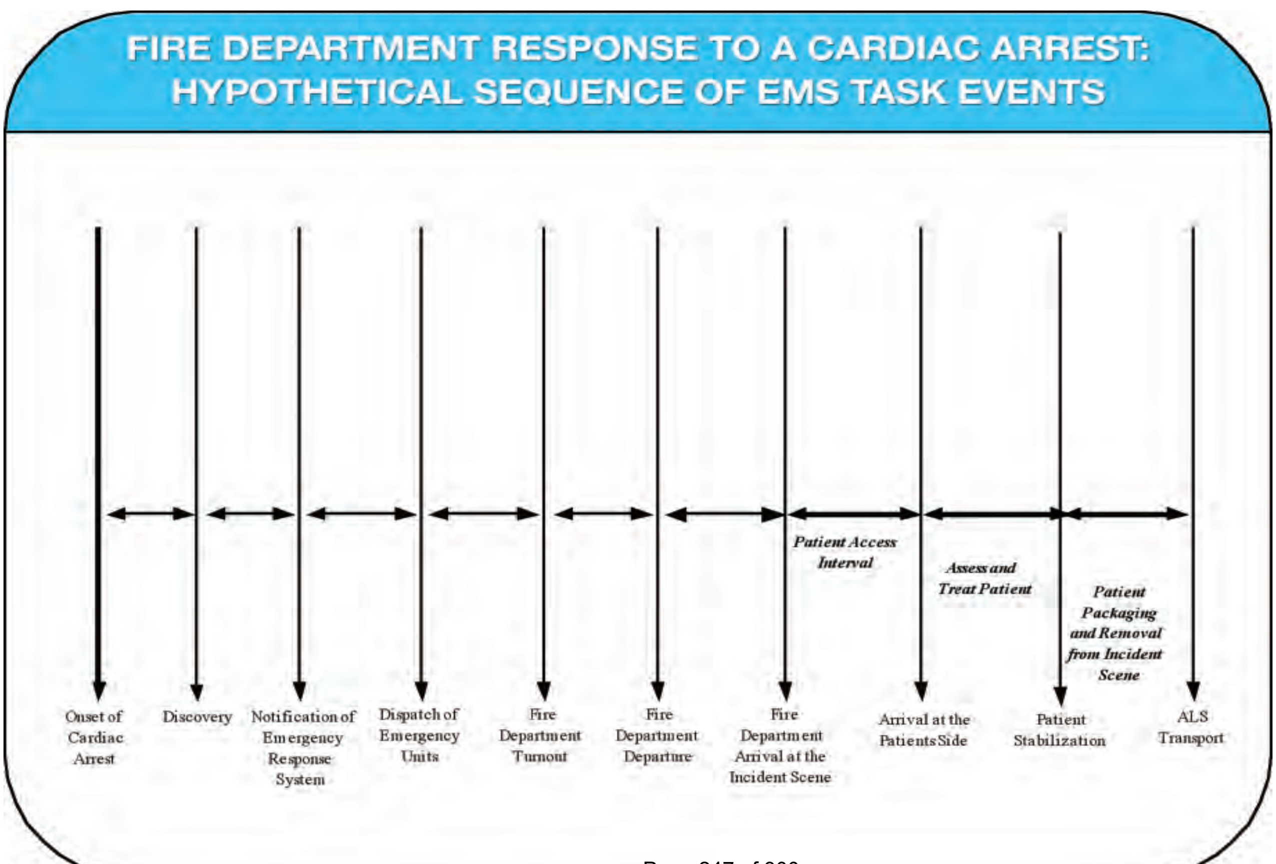

Figure 2: Hypothetical Timeline of a Fire Department Response to an EMS Incident

Standards of Response Cover

Developing a standard of response cover (SORC) related to service commitments to the community is a complex task. A SORC includes the policies and procedures that determine the distribution, concentration, and reliability of fixed and mobile resources for response to emergency medical incidents (CFAI, 2009). Fire departments that provide EMS must evaluate existing (or proposed) resources against identified risk levels in the community and against the tasks necessary to provide safe, efficient and effective emergency medical services. EMS risks that must be considered include population demographics such as socioeconomic status, age, ethnicity and health insurance status, as well as population density, community type (urban, suburban, or rural), access to healthcare, and traffic patterns and congestion. In addition to community risks, leaders must also evaluate geographic distribution and depth or concentration of resources deployed based on time parameters established by community expectation, state or local statute or industry standards.

Recognition and reporting of an emergency medical incident begins a chain of events that occur before firefighters arrive at the scene. These events include call receipt and processing, dispatch of resources, donning protective gear, and travel to the scene. NFPA 1710 defines the overall time from dispatch to the scene arrival as total response time. The standard divides total response time into a number of discrete segments, shown in Figure 2.

Arrival of emergency crews on scene is then followed by a sequence of tasks. Depending on the availability of resources available, tasks may be completed simultaneously or sequentially. Knowing the time it takes to accomplish each task with an allotted number of personnel and equipment can be useful in planning resource deployment. Ideally crews should arrive and intervene in sufficient time to prevent patient brain death, excessive blood loss, and minimize pain and suffering with the goal and expectation of transporting and delivering a viable patient to an appropriate medical facility.

Decision-making regarding staffing levels and geographic distribution of resources must also consider times when there are simultaneous events requiring multiple resource deployment into multiple areas of the jurisdiction. There should be sufficient redundancy or overlap in the system to allow for simultaneous incidents and high volume of near-simultaneous responses without compromising the safety of the patient, the public, or firefighters.

Policy makers have long lacked studies that quantify changes in EMS scene performance based on crew sizes and configuration. These experiments were designed to observe the impact of first responder crew size and ALS configuration on the time it takes to execute essential EMS tasks. It is expected that the results of this study will be used to inform the threshold performance objectives to the NFPA 1710 and 1720 Technical Committees.

Experiment Planning and Methodology

The EMS field experiments consisted of three distinct parts:

- Part 1- Time-to-task experiments related to gaining access to a patient and removing the patient from the incident scene.
- Part 2- Time-to-task experiments related to the care of a victim with multi-system trauma.
- Part 3- Time-to-task experiments related to the care of a victim with chest pain and witnessed cardiac arrest.

Following is a detailed description of the overall methods used throughout the experiments. Specific information pertaining to each part is presented separately.

The following research questions guided the experimental design of the EMS field experiments documented in this report:

- 1. What is the effect of first responder crew size on EMS task times?
- 2. What is the effect of ALS personnel placement on EMS task times?
- 3. What is the effect of the number of ALS trained personnel on EMS task times?

Department Participation

The experiments were conducted in Montgomery County, MD at the Montgomery County Public Safety Training Academy and in Fairfax County, VA at the EMS Simulation Center. Experiments took place during the months of April and May 2009. All experiments took place in daylight between 0800 hours and 1500 hours.

Montgomery County (MD) and Fairfax County (VA) firefighters and paramedics participated in the field experiments. Each day, both departments committed one ALS engine, one ALS ambulance and the associated crews. Firefighters and paramedics were identified and oriented to the experiments. Participants varied with regard to age and experience. The allocation of resources made it possible to conduct back-to-back experiments by rotating firefighters between field work and rehabilitation areas.

Crew Orientation

Daily orientations were conducted. Orientations included a description of the overall study objectives, as well as the actual experiments in which they would be involved. Crews were also oriented to the site layouts and specific scenarios to be conducted.

Cue Cards

Task procedures were standardized for each experiment/scenario. Technical experts worked with the study investigators to break down crew tasks based on crew size. Task flow charts were then created and customized for the various crew sizes. The carefully designed task flow ensured that the same overall workload was maintained in each experiment, but was redistributed based on the number of personnel available for work.

All tasks were included in each scenario and cue cards were developed for each individual participant in each scenario. For example, a four-person first responder crew would have a cue card for each person on the crew including the driver, officer, and two firefighter/EMTs or paramedics. Cards were color coded by crew size to ensure proper use in each scenario.

Tasks

Tasks were completed specific to each scenario (patient access and removal from incident scene, trauma, and cardiac). Meticulous procedures gathered data to measure key areas of focus such as individual start times, task completion times, and overall scenario performance times. Each task in each scenario was assigned a standardized start and end marker, such as retrieving the key from the Knox Box[6] or patient secured with straps to stretcher/cot. All tasks, with the events for measuring start and stop times, are shown in Table 3 through Table 5.

[6] A Knox Box, known officially as the KNOX-BOX Rapid Entry System is a small, wall-mounted safe that holds building keys for firefighters and EMTs to retrieve in emergencies. Local fire companies can hold master keys to all such boxes in their response area, so that they can quickly enter a building without having to force entry or find individual keys held in deposit at the station.

On-Scene EMS Tasks

The on-scene tasks focused on the activities firefighters perform after they arrive on the scene of an emergency medical incident. A number of nationally recognized EMS experts were consulted during the development of the on scene EMS tasks in order to ensure a broad applicability and appropriateness of task distribution.[7] The experiments compared crew performance and workload for typical medical response scenarios using two-, three-, and four-person first responder crews, along with a two-person ambulance crew. In total, 102 experiments were conducted to assess the time it took various crew configurations to complete the overall tasks in Parts 1, 2, and 3. In addition to first responder crew sizes, the experiments assessed the time necessary to access the patient, conduct a patient assessment, deliver on scene patient care, package the patient, and remove the patient from the incident scene to the ambulance. Two scenarios were selected as the basis of Parts 2 and 3. The scenarios included a patient with systemic trauma and a patient with chest pains leading to cardiac arrest.

The experiments also assessed the placement and number of responding ALS-trained personnel. There were 15 crew configurations considered during the experiments. These included the first responder crew being varied from two-, three-, and four-person crews. Additionally, the first responder crew configuration was varied to include either an all BLS crew or a combination crew containing one firefighter trained at the ALS level. The ambulance crew was held constant at two-persons. However, the ambulance crew configuration was varied to include two BLS crew members, one BLS and one ALS crew member, or two ALS crew members. Table 1 shows the crew configurations used throughout the experiments.

During the experiment crews dispatched to various scenarios included a first responder crew and ambulance transport unit or a single ambulance transport unit. For those experiments where both an engine company and an ambulance were dispatched, a three-minute stagger time was imposed for each of those trials. The three minute stagger time was determined from an analysis of deployment data from more than 300 fire departments responding to a survey of fire department operations conducted by the IAFC and the IAFF (2005). Each experiment containing a specific crew configuration was conducted in triplicate and completed in a randomized order (determined by randomization software) before a test configuration was repeated.

First Responder Engine Company	Ambulance Transport Unit	ALS Personnel On-Scene	Total Personnel On-Scene
N/A	2 BLS	0	2
N/A	2 ALS	2	2
N/A	1 BLS/1 ALS	1	2
2 BLS	2 ALS	2	4
3 BLS	2 ALS	2	5
4 BLS	2 ALS	2	6
1 BLS/1 ALS	1 BLS/1 ALS	2	4
2 BLS/1 ALS	1 BLS/1 ALS	2	5
3 BLS/1 ALS	1 BLS/1 ALS	2	6
2 BLS	1 BLS/1 ALS	1	4
3 BLS	1 BLS/1 ALS	1	5
4 BLS	1 BLS/1 ALS	1	6
1 BLS/1 ALS	2 BLS	1	4
2 BLS/1 ALS	2 BLS	1	5
3 BLS/1 ALS	2 BLS	1	6

Table 1: Crew Configurations for Time-to-Task Experiments

Radio Communication

Interoperability of radio equipment used by both participating departments made it possible to use regular duty radios for communication during the experiments. Company officers were instructed to use radios as they would in an actual incident. Montgomery County Fire and Rescue Communications recorded all radio interaction as a means of data backup. Once all data quality control measures were complete, the records were then overwritten as a routine procedure.

Task Timers

Ten observers/timers, trained in the use of identical standard stop watches with split-time feature, recorded time-to-task data for each field experiment. To assure understanding on the observed tasks, firefighters were used as timers, each assigned to specific tasks to observe and record the start and end times.

To enhance accuracy and consistency during recording times, the data recording sheets used several different colors for the tasks (see Appendix A). Each timer was assigned tasks that were coded in the same color as the recording sheet. All timers wore high-visibility safety gear on the incident scene.

Video records

In addition to the timers, video documentation provided a backup for timed tasks and for quality control. Cameras were used to record EMS scene activity from varied vantage points. Observer/timer data were compared to video records as part of the quality control process.

Crew Assignment

Crews from each department that regularly operated together were assigned to work as either a first responder crew or ambulance transport crew in each scenario. Both Fairfax County and Montgomery County crews participated in the experiment.

Crews assigned to each responding company position in one scenario were assigned to another responding company position in subsequent scenarios, with the objective of minimizing learning from one experiment to another. For example, crews in the role of first responder in the morning scenario might be assigned to the ambulance transport crew in the afternoon, thus eliminating learning the exact repetition of a task as a factor in time to completion. Additionally, participating crews from both Montgomery County and Fairfax County were from three different shifts, further reducing opportunities for participant repetition in any one position.

Props

Crews were assigned specific equipment lists to bring for this scenario. All equipment used was actual working equipment from the units assigned to the scenario. Specific items included in all scenarios were an airway bag, medical bag, oxygen cylinder, ECG monitor defibrillator, cot, and clipboard. Items specific to a particular scenario will be listed in that section of the report, including manikins and a live individual acting as a patient.

[7] Technical experts included Greg Mears, Michael McAdams, and Philip Pommerening. More information about the experts is presented in the Acknowledgements later in this report.

Safety Protocols

Participant safety was a primary concern in conducting the experiments. All participants and experiments complied with guidelines and recommendations as outlined in NFPA 450: *Guide for Emergency Medical Services and Systems*, NFPA 1500: *Standard on Fire Department Occupational Safety and Health Program*, and NFPA 1999: *Standard on Protective Clothing for Emergency Medical Operations*.

Figure 3: Safety Officer

A safety officer from the Montgomery County Fire and Rescue Department was assigned to oversee all experiments.

The safety officer ensured all protocols concerning participant safety, under both real and experimental conditions were followed. This included wearing the correct personal protective equipment, vehicle maneuvering, and overall scene safety. The safety officer participated in all orientation activities and daily briefings. The safety officer had full authority to terminate any operation if any safety violation was observed. Radio communication was always available.

A closely related concern to firefighter safety and readiness to repeat experiments with equivalent performance was adequate rehabilitation. Each "team" of participants had ample time between experiments to rest and rehydrate.

Response Time Assumptions

Response time assumptions were made based on time objectives set forth in NFPA 1710. Time stagger allocations were set by project technical advisors in order to assess the impact of arriving unit time separation on task start and completion times, as well as overall scene time. Table 2 shows the values assigned to the various segments in overall response time.

Event Occurrence = time zero
60 seconds for recognition and call to 9-1-1
90 seconds for call processing and dispatch
60 seconds for responder turnout
Travel time = first responder engine = 420 seconds post event
Ambulance = 600 seconds post event

Table 2: Response Time Assumptions

Figure 4: Ascending Stairs to Access Patient

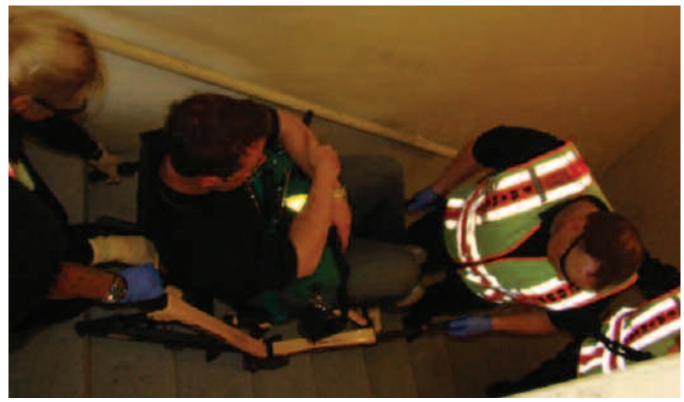

Figure 5: Carrying Patient Using Stair Chair

Figure 6: Trauma Patient Assessment

Figure 7: Trauma Patient Spinal Immobilization

Figure 8: Trauma Patient Packaging

Figure 9: Loading Patient on to Stretcher for Transport

Figure 10: Cardiac Patient Assessment

Figure 11: Cardiac Patient Intubation

Figure 12: Cardiac Patient I.V. & Medication Admin.

Figure 13: Moving Patient for Transport

Part 1: Patient Access and Removal from Incident Scene

Historically, total response time has been measured from the time a responding unit leaves a fire station until the time the unit arrives at the incident location. However, some studies suggest that total response time should include the additional time to locate and access the patient. Previous studies have shown a substantial time difference between the time the first responder arrives on scene and the time of patient access. One study noted that the patient access time interval represented 24 % of the total EMS response time interval among calls originating less than three floors above or three floors below ground and 32 % of those located three or more stories above ground (Morrison et al., 2005).

This study quantifies the time interval from arrival at the incident address until the crew begins the patient assessment, known as "at patient arrival time." The experiment assumed the patient was on the 3rd floor of a garden style apartment complex with stair access. This is representative of a typical structure to which firefighters respond in many residential neighborhoods. Patient assessment and treatment were not performed during the patient access and removal experiment. The primary purpose of this part of the experiment was to ascertain patient access and removal times. This part of the experiment was conducted separately from the patient care scenarios in an effort to establish distinctive timelines for patient access and removal separate from the patient care scenarios where on scene time can vary widely based on patient illness or injury.

Incident Scene

Garden Apartment Complex Scenario:

Firefighters from Fairfax County (VA) and Montgomery County (MD) simulated an initial EMS response for a patient with difficulty breathing in a garden style apartment building, represented by Simulation Lab #1 on the grounds of the Montgomery County Safety Training Academy in Rockville, MD. Simulation Lab #1 is a seven-story building, consisting of concrete scissor stairwells leading to the top floor of the building. The front of the building was equipped with a Knox Box, which firefighters accessed before entering the building. This task was typical of security access at any apartment complex.

Apparatus and crews were staged approximately 500 ft (150 m) from the Montgomery County Simulation Lab #1. Apparatus responded to the incident location, personnel dismounted and assembled equipment. Equipment included a defibrillator, airway bag, oxygen, and drug bag. Additionally, ambulance crews were required to bring the stair chair for patient packaging and removal. A crew member obtained an access key from the Knox Box and gained entry. Once crews entered the building they proceeded with the equipment to locate the patient on the third floor stairwell landing.

Patient assessment and treatment were not performed in this part of the experiments. In each experiment, the patient was packaged onto a stair chair, and then the patient and equipment were carried down three flights of stairs and out of the building. The patient was then transferred to a stretcher and loaded into the ambulance for transport.

Tasks

Tasks for the garden apartment scenario for patient access and removal are delineated in Table 3.

Tasks	Measurement Parameters
1. Arrive on Scene	START- Engine stopped at building - Ambulance stopped at building - Wheels stopped/brake engaged
2. Assemble Equipment	START- Personnel off engine - Personnel off ambulance STOP- Equipment in hand moving toward patient
3. Conduct size-up/Scene safety	START- Officer off engine - Officer off ambulance STOP- Officer begins scene report
4. Enter door/building Knox Box or access code	START- Touch door STOP- Door open
5. Ascend stairs (three stories)	START- Personnel with foot on first stair STOP- Crew assembled at top of stairs
6. Package patient	START- Load onto stair chair with monitor, straps in place STOP- Moving patient out towards exit
7. Descend stairs	START- Personnel with foot on first stair STOP- Crew and patient at bottom of stairs
8. Exit door/building	START- Personnel exits building with patient on stair chair
9 Transfer patient to cot/stretcher	START- Begin transfer of patient onto cot/ stretcher with monitor, straps in place STOP- Patient secure on cot/stretcher
10. Turn ambulance for loading	START- Firefighter in ambulance driver seat STOP- Ambulance positioned for patient loading
11. Load Ambulance	START- Patient secure on cot/stretcher STOP- Patient loaded and ambulance doors

Table 3: Time-to-Task Measures for Garden Apartment Scenario/Patient Access and Removal

Part 2: Trauma Patient

The trauma scenario involved time-to-task experiments focusing on a labor intensive traumatic scenario. In the experiment, a patient had fallen from a 25 ft (7.5 m) ladder at a construction site. This part of the experiment quantified the time intervals for different crew sizes and configurations responding to this event.

Incident Scene

The gymnasium at the Montgomery County (MD) Public Safety Training Academy was used for the trauma experiments. A classroom at the facility was also used for crew orientation and staging. Prior to the start of the experiments, participants were provided with the scenario background. Specifically, the call originated from a construction site that was only accessible by foot.

When cued, crews entered the gym and walked approximately 40 ft (12 m), carrying an airway bag (including suction), oxygen, spinal mobilization equipment, a trauma bag, and a radio and clip board. The "patient" was a 150 lb (68 kg) training manikin "voiced" when prompted by one of the timers. The patient could answer basic questions until the point in the sequence where the patient lost consciousness. During the scenario, when it became clear that the patient needed to be transported, a backboard was brought into the scene by the ambulance crew. After packaging the patient onto a backboard, the patient and equipment were carried out of the construction site to a waiting stretcher approximately 40 ft (12 m) away.

Tasks

The on-scene tasks focused on the activities firefighters regularly perform after they arrive on the scene of a patient with a traumatic injury. The experiments compared time-to-task performance based on varying crew sizes and ALS configurations.

Forty-five trauma experiments were conducted to assess the time it took various crew sizes and ALS configurations to complete the assigned tasks. Time between arrival of the first responding unit and ambulance transport unit was held constant at three minutes.

The following narrative describes the general sequence of activities in Part 2 of the experiments.

The first responding unit arrived, conducted a size-up and initial life safety assessment of the area, and gathered the appropriate equipment. The crew, with equipment, then proceeded into the construction site and located the patient. The patient was lying supine on the ground. The responders introduced themselves, obtained patient consent to examine and treat, and immediately initiated cervical spinal immobilization precautions and the patient interview. Other crew members then followed Airway, Breathing, and Circulation (A, B, C's) protocols. During the patient assessment, it was revealed the patient had a head laceration and an angulated fracture of the tibia/fibula (closed) on the right leg. Patient information was recorded on a standardized form created for the experiments and can be seen in Appendix B.

During the scenario, when the backboard straps were secure, the patient went into respiratory arrest. Crews then rechecked vital signs which revealed the patient had stopped breathing. The crew immediately began respiratory arrest protocol including administering a patent patient airway using an endotracheal tube. Intubation was performed using strict spinal immobilization restriction. With the airway established, the patient was then ventilated using a bag-valve-mask and patient packaging was completed. Crews then carried the patient and all equipment out of the construction site to the waiting stretcher.

Tasks	Measurement Parameters
1 At patient	START- Personnel at patient side One point in time
2. Spinal motion restriction	START- Personnel touches patient to position for immobilization STOP- Patient supine and personnel holding neck tension, patient immobilized
3. A, B, C's	START- At patient STOP- Personnel notes A, B, C's intact
4. Patient interview	START- Ask three questions 1) What happened? 2) Where are you hurting? 3) What is your name STOP- Questions answered 1) Don't know 2) Head and right leg 3) Joe
5. Body sweep- find laceration on head and angulated fracture of tibia/fibula (closed) on Right leg	START- Personnel starts patient survey/sweep- touches patient and explains "Sir, I am going to check you for injuries" STOP- Personnel locates/identifies head laceration and leg fracture. Head-to-toe sweep complete. Starts on right, goes down, the back up left side to shoulder
6. Oxygen (O^2) administration- face mask	START- Accessing O^2 administration equipment STOP- Mask on patient and O^2 on high flow
7. Check vitals	START- Accessing equipment for any vitals check Blood pressure (BP) cuff, stethoscope, cardiac monitor, or pulse oximiter STOP- All vitals checked and reported
8. Expose patient as indicated	START- Touch patient clothing for removal STOP- Patient chest and legs exposed
9. Control bleeding	START- Personnel accesses equipment (bandages) STOP- Head wound bandaged (gauze and tape)
10. Splint leg	START- Personnel accesses equipment (splint) or touch foot to check pulse STOP- Leg splinted- pulse check when splint in place
11. Back board	START- Personnel accesses equipment (board, collar, straps) STOP- Patient secured on back board- all straps in place
Movement causes labored breathing = Agonal Respiration >> Patient Vomits >> Patient Unconscious	
12. Airway- Endotracheal (ET) intubation with spinal motion restriction (completed on ground due to distance from transport unit)	START- Paramedic (and assisting personnel) touches airway bag (including laryngeal scope, ET tube, syringe, and stethoscope) STOP- ET tube in place, cuff inflated, lung sounds checked, and tube secured
13. Bag Valve Mask (BVM)	START- Paramedic touches BVM STOP- BVM- first squeeze
14. Package patient/move for transport	START- Pick up back board to move to cot/stretcher STOP- Ambulance door closed

Table 4: Time-to-Task Measures for Trauma Scenerio

Fourteen tasks were completed in the trauma experiments. Meticulous procedures gathered data to measure key areas of focus, such as individual task start times, task completion times, and overall scenario performance times. Each task was assigned a standardized start and end marker, such as accessing oxygen equipment (start) until the mask was on the patient and oxygen was flowing (stop). The 14 tasks can be seen in Table 4.

Part 3: Cardiac Patient

The cardiac scenario involved time-to-task experiments focusing on a labor-intensive medical event, i.e., a patient that experiences a myocardial infarction leading to cardiac arrest. This part of the experiment quantified the time intervals for different crew sizes and ALS configurations responding to the event.

Incident Scene

The cardiac experiments were conducted in a laboratory at the Fairfax County Fire and Rescue Department EMS Simulation Center. The Simulation Center houses classrooms, laboratories, and offices for training of EMT's and paramedics. Assorted furniture was staged in the laboratory to duplicate a "home" setting. When cued, crews entered the room and proceeded approximately 10 ft (3 m) to the patient. The patient was represented by SimMan® by Laerdal. SimMan® is an adult-sized manikin that can produce vital signs including, a pulse, heartbeat, lung sounds, blood pressure and other signs noted in real humans. SimMan® also had vocal capabilities such as speaking or crying (Laerdal, 2010). SimMan® was operated remotely from a control booth adjacent to the laboratory.

Prior to the start of the experiments, participants were provided with the scenario background. Specifically, the call originated from a private residence and the caller complained of chest pain. Responders entered the room carrying an airway bag, oxygen, drug bag, and defibrillator. The defibrillator was either an AED and/or a 12-Lead ECG model defibrillator dependent upon the arrival of ALS trained personnel. During the scenario, the patient went into cardiac arrest on cue and crews reacted by changing their path of patient care for chest pain to a more time-critical path of treatment for a pulseless, apneic patient. When crews had completed on-scene patient care tasks, the patient was packaged onto a backboard and stretcher. The patient and all equipment were removed from the room to conclude the experiment.

Tasks

As noted previously, the on-scene tasks focused on the activities firefighters perform after they arrive on the scene of a patient with a cardiac emergency. The experiments compared crew performance for a typical cardiac scenario using a combination of varying crew sizes and configurations.

Forty-five cardiac experiments were conducted to assess the time it took various crew sizes and configurations to complete the assigned tasks. Time between arrival of the first responding unit and ambulance transport unit was held constant at three minutes.

The following narrative describes the general sequence of activities in Part 3 of the experiments.

> The first responding unit arrived, conducted a size-up and initial life safety assessment of the building and gathered the appropriate equipment. The crew, with equipment, then proceeded to the front door of the patient residence, knocked, and entered. After confirming the scene was safe, patient assessment was begun.
>
> The responders introduced themselves, obtained the patient's consent to examine and treat and then proceeded to conduct the patient interview. The patient interview was standardized to include SAMPLE and OPQRST protocols. Patient information was recorded on a standardized form created for the experiments and can be seen in Appendix C.
>
> During the scenario, on cue, the patient went into cardiac arrest. Upon patient arrest, the crew rechecked the patient's vital signs which revealed the patient had stopped breathing and had no pulse.
>
> The crew then followed protocol and moved the patient to the floor where they could immediately begin CPR and prepare to administer defibrillation. Study protocol then followed Advanced Cardiac Life Support guidelines for patient care (AHA, 2005).

Twenty-two tasks were completed in the cardiac experiments. Meticulous procedures gathered data to measure key areas of focus, such as individual task start times, task completion times, and overall scenario performance times. Each task was assigned a standardized start and end marker, such as accessing oxygen tank equipment (start) until the mask was on patient and oxygen was flowing (stop). The 22 tasks can be seen in Table 5.

Table 5: Time-to-Task Measures for Cardiac Scenerio

Tasks	Measurement Parameters
1. Identify and enter door/ patient quarters	START- Enter door STOP- One point in time
2. At patient	START- Personnel at patient side STOP - One point in time
3. A, B, C's	START- At patient's side STOP- Personnel notes A, B, C's intact
4. Patient interview	START- Ask patient history questions, "SAMPLE", and "OPQRST" pain survey STOP- Questions asked and answered
5. O^2 administration	START- Accessing O^2 administration equipment "Let's put patient on four liters O^2 " STOP- Cannula on patient and O^2 flowing
6. Check vitals (pulse, respiratory rate, BP, pulse oximetry)	START- Accessing equipment for vitals check (BP cuff, stethoscope, cardiac monitor, or pulse oximeter) STOP- All vitals checked and reported BLS = Pulse, respiratory rate, BP, and pulse oximetry ALS = cardiac monitor, 12-lead in place
7. ALS vitals- Electrocardiogram (ECG) 12-lead	START- Touch patient shirt for removal STOP- 12-lead monitor in place
8. Expose patient	START- Touch patient shirt for removal STOP- Chest exposed
PATIENT ARREST	START - Timer cued when task complete STOP - Witnessed arrest
9. Position Patient	START- Touch patient to move to floor STOP- Patient supine on floor
10. A, B, C's	START- Personnel touches patient STOP- Airway, breathing, and pulse checked and reported "No pulse, no breathing"
11. Apply defibrillator pads	START- Access defibrillation equipment (pads) STOP- Pads in place (4)- push analyze button
12. Defibrillate- shock #1 Shock works = NO	START- Push button to charge machine STOP- Shock delivered
13. A, B, C's	START- Personnel touches patient STOP- Airway, breathing and pulse checked and reported "No pulse, no breathing"
14. CPR- bag valve	START- Lead personnel says "start CPR" STOP- CPR begun- including chest compressions and bag valve mask
15. Airway intubation- ET	START- Paramedic (and assisting personnel) accesses equipment including laryngeal scope, ET tube, syringe, and tape STOP- ET tube in place, cuff inflated, and lung sounds checked and tube secured
16. Intravenous (IV) access	START- Paramedic (and assisting personnel) accesses equipment including catheter, bag, tubing, tourniquet, and tape STOP- IV in place, taped, and fluid running
17. Meds- 1 Epinephrine (Epi)	START- Paramedic (and assisting personnel) accesses equipment- "let's push 1 Epi" STOP- Epi pushed in IV line- "Epi in"
18. AED auto countdown "Analyze patient"	START- push button to analyze >>>>>>>>>>>>>
19. Defibrillate- shock #2 Shock works = YES	START- Push button to charge machine STOP- Shock delivered
20. Check vitals (Pulse, Respiratory rate, BP, pulse oximetry) Patient unconscious	START- Accessing equipment for vitals check (BP cuff, stethoscope, cardiac monitor, or pulse oximeter) STOP- All vitals checked and reported (pulse, respiratory rate, BP, pulse oximetry)
21. Meds (1 lidocaine bolus)	START- Paramedic (and assisting personnel) accesses equipment "Let's push 1 bolus lidocaine" STOP- Lidocaine pushed in IV line "Lidocaine in"
22. Package patient	START- Access equipment- (board, spider straps) STOP- Stretcher, personnel, and equipment out door

Analysis of Experimental Results

This section describes the analytic approaches used to address the research objectives of the study. The statistical methods used to analyze the EMS time-to-task observations are presented. Then the time-to-task results are reported for EMS responses in three scenarios:

- access and removal of patient;
- a trauma event; and
- a cardiac event.

Time-to-Task Analysis

Time-to-task data were compiled into a database and assessed for outliers and missing entries. As is common in a repeated experiment with many pieces of data to be entered, occasionally data elements were not collected. Missing data occurred in less than 1 % of timing observations. Such instances were reviewed via video and/or radio tapes. Missing data attributable to timer error were replaced by the time observed in the video. Where video and/or radio documentation proved inadequate, missing data were imputed with the mean of the observed corresponding task times from the other two experiments. The extremely low occurrence of missing data and associated imputation should have a negligible impact on the statistical findings in the analyses.

Data Queries

The statistical methods used to analyze the time-to-task data were driven by the principal goals of this research project —- to assess the effect of crew size, ALS placement on the responding crews, and the number of ALS trained personnel in the crew configuration on time-to-task for critical steps in each EMS scenario. The research goal motivated the development of four specific research questions (see Figure 14) that in turn pointed to specific statistical analyses to generate inference and insight.

TIME-TO-TASK RESEARCH QUESTIONS

For Response Access & Removal:

1. What are the effects of first responder crew size regardless of ALS placement with respect to:

   a. reaching a patient?
   b. removing a patient after packaging?

For Cardiac and Trauma Scenarios (task timings measured between *arrival at patient* to the *completion of patient packaging*):

1. What is the effect of crew size on EMS task times?

2. What is the effect of ALS personnel placement on EMS task times?

3. What is the effect of the number of ALS trained personnel on EMS task times?

Figure 14: Research Questions for Time-to-Task Experiments

Statistical Methods

The analysis of the time-to-task data involved a sequence of ordinary least squares regression models. The models relate the *experimental outcomes* (i.e., various measures of time — start time, completion time, or duration of the task) to *key dimensions* for each scenario as follows:

For Access and Removal:

- first responder crew size (regardless of ALS placement), and
- ambulance-only versus ambulance with first responder engine with varying crew sizes.

For Trauma and Cardiac scenarios:

- presence of an engine at the scene,
- crew size on the first responder engine, and
- placement and number of ALS personnel (on the engine, on the ambulance, or both).

To account for these dimensions in the analyses, indicator variables representing each key dimension were employed. For example, for the trauma and cardiac scenarios there were indicators for the number of first responders on the engine, three indicators of the assignment of ALS personnel to the ambulance or engine, and indicators for the "no engine" scenarios.

Using these indicators, sets of regression equations were developed for the analysis of each scenario. Indicators corresponding to the three scenarios and multiple dimensions listed above were included. For example, when an engine was sent, the number of first responders (two, three, or four) assigned to the engine were varied, as well as the placement of ALS personnel (one ALS on the engine only; one on the ambulance only; two on the ambulance; and one ALS each on the ambulance and engine). When no engine was sent, zero, one, or two ALS personnel were placed on the ambulance.

The regression equations took the form:

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_k x_{ik} + \varepsilon_i$$

Where the x_k represented the test conditions such as presence of an engine or placement of ALS personnel, and the dependent variable y represents the observed outcome (e.g., task duration).

The model coefficients from the completed regressions provided direct estimates of the change in time associated with the number of first responders (e.g., four versus two, three versus two), as well as the change in time associated with alternative assignments of ALS personnel. These estimates are generally the same as those obtained by comparing the difference in means across groups. However, for a small number of outcomes, the estimates differ from those obtained using difference in means by appropriately accounting for data that are missing in particular scenarios.

Table 6 to Table 8 present the list of time-related outcomes that were used to explore effects on outcomes for patient access/removal, as well as for cardiac and trauma scenarios, respectively. Not all tasks were subjected to testing for this report. Only substantively critical milestones in the task sequence were considered. For instance, the *assembly of equipment* and *conduct* *of size*-up were **not** assessed for the Access and Removal scenario. Instead, the elapsed time from arrival on scene to reaching the patient (as denoted by completing the ascent of stairs) was determined to be of primary importance. Similarly, the elapsed time between packaging patient and the completion of loading the ambulance was assessed rather than individual timings of any task in the sequence between these two major milestones. Similar judicious choices of critical milestones were made in the assessments of trauma and cardiac, and these are depicted in the outcome measures tables.

Although several of the analytic questions of interest can be obtained directly from the model, others require a linear combination of the coefficients. The statistical software (Stata) calculates both the desired combination of coefficients and the measure of statistical significance via t-test.

	ACCESS & REMOVAL -- Outcome Measures		
	Task:	***Elapsed Time Arrival to Completion***	***Elapsed Time Package Patient to End of Loading***
1	**Arrive on Scene**		
2	Assemble Equipment		
3	Conduct Size Up - Scene Safety		
4	Enter Door - Building - 'Knox box'		
5	**Ascend - Stairs (2 stories—ground floor to third floor)**	**X**	
6	**Package Patient - stair chair**		
7	Descend Stairs (2 stories – third floor to ground) with Patient		
8	Exit Door - Building		
9	Transfer Patient to Cot/stretcher		
10	Turn Ambulance for Loading		
11	**Load Ambulance / Seat Belt**		**X**

Table 6: Outcome Measures for Access and Removal Scenario by Task

	Task:	TRAUMA -- Outcome Measures: *Elapsed Time Until Start*	*Task Duration*	*Elapsed Time to Completion*
1	At Patient - Engine			
2	At Patient - Ambulance			
3	Spinal Motion Restriction	X		
4	ABC's	X	X	
5	Patient Interview	X		
6	Body Sweep	X	X	
7	O2 Administration	X		
8	Check Vitals	X	X	
9	Expose Patient	X		
10	Wound Bandaged	X		
11	Splint Leg	X	X	
12	Back Board	X	X	
13	Airway - Intubation ET	X	X	
14	Bag Valve Mask	X		
15	Package Patient /Equipment	X		X

Table 7: Outcome Measures for Trauma Scenario by Task

	Task:	CARDIAC -- Outcome Measures: *Elapsed Time Until Start*	*Task Duration*	*Elapsed Time to Completion (from arrest)*
1	At Patient			
2	ABCs	X	X	
3	Patient Interview	X		
4	O2 Administration	X		
5	Check Vitals	X	X	
6	ALS Vitals 12-Lead	X		
7	Expose Chest	X		
8	Patient Arrest			
9	Position Patient			
10	ABC's *(from Arrest time)*	X		
11	Defibrillator pads *(from Arrest time)*	X		
12	Analyze / Shock #1	X		
13	ABC's after Shock #1 *(from Arrest time)*	X		
14	CPR			
15	Airway Intubation *(from Arrest time)*		X	
16	IV Access	X	X	
17	Meds (Epinephrine) *(from Arrest time)*	X		
18	Analyze / Shock #2 *(from Arrest time)*	X		
19	ROSC			
20	Meds (Lidocaine) *(from Arrest time)*	X		
21	Package Patient/Equip *(from Arrest time)*	X		X

Table 8: Outcome Measures for Cardiac Scenario by Task

The objective of the experiments was to determine the relative effects of first responder crew size, ALS provider placement and the number of ALS providers on the effectiveness of the EMS crews relative to key milestones among the task intervention times for each of the three scenarios. The experimental results are discussed below.

Of the various EMS tasks measured during the experiments, those described in the remainder of this section were determined to have significant differences based on the crew configurations studied. Their differential outcomes based on variation of first responder crew size, ALS crew configuration, and the number of ALS level providers on scene, are statistically significant at the 95 % confidence level or better. Times reported in seconds are rounded to the nearest five seconds. As a final technical note, we did not adjust significance levels to take into account the large number of tests being conducted. The observed number of significant results far exceeds what would be expected simply by chance.

Measurement Uncertainty

The measurement of tasks using stopwatch timing has unique components of uncertainly that must be evaluated in order to determine the fidelity of the data. All timers were equipped with the same model of digital stopwatch with a resolution of 0.01s and an uncertainty of $\pm$ 3s per 24 hr. The uncertainty of the timing mechanism in the stopwatches is small enough over the duration of an experiment that it can be neglected.

There are three components of uncertainty when using people to time the EMS tasks. First, timers may have a bias depending on whether they record the time in anticipation of, or in reaction to an event. Second, multiple timers were used to record all tasks. Third, the mode of the stimulus to which the timer is reacting—audible or visual.

Milestone events in the EMS experiments were recorded both audibly and visually. A test series described in the *NIST Recommended Practice Guide for Stopwatch and Timer Calibrations* noted that reaction times for the two modes of stimulus to be approximately the same, so this component can be neglected. Based on the assumptions made in the Residential Fireground Experiments (Averill et al., 2010), bias estimated for timer reaction time was determined to be 230 ms as a worst case scenario.

Considering the above, the total estimated combined standard uncertainty is $\pm$ 3.23 s. The magnitude of uncertainty associated with these measurements has no impact on the statistical inferences presented in this report.

How to Interpret the Time-to-Task Graphs

Figure 15 presents a sample of a time-to-task results graph. Each crew size/configuration has a bar graphic showing the start time and completion time for the task. Visually, bars start from the left and extend horizontally across the graph based on time expended by various EMS crew configurations. The length of the bar graphic is a visualization of the duration of the task. Longer bars indicate longer duration times. Actual time data are also shown on each bar.

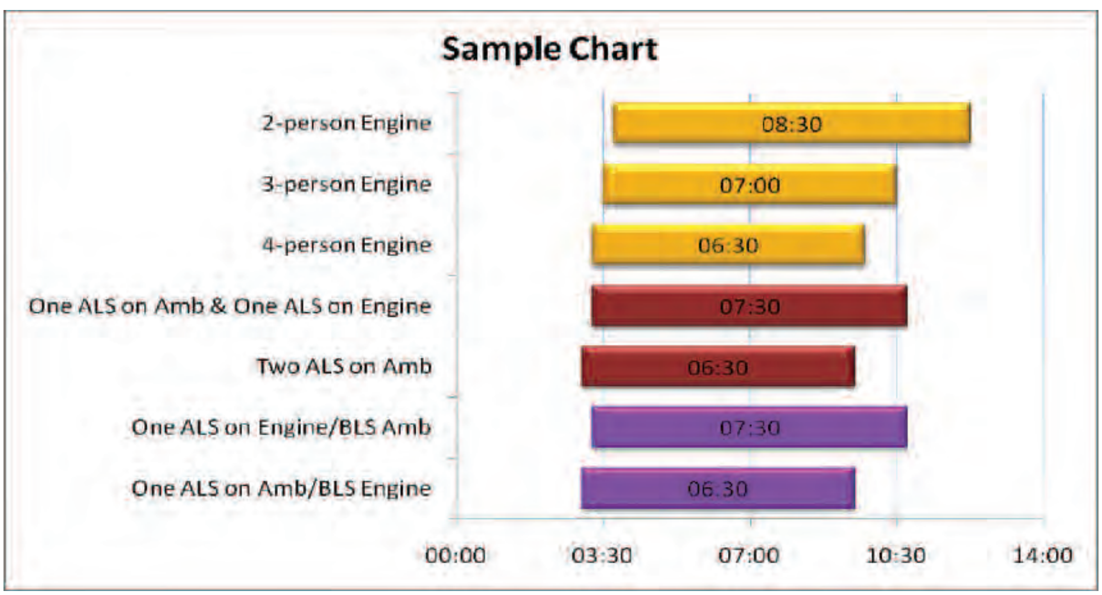

Figure 15: Sample Time-to-Task Graph

Time-to-Task Graphs

Part 1- Patient Access and Removal

Overall Scene Time (Time to complete all EMS tasks for Patient Access and Removal)

Access

The crews can differ in the time required to reach the patient (*access*) and in the time needed for patient *removal*. To address these tasks, sets of simulations were conducted by varying crew size on the first responding engine. Ambulance crews were held constant at two persons. As noted previously, the arrival times were staggered between the engine and the ambulance. When an ambulance was sent without a first responder engine, for measurement consistency, it was assumed to arrive at the scene *at the same time* as would an engine (i.e., there is no systematic, built-in delay).

The results for *patient access* show that two-person first responder crews take longer to reach a patient than configurations with larger crew sizes. Two-person crews finished the patient access tasks approximately *half a minute* later than larger first responder crews. Moreover, the ambulance crew alone finished with a time between that of the two-person and the larger first responder crews. The *ambulance alone* result is likely attributed to the removal of the staggered arrival time when first responder crews were not sent. (See Appendix E for the timings by staffing configuration, difference of means and associated t-tests.)

Patient Removal

The patient removal results show substantial differences associated with crew size. Crews with two-person first responder crews completed patient removal between (1.2 – 1.5) minutes slower than larger crews, depending on crew size. This is largely the result of work load in carrying equipment, supplies and the patient with fewer crew members. All crews with first responders completed removal substantially faster (by 2.6 min. - 4.1 min.) relative to the ambulance-only crew. Again, this is largely the result of the difficulty of carrying and loading the patient, as well as the equipment and supplies with only a two-person crew, given that one person must remain with the patient at all times. (See Appendix E)

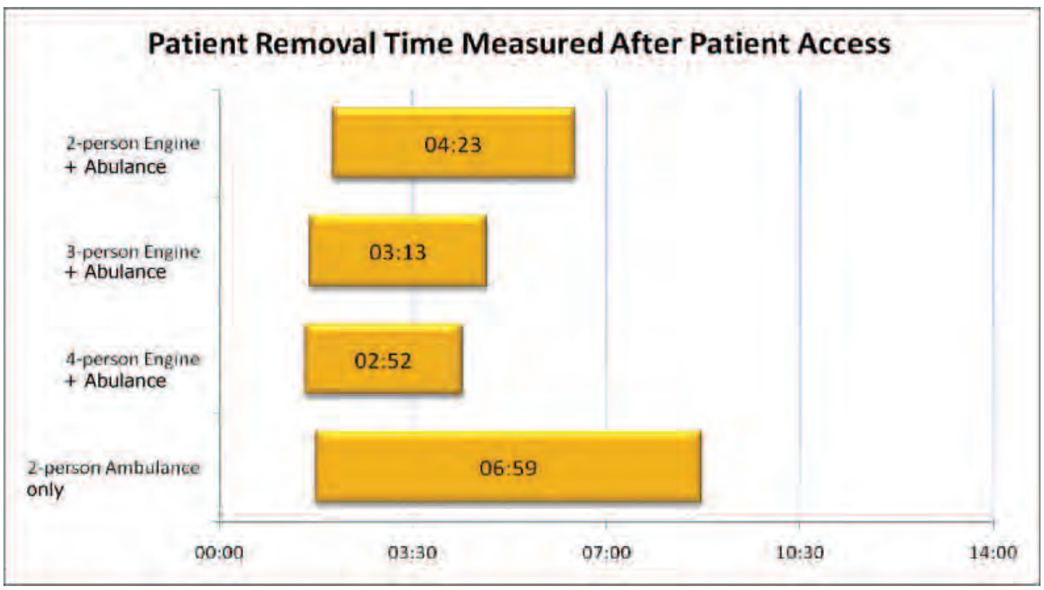

Figure 16: Patient Removal Time

Part 2- Multi-System Trauma

Overall Scene Time (Time to complete all EMS tasks for Trauma Patient)

As previously noted, for the trauma scenario part of the experiments, there was an assumed three minute stagger in arrival between the first responder crew and the ambulance crew.

Crews responding with one ALS provider on the engine and on the ambulance completed all trauma tasks 2.3 minutes (2 minutes and 16 seconds) faster than crews with a BLS engine and an ALS ambulance with two ALS level providers.

Crews responding with four-person first responder crews, regardless of ALS configuration, completed all trauma tasks 1.7 minutes (1 minute and 50 seconds) faster than first responder crews with three persons, and 3.4 minutes (3 minutes and 25 seconds) faster than first responder crews with two persons. This suggests that for trauma scenarios, the more hands available, the easier it is to implement the full portfolio of tasks to be completed.

The statistical tests that correspond to these findings appear in Appendix F. Appendix H shows the original regression coefficient estimates upon which the tests in Appendix F were constructed.

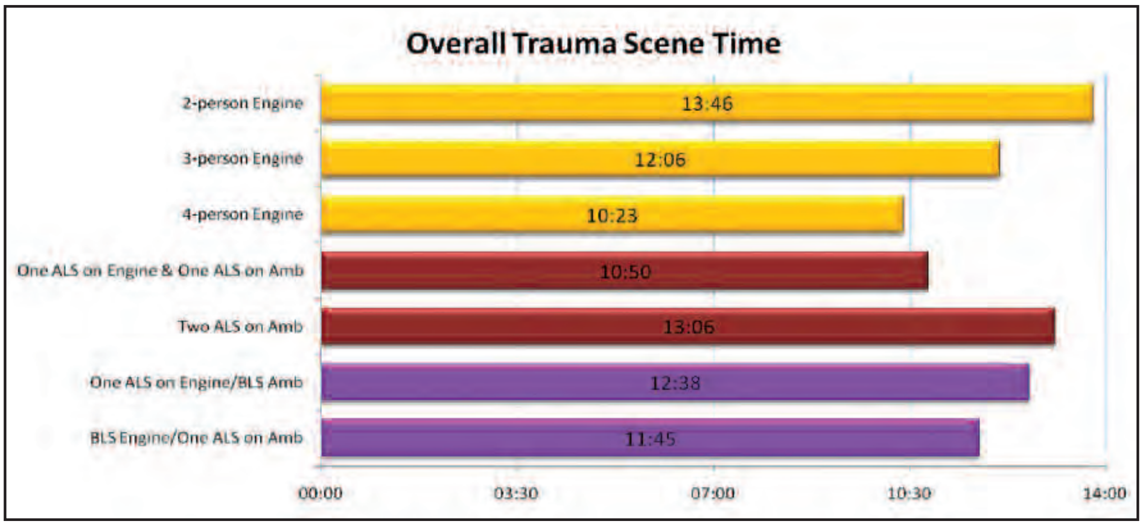

Figure 17: Overall Trauma Scene Time

Individual Task Times

Oxygen Administration

First responders with four-person crews were able to begin oxygen administration to the patient nearly a full minute (55 seconds) sooner than the three-person crew.

Vital Sign Assessment

First responders with four-person crews were able to begin checking the patient's vital signs nearly one minute (55 seconds) sooner than a two-person crew. They also completed the check about 80 seconds faster than the two-person crew. First responders with four-person crews were able to begin checking the patient's vital signs 30 seconds sooner than a three-person crew. To the extent that checking vitals is a critical task in a trauma response sequence, the reduction of half a minute to a minute of time could be seen as an important improvement.

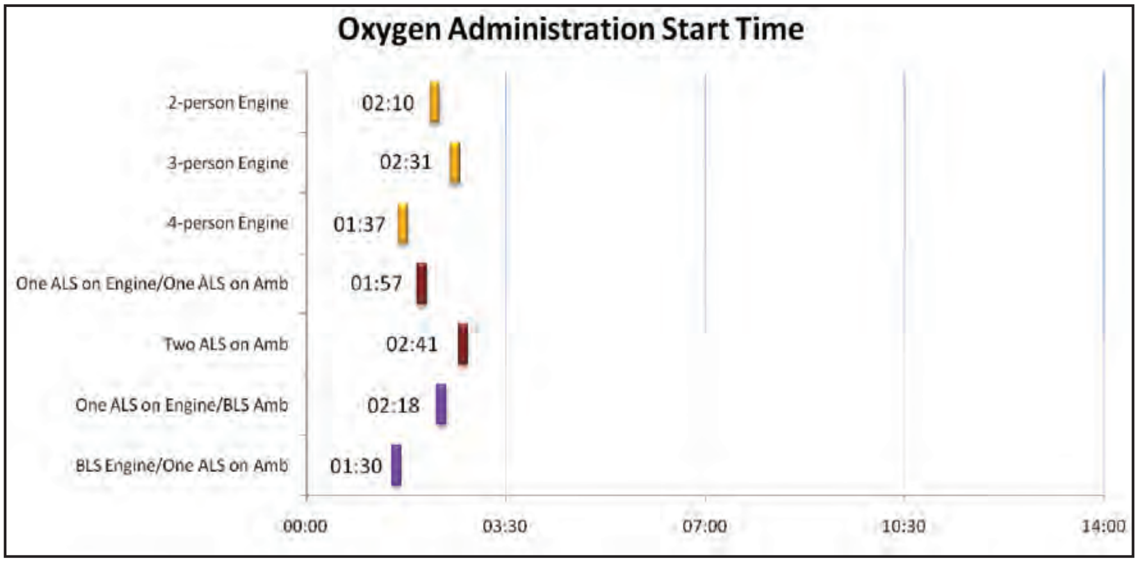

Figure 18: Oxygen Administration Start Time

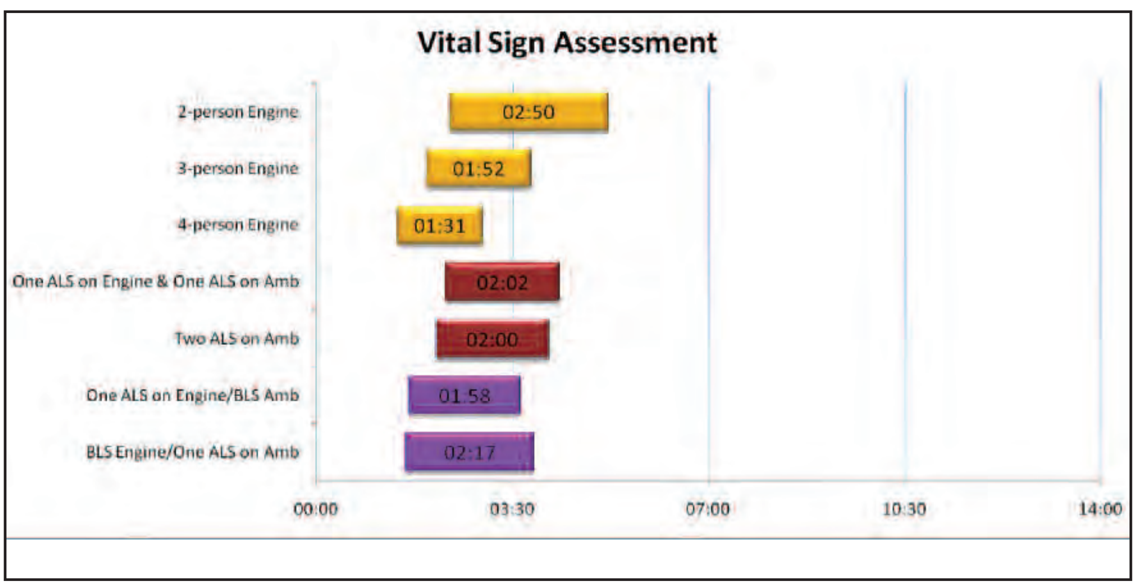

Figure 19: Vital Sign Assessment Start and Duration

Wound Bandaging

First responders with three-person crews were able to begin bandaging the patient's wounds a minute and 40 seconds sooner than first responders with two-person crews. The value of a four-person crew witnessed in the earlier tasks (e.g., checking vitals) did not manifest for this task.

Splint Leg

First responders with four-person crews were able to begin splinting the patient's leg approximately a minute faster than either the two- or three-person crews. A small advantage of a four-person crew re-emerges at this next step (i.e., following bandaging) in the response task sequence.

Crew configurations with one ALS provider on the first responding engine and one on the ambulance were able to begin splinting the patient's leg 40 seconds sooner than crews with two ALS providers on the ambulance.

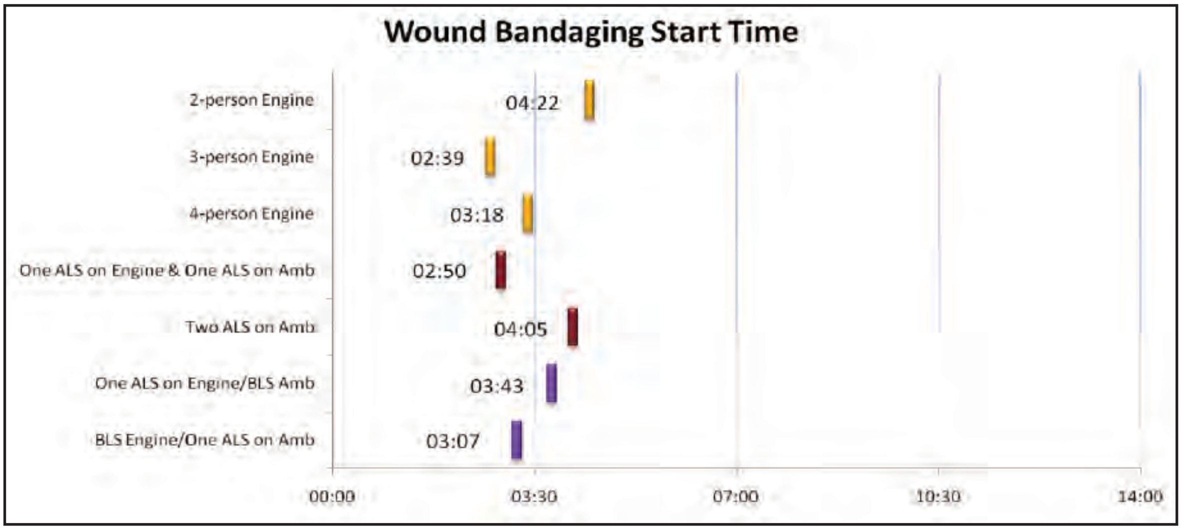

Figure 20: Wound Bandaging Start Time

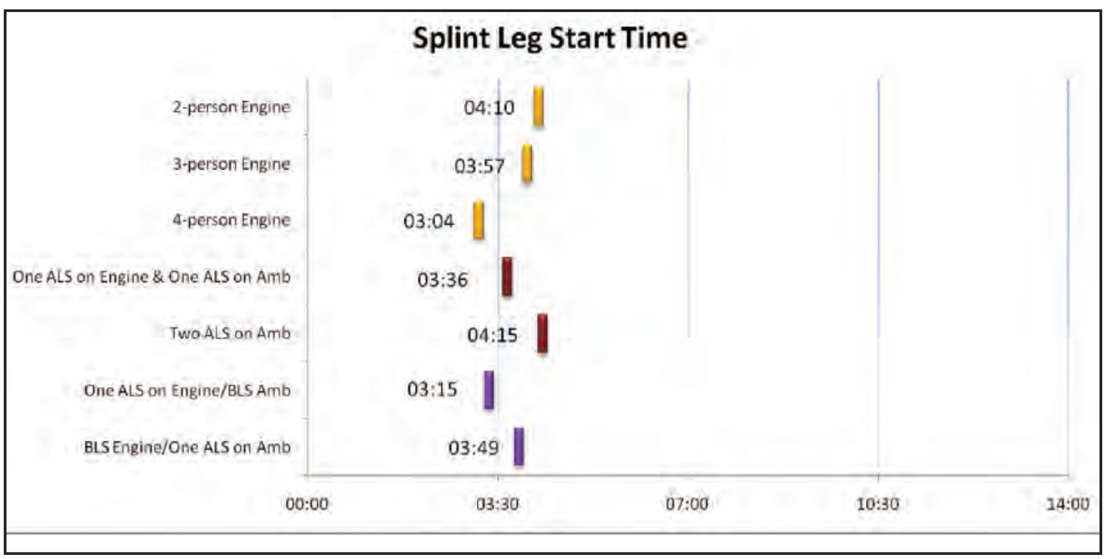

Figure 21: Splint Leg Start Time

Spinal Immobilization/ Back board

First responders with four-person crews were able to conduct spinal immobilization/back-boarding of the patient two minutes faster than either two- or three-person crews. No differences were observed based on placement or number of the ALS personnel.

Airway — Endotracheal Intubation

First responders with four-person crews were able to begin securing the patient's airway using endotracheal intubation two and one-half minutes (2 minutes and 35 seconds) sooner than the two-person crews and two minutes sooner than the three-person crews.

Crew configurations with one ALS provider on the first responding engine and one on the ambulance were able to begin securing the airway using endotracheal intubation one minute and 25 seconds sooner than crews with two ALS providers on the ambulance.

Additional personnel marginally speed up the intubation procedure. A second ALS person and having more than two persons on the engine each reduce the time of the intubation by half a minute.

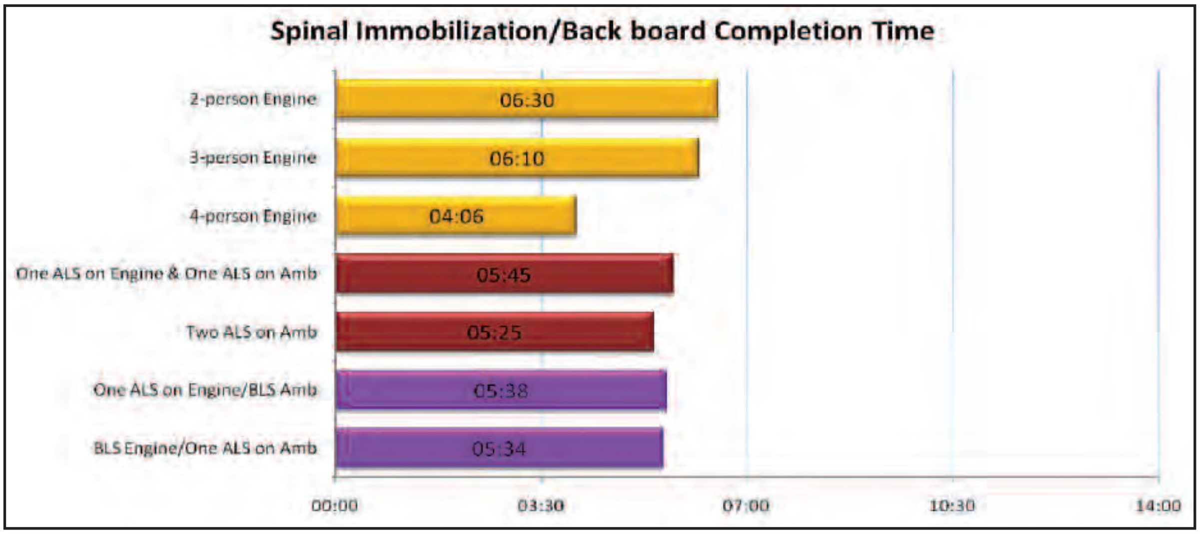

Figure 22: Spinal Immobilization Time Airway – Endotracheal Intubation

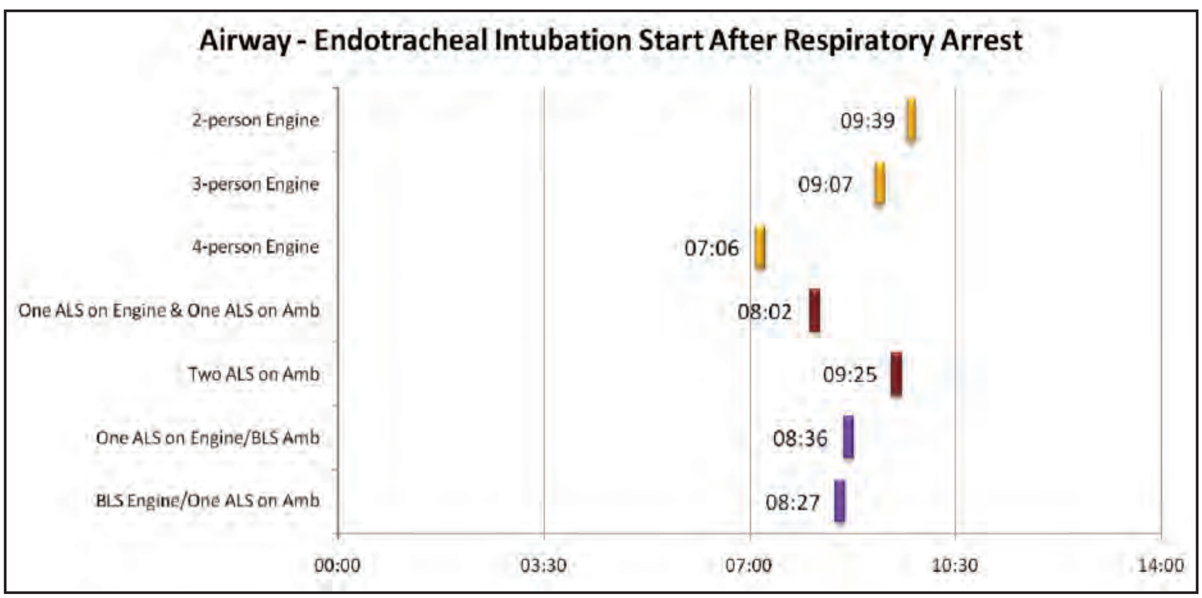

Figure 23: Airway – Intubation Start Time

Bag Valve Mask

First responders with four-person crews were able to begin bag valve mask ventilation after intubation two minutes and 35 seconds sooner than the two–person crews and nearly two minutes (110 seconds) sooner than the three-person crews.

Crew configurations with one ALS provider on the first responding engine and one on the ambulance were able to begin bag valve mask ventilation after intubation one and one-half minutes (one minute and 29 seconds) sooner than crews with two ALS providers on the ambulance.

Patient Packaging

Additional first responders reduce the times until the start and completion of packaging. First responders with four-person crews were able to begin patient packaging 3.1 minutes (three minutes and 5 seconds) sooner and complete all packaging activities moving toward transport nearly 3.4 minutes (three minutes and 25 seconds) sooner than the two-person crews. In addition, the four-person crews were able to begin patient packaging 1.6 minutes (one minute 35 seconds) sooner and complete all packaging activities moving toward transport 1.7 minutes (one minute 40 seconds) sooner than the three–person crews.

Crew configurations with one ALS provider on the first responding engine and one on the ambulance were able to begin patient packaging 2.1 minutes (two minutes and 5 seconds) sooner and complete all packaging activities moving toward transport 2.3 minutes (two minutes and 15 seconds) sooner than crews with both ALS personnel arriving on the ambulance. No differences were associated with placement of a single ALS

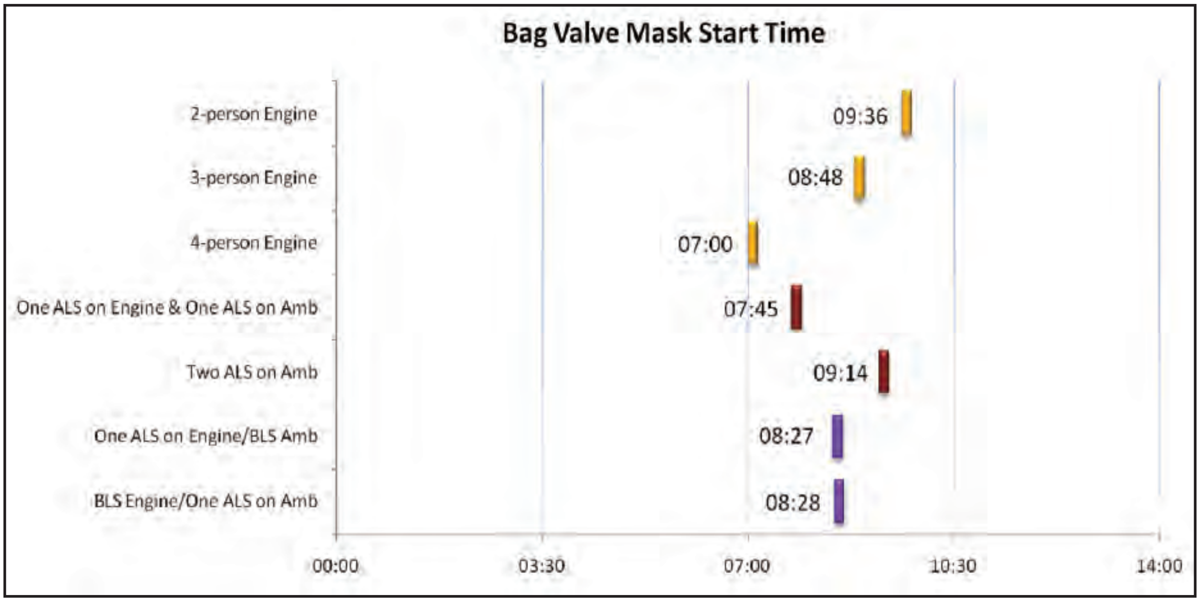

Figure 24: Bag Valve Mask Start Time

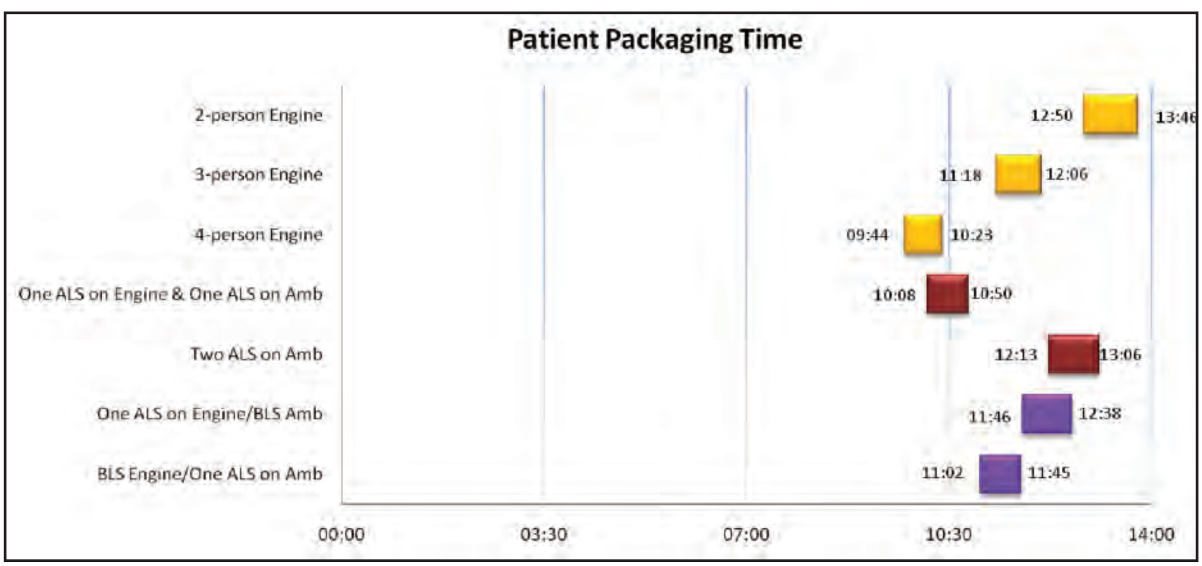

Figure 25: Patient Packaging Start and End Times

provider or with the availability of a second ALS provider.

Patterns in the Trauma Scenario

The preceding presentation focuses on the specific tasks that comprise the overall trauma response sequence. Examination of the collection of findings across tasks, reveals patterns that provide insight into how crew configurations affect trauma response. To examine this, the occurrences of significant differences of elapsed time to start by task were tabulated. Table 9 presents the task sequence and statistically significant differences when comparing ALS placement (Columns A and B) and contrasting crew sizes (Columns C – E) for the outcome "elapsed time to the start of a task." Column A shows a clear advantage to placing one ALS on the engine (with one on an ambulance that arrives three minutes later) versus two ALS on a later arriving ambulance. The time advantage manifests in the last third of the task sequence, beginning with splinting the leg. One explanation for this would be that that having an ALS on the engine creates small increments of time that cumulate and finally manifest (at a statistically significant level) beginning with splinting the leg and carrying forward to all subsequent tasks. Another factor may be that certain tasks may be performed concurrently rather than sequentially when enough hands are available at the scene and this leads to overall time reductions relative to smaller crews that are forced to complete some set of tasks sequentially.

No clear pattern emerges for starting time significant differences when contrasting the addition of a second ALS person (Column B). The same appears to be true for comparing the crew sizes of three versus two (see Column C).

On the other hand, distinct patterns are seen in Columns D and E of Table 9 which depict the comparison of four versus two and four versus three crew sizes, respectively. Although there is some evidence of real time savings (as far as elapsed time to start a task) for the middle third of tasks in the sequence (for example between O^2 administration and splint leg), a consistent pattern favoring a crew size of four is seen beginning with airway intubation and continuing through patient packaging.

Taken as a whole, Table 9 suggests that while a crew size of four may not consistently produce time savings in the start of tasks initially in the trauma task sequence, there are clear advantages as work progresses, beginning with airway intubation through patient packaging. The same can be seen (beginning earlier with leg splinting) when comparing the start times for one ALS on the engine and one on the ambulance versus two ALS on the ambulance. No such pattern emerges for the single ALS provider regardless of placement on the engine versus the ambulance.

Trauma Scenario Coefficient Direction and Significant Differences for Elapsed Time to Start* by Task and Staff Configuration**

	A	B	C	D	E
TRAUMA Task Sequence:	**PLACEMENT: 1 ALS on Amb and 1 ALS on Engine vs 2 on Ambulance**	**PLACEMENT: 2 ALS vs 1 ALS**	**CREW SIZE: 3 vs. 2**	**CREW SIZE: 4 vs. 2**	**CREW SIZE: 4 vs. 3**
Spinal Motion Restriction					
ABCs			S +		
Patient Interview		S +			
Body sweep					
O2 administration					S -
Check Vitals		S +		S -	S -
Expose patient					
Wound Bandaged					
Splint Leg	S -			S -	S -
Back Board	S -				
Airway - intubation	S -			S -	S -
Bag Valve Mask	S -			S -	S -
Package Patient / move for transport	S -		S -	S -	S -

* An 'S' cell entry denotes a statistically significant difference at the 0.05 level for Elapsed Time to Start under the test shown in the Column heading. Also, a '+' indicates a positive coefficient value (longer time) ; a '−' denotes a negative coefficient value (shorter time).
** The contrast of one ALS on Engine vs one ALS on Ambulance showed no statistically significant differences for start time and therefore is not presented in this table.

Table 9: Trauma Scenario Coefficient Direction and Significant Differences

Part 3- Chest Pain and Witnessed Cardiac Arrest

Overall Scene Time

Crews responding with four first responders, regardless of ALS configuration, completed all cardiac tasks from the "at patient time" 70 seconds faster than first responder crews with three persons, and two minutes and 40 seconds faster than first responder crews with two persons.

Additionally, crews responding with one ALS provider on both the engine and ambulance completed all scene tasks from the "at patient time" 45 seconds sooner than crews with two ALS providers on the ambulance and a BLS engine.

Crews responding with an ALS Engine and a BLS Ambulance completed tasks from "at patient time" two minutes 36 second sooner than crews with a BLS Engine and one ALS provider on the Ambulance.

These results echo the trauma findings.

Due to the nature of the cardiac scenario, where crews began the experiment with a chest pain patient who then went into cardiac arrest (no pulse and no respirations), it was necessary to assess some tasks relative to the time the patient arrested. The arrest was cued from the end time for the 12-Lead ECG task.

Crews responding with four first responders, regardless of ALS configuration, completed cardiac tasks following the patient going into cardiac arrest 85 seconds faster than first responder crews with two persons.

Crews responding with a BLS engine and an ambulance with two ALS level providers completed all cardiac tasks following the patient arrest 50 seconds sooner than crews with an ALS provider on both the engine and ambulance. This counter-intuitive difference in the results may be attributable to the delay of the patient arrest time based on the arrival of the 12-Lead ECG monitor with the two-person ALS Ambulance crew. The 12-Lead ECG task *end time* was the arrest *start time*. In this scenario, there were instantaneously two ALS providers present at the arrest rather than the one ALS provider placing the 12-Lead ECG device in the ALS engine /ALS Ambulance crew.

The statistical tests that correspond to these findings appear in Appendix G. Appendix H shows the original regression coefficient estimates upon which the tests in Appendix G were constructed.

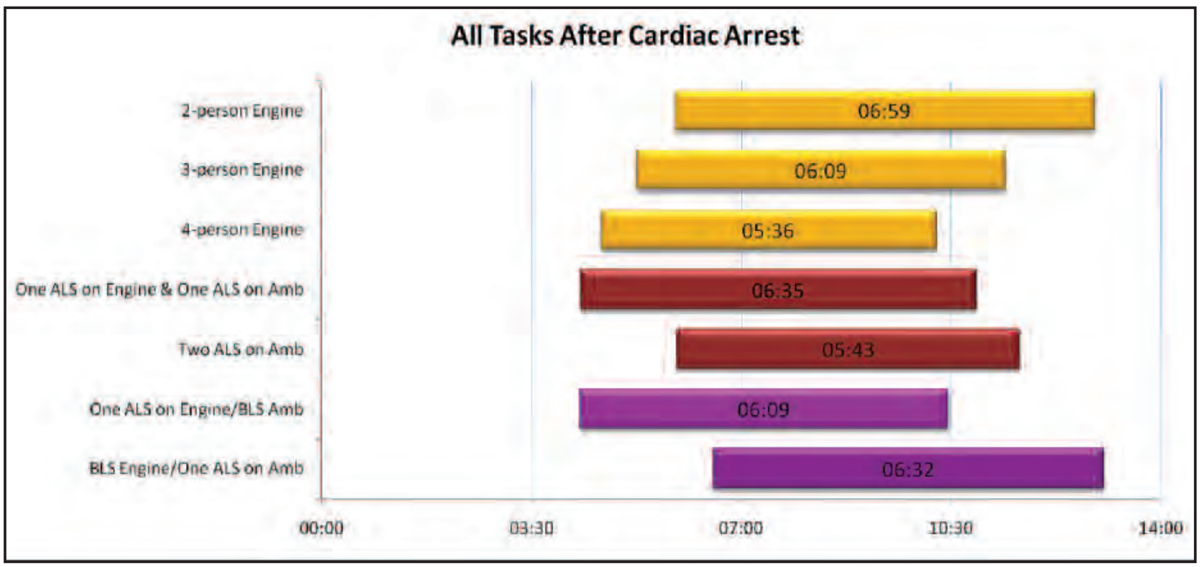

Figure 27: Total Cardiac Completion Time

Individual Task Times

12-Lead ECG Monitor

Crew configurations with one ALS provider on the first responding engine and one ALS level provider on the ambulance were able to apply the 12-lead ECG device two minutes and 20 seconds sooner than crews with both ALS providers on the ambulance.

Similarly, crew configurations with one ALS provider on the first responding engine and no medic on the ambulance also were able to apply the 12-lead ECG device two minutes and 20 seconds sooner than crews with no ALS on the first responding engine and a single ALS level provider on the ambulance.

These results may be influenced by the fact that this task can only be administered by ALS level providers. When ALS personnel are only on the ambulance, the task cannot begin until three minutes after the start of the experiment – the ambulance arrival time built into the experiments. Nonetheless, this finding is noteworthy given that national data show that ambulances typically arrive later than first responder crews.

Only a small difference in the time to begin applying the ECG device was associated with having a second ALS provider on the scene. This is not surprising, as ECG application typically requires a single ALS trained provider. Other ALS tasks later in the sequence show greater significance for having two ALS personnel on scene.

IV Access

Crew configurations with one ALS provider on the first responding engine and no medic on the ambulance were able to start the procedure for IV access two minutes and 30 seconds sooner than crews with no ALS on the first responding engine and a single ALS level provider on the ambulance. No reductions in the time to IV access were associated with a second ALS on scene. Although likely a by-product of the three-minute ambulance stagger, this finding is noteworthy because of the typical lag (behind first responders) in the arrival of an ambulance.

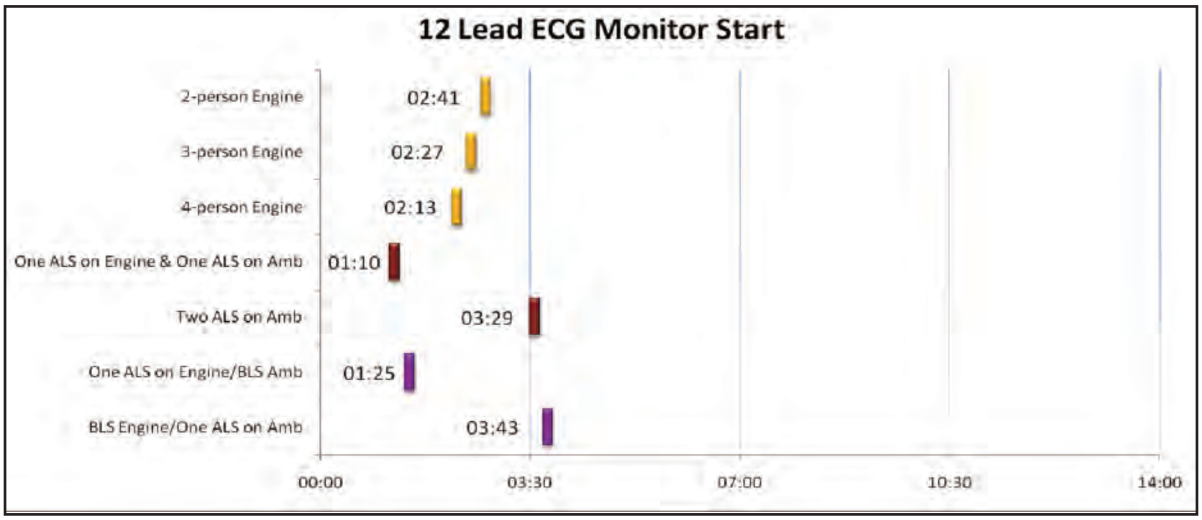

Figure 28: 12-Lead ECG Start Time

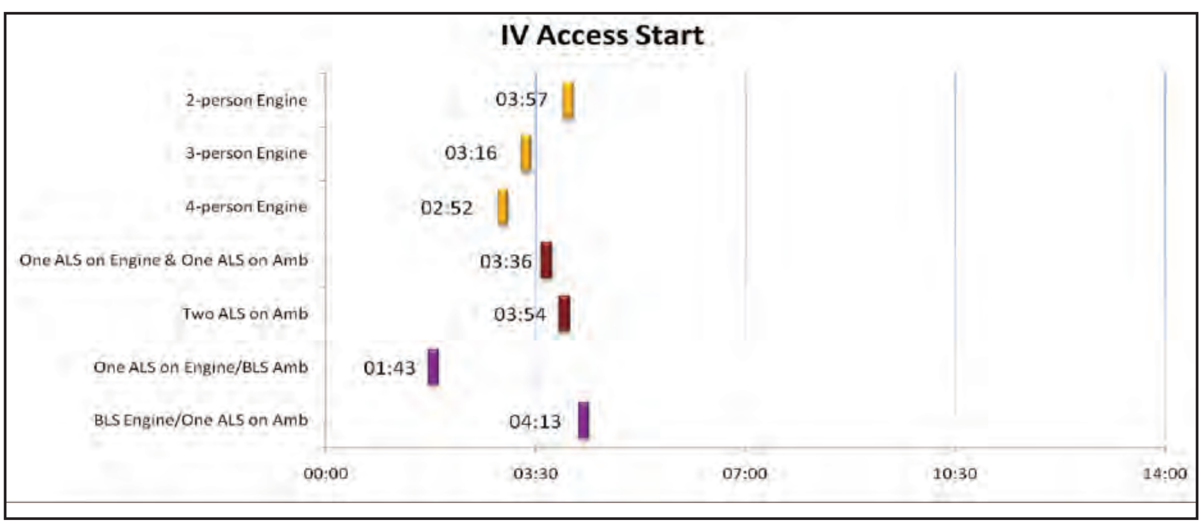

Figure 29: IV Access Start Time

Airway- Endotracheal Intubation

Crew configurations with two ALS level providers were able to begin to secure the patient's airway using endotracheal intubation over a minute (65 seconds) sooner than crew configurations with one ALS provider.

Patient Packaging

Measured from the time of arrest, first responders with four-person crews were able to begin patient packaging one minute sooner and complete all packaging activities moving toward transport one minute and 25 seconds sooner than the two-person crews.

First responders with three-person crews were able to complete all patient packaging activities moving toward transport 50 seconds sooner than the two-person crews, while four-person crews were able to complete all patient packaging activities moving toward transport 85 seconds sooner than the two-person crews.

Crew configurations with two ALS personnel arriving on the ambulance were able to complete all packaging activities, post arrest and move toward transport 50 seconds sooner than crews with one ALS provider on the first responding engine and one on the ambulance.

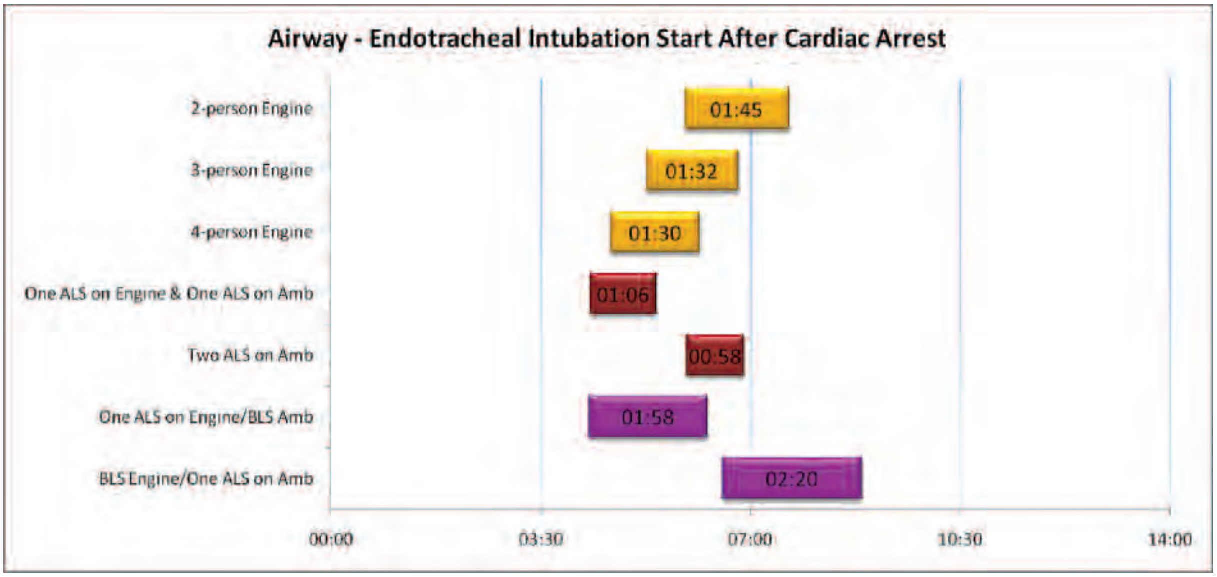

Figure 30: Airway- Intubation After Patient Arrest

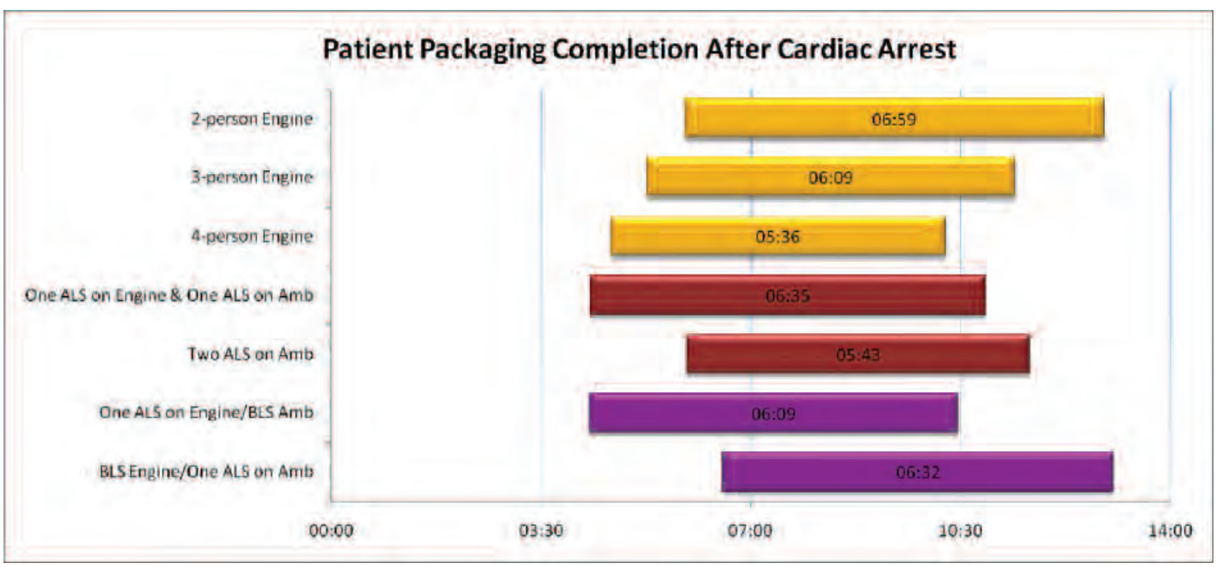

Figure 31: Patient Packaging Completion After Patient Arrest

Patterns in the Cardiac Scenario

As with the trauma analysis, the preceding presentation of findings focused on specific tasks that comprise an EMS cardiac response. The significant differences of elapsed task start times were tabulated by task and appear as Table 10. The table presents the task sequence and statistically significant differences when comparing ALS placement (Columns A – C) and contrasting crew sizes (Columns D – F) for the outcome "elapsed time to the start of a task."

The results appear mixed. Column A shows that an ALS provider on an engine has advantages over an ALS provider on an ambulance for start times in earlier tasks – ALS Vitals 12-Lead through IV access. No other ALS provider placement advantages appear for the remainder of the response sequence.

Columns B and C show sporadic task-specific advantages for start times in a few tasks. For example, when comparing crews with one ALS provider on the engine and one ALS provider on the ambulance versus two ALS providers on ambulance, and when comparing crew configurations with two ALS providers (regardless of placement) to crews with one ALS provider. A Similar sporadic advantage appears when comparing first responder crew sizes of three versus a crew size two.

A pattern similar to that observed with trauma appears when comparing the start times for a first responder crew of four versus a first responder crew of two. The advantage of the four-person crew appears in a few early tasks with at least two tasks being completed sequentially, including the initial ABC's being completed with the vital sign check, and the 12-Lead ECG being completed with exposing the patient's chest task. However, comparing these first responder crew sizes, a greater sequential time advantage is revealed for the last three tasks (analyze shock #2 through package patient), as shown in the last three rows of Column E.

Cardiac Scenario Coefficient Direction and Significant Differences for Elapsed Time to Start* by Task and Staff Configuration**

	A	B	C	D	E
CARDIAC Tasks:	**PLACEMENT: 1 ALS on Engine vs 1 ALS on Ambulance**	**PLACEMENT: 1 ALS on Amb and 1 ALS on Engine vs 2 on Ambulance**	**PLACEMENT: 2 ALS vs 1 ALS**	**CREW SIZE: 3 vs. 2**	**CREW SIZE: 4 vs. 2**
ABCs				S -	S -
Patient Interview					
O2 administration					
Check Vitals					
ALS Vitals 12-Lead	S -	S -			S -
Expose Chest	S -	S -			S -
IV Access	S -				
Position Patient (from arrest)			S -		
ABCs (from arrest)					
Defib pads (from arrest)					
Analyze / Shock #1 (from arrest)					
ABCs – After Shock #1 (from arrest)					
CPR – CPR (from arrest)					
Airway Intubation (from arrest)			S -		
Meds (Epi) (from arrest)		S +			
Analyze / Shock #2 (from arrest)				S -	S -
Medis (Lidocaine) (from arrest)			S -		S -
Package Patient/Equip (from arrest)					S -

Table 10: Cardiac Scenario Coefficient Direction and Significant Differences

Conclusions

The objective of the experiments was to determine how first responder crew size, ALS provider placement, and the number of ALS providers is associated with the effectiveness of EMS providers. EMS crew effectiveness was measured by task intervention times in three scenarios including patient access and removal, trauma, and cardiac arrest. The results were evaluated from the perspective of firefighter and paramedic safety and scene efficiency rather than as a series of distinct tasks. More than 100 full-scale EMS experiments were conducted for this study.

As noted in the literature review, hundreds of firefighters and paramedics are injured annually on EMS responses. Most injuries occur during tasks that require *lifting or abnormal movement* by rescuers. Such tasks include lifting heavy objects (including human bodies both conscious and unconscious), manipulating injured body parts and carrying heavy equipment. Several tasks included in the experiments fall into this category, including splinting extremities, spinal immobilization (back boarding) and patient packaging. During the experiments larger crews completed these tasks more efficiently by distributing the workload among more people thereby reducing the likelihood of injury.

A number of tasks are also *labor intensive*. These tasks can be completed more efficiently when handled by multiple responders. Several tasks in the experiments are in this category. These include checking vital signs, splinting extremities, intubation with spinal restriction, establishing IV access spinal immobilization, and patient packaging. Similar to the lifting or heavy work load task, larger crews were able to complete labor intensive tasks using multiple crew members on a single task to assure safe procedures were used reducing the likelihood of injury or exposure.

Finally, there are opportunities on an EMS scene to reduce scene time by completing tasks simultaneously rather than concurrently thus increasing operational efficiency. Since crews were required to complete all tasks in each scenario regardless of their crew size or configuration, overall scene times reveal operational efficiencies.

Each of these perspectives is discussed below for the patient access/removal scenario, as well as both the trauma and the cardiac scenarios.

Patient Access and Removal

With regard to accessing the patient, crews with three or four first responders reached the patient around half a minute faster than smaller crews with two first responders. With regard to completing patient removal, larger first responder crews in conjunction with a two-person ambulance were more time efficient. The removal tasks require heavy lifting and are labor intensive. The tasks also involve descending stairs while carrying a patient, carrying all equipment down stairs, and getting patient and equipment out multiple doors, onto a stretcher and into an ambulance.

The patient removal results show substantial differences associated with crew size. Crews with three- or four-person first responders complete removal between (1.2 – 1.5) minutes faster than smaller crews with two first responders. All crews with first responders complete removal substantially faster (by 2.6 min. - 4.1 min.) than the ambulance-only crew.

These results suggest that time efficiency in access and removal can be achieved by deploying three-or four-person crews on the first responding engine (relative to a first responder crew of two). To the extent that each second counts in an EMS response, these staffing features deserve consideration. Though these results establish a technical basis for the effectiveness of first responder crews and specific ALS crew configurations, other factors contributing to policy decisions are not addressed.

Trauma

Overall, field experiments reveal that four-person first responder crews completed a trauma response faster than smaller crews. Towards the latter part of the task response sequence, four-person crews start tasks significantly sooner than smaller crews.

Additionally, crews with one ALS provider on the engine and one on the ambulance completed all tasks faster and started later tasks sooner than crews with two ALS providers on the ambulance. This suggests that getting ALS personnel to the site sooner matters.

A review of the patterns of significant results for task start times reinforced these findings and suggests that (in general) small non-significant reductions in task timings accrue through the task sequence to produce significantly shorter start times for the last third of the trauma tasks.

Finally, when assessing crews for their ability to increase on-scene operational efficiency by completing tasks simultaneously, crews with an ALS provider on the engine and one ALS provider on the ambulance completed all required tasks 2.3 minutes (2 minutes 15 seconds) faster than crews with a BLS engine and two ALS providers on the ambulance. Additionally, first responders with four-person first responder crews completed all required tasks 1.7 minutes (1 minute 45 seconds) faster than three-person crews and 3.4 minutes (3 minutes and 25 seconds) faster than two-person crews.

Cardiac

The overall results for cardiac echo those of trauma. Regardless of ALS configuration, crews responding with four first responders completed all cardiac tasks (from at-patient to packaging) more quickly than smaller first responder crew sizes. Moreover, in the critical period following cardiac arrest, crews responding with four first responders also completed all tasks more quickly than smaller crew sizes. As noted in the trauma scenario, crew size matters in the cardiac response.

Considering ALS placement, crews responding with one ALS provider on both the engine and ambulance completed all scene tasks (from at-patient to packaging) more quickly than a crew with a BLS engine and two ALS providers on the ambulance. This suggests that ALS placement can make a difference in response efficiency. One curious finding was that crews responding with a BLS engine and an ambulance with two ALS providers completed the tasks that follow cardiac arrest 50 seconds *sooner* than crews with an ALS provider on both the engine and ambulance. As noted, this counter-intuitive difference in the results may be attributable to the delay of the patient arrest time based on the arrival of the 12-Lead ECG monitor with the two-person ALS Ambulance crew. The 12 -Lead ECG task *end time* was the arrest *start time*. In this scenario, there were instantaneously two ALS providers present at the arrest rather than the one ALS provider placing the 12-Lead ECG device in the ALS engine /ALS Ambulance crew.

A review of the patterns of significant results across task start times showed mixed results. An ALS on an engine showed an advantage (sooner task starting times) over an ALS on an ambulance for a few tasks located earlier in the cardiac response sequence (specifically, ALS Vitals 12-Lead through IV access). A crew size of four also showed shorter start times for a few early tasks in the cardiac response sequence (initial ABC's, and the ALS Vitals 12-Lead and expose chest sequence). More importantly, a sequential time advantage appears for the last three tasks of the sequence (analyze shock #2 through package patient).

Finally, when assessing crews for their ability to increase on-scene operational efficiency by completing tasks simultaneously, crews with an ALS provider on the engine and one ALS provider on the ambulance completed all required tasks 45 seconds faster than crews with a BLS engine and two ALS providers on the ambulance. Regardless of ALS configuration, crews responding with four first responders completed all cardiac tasks from the "at patient time" to completion of packaging 70 seconds faster than first responder crews with three persons, and two minutes and 40 seconds faster than first responder crews with two persons. Additionally, *after the patient arrested*, an assessment of time to complete remaining tasks revealed that first responders with four-person crews completed all required tasks 50 seconds faster than three-person crews and 1.4 minutes (1 minute 25 seconds) faster than two-person crews.

Summary

While resource deployment is addressed in the context of three basic scenarios, it is recognized that public policy decisions regarding the cost-benefit of specific deployment decisions are a function of many factors including geography, resource availability, community expectations as well as population demographics that drive EMS call volume. While this report contributes significant knowledge to community and fire service leaders in regard to effective resource deployment for local EMS systems, other factors contributing to policy decisions are not addressed. The results however do establish a technical basis for the effectiveness of first responder crews and ALS configuration with at least one ALS level provider on first responder crews. The results also provide valid measures of total crew size efficiency in completing on-scene tasks some of which involve heavy lifting and tasks that require multiple responders to complete.

These experimental findings suggest that ALS provider placement and crew size can have an impact on some task start times in trauma and cardiac scenarios, especially in the latter tasks leading to patient packaging. To the extent that creating time efficiency is important for patient outcomes, including an ALS trained provider on an engine and using engine crew sizes of four are worth considering. The same holds for responder safety – for access and removal and other tasks in the response sequence, the availability of additional hands can serve to reduce the risks of lifting injuries or injuries that result from fatigue (e.g., avoid having small crews repeatedly having to ascend and descend stairs). Cost considerations for EMS response and crew configurations were not considered in this study.

Study Limitations

The scope of this study is limited to understanding the relative influence of deployment variables on labor-intensive emergency medical incidents, specifically multi-system trauma and cardiac arrest events. It should be noted that the applicability of the conclusions from this report to a large scale hazardous or multiple-casualty event have not been assessed and should not be extrapolated from this report.

The crews involved in this study typically operate using three- to four-person engine crews, and two-person ambulance crews. However, other departments across the United States vary in crew sizes, some using two- to five-person first responder engine crews and three-person ambulance crews.

Every attempt was made to ensure the highest possible degree of realism in the experiments including the use of multiple crews from multiple shifts in the participant departments. However, as the trauma and cardiac experiments were repeated a minimum of 45 times, for crews involved in more than one experiment, a learning curve on the part of the participants may have been established.

All experiments were conducted indoors, during daylight hours. Treating patients outside among varying weather conditions or at night, when visibility is lower, could pose additional obstacles.

Additionally, the actual effect of ALS interventions on patient outcome is beyond the scope of this study. Patient outcomes were not quantified or estimated.

The design of the experiments limited the patient care scenarios to a systemic trauma event and a medical cardiac event. Other patient illnesses and injuries including diabetes, seizures, gunshot wounds, stabbings, and motor vehicle accidents were not considered.

EMS protocols pertaining to the treatment and transport of patients vary by departments. For the purpose of this study, tasks were standardized by technical experts and individual times were recorded for each task. In real-world situations, as in this study, many of these can be performed simultaneously based on the number and training level of responding personnel. Attempts to generalize the results from these experiments to individual departments must take into account protocols and equipment that vary from those used in the experiments.

Finally, data from U.S. fire departments were used to set response and arrival time assumptions. For departments with different deployment capability for both first responder crews and ambulances, the results may vary.

Future Research

In order to realize a significant reduction in firefighter and paramedic line-of-duty injury, fire service leaders must focus directly on resource allocation and the deployment of resources, a known contributing factor to LOD injury. Future research should use similar methods to evaluate firefighter/paramedic deployment to other medical emergencies as well as combination scenes where both fire suppression and EMS resources are needed. Additionally, resource deployment to multiple-casualty disasters or terrorism events should be studied to provide insight into levels of risks specific to individual communities and to recommend resource deployment proportionate to such risk. Future studies should continue to investigate the effects of resource deployment on the safety of firefighters, paramedics and the civilian population to better inform public policy. Finally, the ability to relate response and task timing to patient outcomes and survival rates should be quantified.

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A project of this magnitude extends well beyond the capabilities and expertise of the authors of this report. The following individuals were instrumental to the success of the EMS experiments.

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References

- American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiac Care (2005). Circulation, Vol. 112, No. 24 (Suppl), Pg 1-88.
- Averill, J.D., et al.; Moore-Merrell, L. ;Barowy, A.; Santos, R.; Peacock, R.; Notariann, K.; Wisooker, D. (2010), NIST Report on Residential Fireground Field Experiments. Natl. Inst. Stand. Technol, NIST Technical Note 1661.
- Becker, L.B.; Ostrander, M.P.; Barrett, J.; Kondon, G.T. (1991). Outcome of CPR in a Large Metropolitan Area- Where are the Survivors? Ann Emerg Med, Vol. 20, No. 4, Pg. 355.
- Boyd, C.R.; Tolson, M.A.; and Copes, W.S. (1987). Evaluating Trauma Care: The TRISS Method. J. Trauma, Vol. 27, No. 4, 370-378.
- Braun, O.; McCallion, R.; Fazackerley, J. (1990). Characteristics of Midsized Urban EMS Systems. Ann Emerg Med, Vol. 19, No. 5, Pg. 536.
- Brown, L. H.; Owens Jr., C. F.; March, J. A.; Archino, E. A. (1996). Does Ambulance Crew Size Affect On-Scene Time or Number of Prehospital Interventions? Prehosp Disast Med, Vol. 11, No. 3, Pg. 214.
- Commission on Fire Accreditation International (CFAI) Standards of Cover, Fifth Edition (2008) Chantilly, VA
- Chu, K.;Swor, R.; Jackson, R.; Domeier, R.; Sadler, E.; Basse, E.; Zaleznak, H.; Gitlin, J. (1998). Race and Survival after Out-of-Hospital Cardiac Arrest in a Suburban Community. Ann Emerg Med, Vol. 31, No. 4, Pg. 478.
- Cummins, R. O.; Ornato, J. P.; Thies, W. H.; Pepe, P. E. (1991). Improving Survival from Sudden Cardiac Arrest: The "Chain of Survival Concept." Circulation, Vol. 83, No. 5, Pg. 18-32.
- DeMaio, V.J.; Stiell, I.G.; Nesbitt, L.; Wells, G.A. (2005). Faster Advanced Life Support Response Intervals May Improve Cardiac Arrest Survival. Acad Emerg Med, Vol. 12, No. 5, Pg. 16.
- Eisenberg, M.S.; Horwood, B.T.; Cummins, R.O.; Reynolds-Haertle, R.; Hearne, T.R. (1990). Cardiac Arrest and Resuscitation: A Tale of 29 Cities. Ann Emerg Med, Vol. 19, No. 2, Pg. 179-186.
- Hallstrom, A.P.; Ornato, J.P.; Weisfeldt, M.; Travers, A.; Christenson, J.; McBurnie, M.A.; Zalenski, R.; Becker, L.B.; Schron, E.B.; Proschan, M. (2004). Public-Access Defibrillation and Survival after Out-of-Hospital Cardiac Arrest. N Engl J Med, Vol. 21, No. 7, Pg. 637.
- Heick, R.; Young, T.;Peek-Asa, C. (2009). Occupational Injuries Among Emergency Medical Service Providers in the United States. J Occup Med, Vol. 51, No. 8, Pg. 963-968.
- IAFC/IAFF Fire and EMS Operation Database: Analysis of Response Times (2005).
- Karter, M.J. Jr.; Molis, J.L. (2009). U.S. Firefighter Injuries-2008. NFPA Journal, November/December 2009.
- Kellerman, A.L.; Hackman, B.B.; Somes, G.; Kreth, T.K.; Nail, L.; Dobyns, P. (1992). Impact of First Responder Defibrillation in an Urban EMS System. Ann Emerg Med, Vol. 21, No. 14, Pg. 1708.
- Laerdal Medical Corporation. (n.d.) Retrieved from http://www.laerdal.com/doc/7320252/SimMan.html.
- Litwin, P. E.; Eisenberg, M. S.; Hallstrom, A. P.; Cummins, R. O. (1987). The Location of Collapse and its Effect on Survival from Cardiac Arrest. Ann Emerg Med, Vol. 16, No. 7, Pg. 787.
- Maguire, B.J.; Hunting, K.L., Guidotti, T.L.; Smith, G.S. (2005). Occupational Injuries Among Emergency Medical Services Personnel. Prehop Emerg Care, No. 4, Pg. 405-411.
- Moore, L.L. Quality Performance Measures for Fire Department-Based EMS Systems. UMI, Ann Arbor, Michigan (2002).
- Morrison, L.J.; Angelini, M.P.; Vermeulen, M.J.; Schwartz, B. (2005). Measuring the EMS Patient Access Time Interval and the Impact of Responding to High-rise Buildings. Prehosp Emerg Care, Vol. 9, No. 1, Pg. 14-18.
- National Fire Academy (1981). Fire Engines are Becoming Expensive Taxi Cabs: Inadequate Manning. United States Fire Administration, Emmitsburg, MD.
- NFPA (2009). 450: Standard for Emergency Medical Services and Systems. National Fire Protection Association, Quincy, MA.
- NFPA (2007). 1500: Standard on Fire Department Occupational Safety and Health Program. National Fire Protection Association, Quincy, MA.
- NFPA (2010). NFPA 1710: Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments. National Fire Protection Association, Quincy, MA.
- NFPA (2010). NFPA 1720: Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Volunteer Fire Departments. National Fire Protection Association, Quincy, MA.
- NFPA (2008) 1999: Standard on Protective Clothing for Emergency Medical Operations. National Fire Protection Association, Quincy, MA.
- Olson, D.W.; LaRochelle, J.; Fark, D.; et al. (1989). EMT-Defibrillation: The Wisconsin Experience. Ann Emerg Med, Vol. 18, No. 8, Pg. 806.

- Pratt, F.D.; Katz, S.; Pepe, P.E.; Persse, D. (2007). Prehospital 9-1-1 Emergency Medical Response: The Role of the United States Fire Service in Delivery and Coordination. White paper.

- Studnek, J.R.; Ferketich, A.; Crawford, J.M. (2007) On the Job Illness and Injury Resulting in Lost Work Time Among a National Cohort of Emergency Medical Services Professionals. Am J Indus Med, Vol. 50, No.12, Pg. 921-931.

- Sweeney, T.A.; Runge, J.W.; Gibbs: et al. (1998). EMT Defibrillation Does Not Increase Survival from Sudden Cardiac Death in a Two-Tiered Urban-Suburban EMS System. Ann Emerg Med, Vol. 31, No. 2, Pg. 234.

Glossary

12-Lead Electrocardiogram (ECG) — A representation of the heart's electrical activity recorded from 10 electrodes placed in standard positions on the body's surface.

Advanced Cardiac Life Support (ACLS) — A set of clinical interventions for the urgent treatment of cardiac arrest and other life threatening medical emergencies, as well as the knowledge and skills to use those interventions.

Advanced Life Support (ALS) — Emergency medical treatment beyond basic life support that provides for advanced airway management including intubation, advanced cardiac monitoring, defibrillation, establishment and maintenance of intravenous access, and drug therapy.

Ambulance Transport Unit — Provides transport for patients from the incident scene to a health care facility.

Automated External Defibrillator (AED) — A portable electronic device that automatically diagnoses potentially life-threatening cardiac arrhythmias of ventricular fibrillation, and is able to treat them through defibrillation, the application of electrical therapy which stops the arrhythmias, allowing the heart to reestablish an effective rhythm.

Basic Life Support (BLS) — A specific level of prehospital medical care provided by trained responders, focused on rapidly evaluating a patient's condition; maintaining a patient's airway, breathing, and circulation; controlling external bleeding; preventing shock; and preventing further injury or disability by immobilizing potential spinal or other bone fractures.

Cardiac Arrest — Sudden cessation of heartbeat and heart functions, resulting in the loss of effective circulation.

Cardiopulmonary Resuscitation (CPR) — Procedure designed to support and maintain breathing and circulation for a person who has stopped breathing (respiratory arrest) or whose heart has stopped (cardiac arrest).

Chain of Survival — The four components of EMS response to out-of-hospital cardiac arrest that are thought to effect the most optimal patient outcome. The four components include early recognition and EMS access, early CPR, rapid defibrillation, and advanced life support.

Combination Fire Department — Fire department consisting of both paid (career) and volunteer personnel.

Crew configurations — Specific ways of staffing or organizing members of the work force.

Definitive Medical Care — Medical treatment or services beyond emergency medical care, initiated upon inpatient admission to a hospital or health care facility.

Emergency Medical Services (EMS) — The treatment of patients using first aid, cardiopulmonary resuscitation, basic life support, advanced life support, and other medical procedures prior to arrival at a hospital or other health care facility.

EMS Protocols — Written medical instructions authorized by an EMS medical director to be used by personnel in the field without the necessity of on-line or real-time consultation with a physician or nurse.

Emergency Medical Technician (EMT) — A member of the emergency medical services team who provides out-of-hospital emergency care, trained to any level of emergency medical services.

Emergency Medical Technician- Basic (EMT-B) — A member of the emergency medical services team who provides out-of-hospital emergency care, trained in the delivery of Basic Life Support services.

Emergency Medical Technician- Defibrillator (EMT-D) — A member of the emergency medical services team with special training in the use of cardiac defibrillating equipment. (Defibrillation training is now part of Basic Emergency Medical training.)

Emergency Medical Technician- Paramedic (EMT-P) — A member of the emergency medical services team who provides out-of-hospital emergency care, trained in the delivery of Advanced Life Support services.

Endotrachael Tube (ET) — Flexible plastic catheter placed into the trachea to protect the airway and provide a means of mechanical ventilation.

First Responder — Functional provision of initial assessment (i.e., airway, breathing, and circulatory systems) and basic first-aid intervention, including CPR and automatic external defibrillator capability.

First Responder Unit — The first arriving unit at an emergency medical incident, whether it be a fire suppression vehicle or ambulance.

Intervention — Act designed to alter or hinder an action or development.

Intravenous (IV) — An injection administered into a vein.

Intubation — Insertion of a tube through the mouth or nose and into a patient's lungs to help them breathe.

Knox Box Rapid Entry System — Small, wall-mounted safe that holds building keys for firefighters and EMTs to retrieve in emergencies.

Mayocardial Infarction — Heart attack.

Measurement uncertainty — Parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measure.

National Fire Protection Association (NFPA) — A nonprofit organization, established in 1896, with the mission to reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training and education.

NFPA 450— Guide for emergency medical services and systems.

NFPA 1500 — Standard on fire department occupational safety and health program.

NFPA 1710 — Standard for the organization and deployment of fire suppression operations, emergency medical operations, and special operations to the public by career fire departments.

NFPA 1720 — Standard for the organization and deployment of fire suppression operations, emergency medical operations, and special operations to the public by volunteer fire departments.

NFPA 1999 — Standard on protective clothing for emergency medical operations.

One-Tier EMS System — EMS system in which all units are advanced life support.

Operational Effectiveness — Capable of producing a particular desired effect in "real world" circumstances.

Operational Efficiency — The effect or results achieved in relation to the effort expended.

Ordinary Least Squares (OLS) — In statistics and econometrics, OLS or linear least squares is a method for estimating the unknown parameters in a linear regression model.

Out-of-hospital — Care for the sick or injured in settings other than hospitals or hospital-affiliated outpatient medical or surgical facilities, typically beginning with a call to 9-1-1.

Patient Packaging — Securing a patient to a mobile contrivance (e.g., stretcher or stair chair) for moving to the transport unit.

Pulse Oximeter — Medical device that measures the oxygen saturation of a patient's blood.

Regression analysis — Includes any techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps us understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held.

Standard of Response Cover (SORC) — Policies and procedures that determine distribution, concentration, and reliability of fixed and mobile resources for an emergency response system.

Standard t-test — Measures whether there is any statistical difference in the mean of two groups.

Statistical significance — A number that expresses the probability that the result of a given experiment or study could have occurred purely by chance. This number can be a margin of error or it can be a confidence level.

System resources — Personnel, vehicles, and equipment used in providing EMS.

Systemic trauma — Injury or shock affecting the body generally.

Transport — Conveyance of the sick or injured in an ambulance or emergency vehicle to a hospital setting.

Trauma and Injury Severity Scores (TRISS) — A system developed in the 1980's to improve the prediction of patient outcomes through the use of physiological and anatomical criteria.

Two-Tier EMS System — EMS system that uses first responder or BLS units that typically arrive and begin treatment prior to the arrival of a transport unit.

Acronyms

- **A, B, C's —** Airway, Breathing, and Circulation
- **ACLS —** Advanced Cardiac Life Support
- **AED —** Automated External Defibrillator
- **AHA —** American Heart Association
- **ALS —** Advanced Life Support
- **BLS —** Basic Life Support
- **CFAI —** Commission on Fire Accreditation International
- **CPR —** Cardiopulmonary resuscitation
- **DHS —** Department of Homeland Security
- **DOL —** Department of Labor
- **ECG —** Electrocardiogram
- **EMS —** Emergency Medical Services
- **EMT —** Emergency Medical Technician
- **EMT-B —** Emergency Medical Technician- Basic
- **EMT-D —** Emergency Medical Technician- Defibrillator
- **EMT-P —** Emergency Medical Technician- Paramedic
- **FEMA —** Federal Emergency Management Agency
- **IAFC —** International Association of Fire Chiefs
- **IAFF —** International Association of Fire Fighters
- **LOD —** Line-of-Duty
- **NFPA —** National Fire Protection Association
- **NIST —** National Institute of Standards and Technology
- **OHCA —** Out-of-hospital cardiac arrest
- **OPQRST —** Onset, Provokes, Quality, Radiates, Severity, Time
- **SAMPLE —** Signs and Symptoms, Allergies, Previous history, Medications, Last oral intake, Events leading up to
- **SORC —** Standard of Response Cover
- **TBI —** Traumatic brain injury
- **TRISS —** Trauma and Injury Severity Scores
- **WPI —** Worcester Polytechnic Institute

Appendix A: Time to Task Measures

Time-to-Task Data Collection Chart -EMS

(Overall Response- Patient Access and Removal)

Date ___________ Start Time____________ End Time (all tasks complete) ___________

Crew Used: ❑ Montgomery County ❑ Fairfax County

Timer Name____

Task	Start Time	Completion Time	Difference
Arrive on Scene			
Assemble Equipment			
Conduct Size-up – Scene Safety			
Enter Door- Building- 'Knox box'			
Ascend – Stairs (3 stories)			
Package Patient – stair chair			
Descent – Stairs (3 stories) with patient in stair chair			
Exit Door – Building			
Transfer Patient to cot/stretcher			
Turn Ambulance for Loading			
Load Ambulance/ Seat Belt			

Time-to-Task Data Collection Chart -EMS

(Trauma — BLS — ALS on scene)

Date ___________ Start Time____________ End Time (all tasks complete) ___________

Timer Name____

Task	Start Time	Completion Time	Difference
At Patient			
Spinal motion restriction			
A, B, C's			
Patient Interview			
Body sweep – find laceration on head and angulated fracture of tib/fib (closed) on Right leg			
O^2 Administration – face mask			
Check Vitals (Pulse, Resp., BP, Pulse Ox)			
Expose patient as indicated			
Control Bleeding			
Splint leg			
Back Board			
Movement causes labored breathing – Agonal Respiration ➔ Patient vomits (projectile)			
Airway – Intubation ET with spinal motion restriction – on ground due to distance from transport unit			
Bag Valve Mask			
Package patient / move for transport			

Time-to-Task Data Collection Chart -EMS

(Medical — Cardiac)

Date ___________ Start Time____________ End Time (all tasks complete) ___________

Timer Name____

Task	Start Time	Completion Time	Difference
At Patient			
A, B, C's			
Patient Interview			
O^2 Administration			
Check Vitals (Pulse, Resp., BP, pulse Ox)			
ALS Vitals - ECG 12-Lead			
Expose patient as indicated			
Patient Arrest >>>>>>>>			
Position patient			
ABC's			
Apply Defibrillator pads			
Defibrillate – Shock # 1 – Shock works = NO			
ABC's			
CPR – Bag Valve			
Airway Intubation - ET			
IV access			
Meds (1 Epi)	>>>>	>>>>>>>>>	>>>>>
AED Auto Countdown- "Analyze Patient"			
Defibrillate – Shock #2 – Shock works = **YES**			
Check Vitals – ROSC - unconscious			
Meds (1 Lidocaine Bolus)			
Package Patient			

Appendix B: Trauma Patient Assessment and Interview Form

Name:______________________________________ Age: _______ Male / Female

Chief Complaint: ____

Mechanism of Injury: ____

Primary Survey:

Airway status: open / occluded

Breathing: normal / labored-abnormal / none

Circulation: normal / shocky / none

Mental Status: alert / voice / pain / unresponsive

Body Sweep Findings? ______________________

Secondary / Focused Survey Findings:

Head	L Arm
Face	R Arm
Neck	Abdomen
Chest	L Leg
Back	R Leg

Vital Signs:

BP ______ Pulse: ______ Resp:______ PulseOx: ______

BP ______ Pulse: ______ Resp:______ PulseOx: ______

Treatment:

❑ oxygen ❑ C-spine ❑ Splinting ❑ Bandaging

Appendix C: Medical Patient Interview Form

Name:____ Age: _______ Male / Female

Chief Complaint: ____

Mechanism of Injury: ____

"SAMPLE" history	"OPQRST" pain survey
Signs & Symptoms	**Onset?** What were you doing?
Allergies	**Provokes?** What makes it better or worse?
Medications	**Quality?** "What does it feel like?
Previous Medical History	**Radiation?** "Does it go anywhere?"
Last Oral Intake	**Severity?** 1-10 scale
Events Leading Up to?	**Time?** When did it begin?

Vital Signs:

BP ______ Pulse: ______ Resp: _____ PulseOx: _____

Treatment:

❑ oxygen ❑ ECG ❑ 12-lead ❑ IV

❑ medications? ____

Appendix D: Medical Patient Assessment/Interview Form

"SAMPLE HISTORY"

Signs & Symptoms "What is bothering you this morning?	Pain under my breastbone.
Allergies "Are you allergic to any medications?"	None
Medications "Do you take any medications?"	Aspirin and Cardizem.
Previous History "Do you have any medical problems? Has this ever happened to you before?"	I was diagnosed with high blood pressure two years ago. No, I have never felt pain like this before.
Last Oral Intake "Have you been eating normally?"	Yes. Had a full breakfast this morning.
Events Leading Up to? "What happened prior to you developing this pain?"	Nothing, I was feeling fine before this.

PAIN SURVEY

PAIN SURVEY Onset? "What were you doing when pain began?"	I was sitting on the couch watching television.
Provokes? "Have you done anything that makes the pain better?"	No, it is a steady pain and I can't get in a comfortable position.
Radiates? "Do you feel the pain anywhere besides your chest?"	Yes, I feel it in my spine also.
Severity? "On a scale of 1 to 10, with ten worst pain you can imagine, how severe is your pain now?"	It is a 6.
Time? "When did your chest pain begin?"	About 30 minutes ago.

Average Timing in Seconds by Numbers of First Responders Regardless of ALS Placement				
Task:	**No First Responder**	**2-person First Responder Crews**	**3-Person First Responder Crews**	**4- Person First Responder Crews**
Arrive Scene				
Assemble equipment	29.7	46.7	26.7	22.7
Conduct scene size up	31.7	181.7	167.3	172.0
Enter building	19.7	13.3	15.7	7.3
Ascend stairs	22.0	30.0	20.3	23.3
Time between Arrival and ascent of stairs	***104.7***	***123.0***	***98.3***	***93.0***
Package patient	59.7	46.3	59.0	36.0
Descend stairs	87.0	69.7	78.7	91.0
Exit door	102.7	114.3	92.3	89.0
Transfer patient	55.0	54.0	42.0	31.7
Turn ambulance	56.3	84.3	87.0	60.3
Load ambulance	76.3	53.3	31.0	18.3
Time between packaging patient and completion of loading patient	***418.7***	***263.3***	***192.7***	***171.7***

Access and Removal Differences of Means and Associated T-Tests (Time in Minutes)						
Dependent Variable:	**Ambulance vs. 2 Crew**	**Ambulance vs. 3 Crew**	**Ambulance vs. 4 Crew**	**Value of 3 vs. 2 Crew**	**Value of 4 vs. 2 Crew**	**Value of 4 vs. 3 Crew**
ACCESS: Arrival end to ascend stairs	**-0.306**	**0.106**	**0.194**	**-0.411**	**-0.500**	**-0.089**
SE	0.167	0.167	0.167	0.167	0.167	0.167
p-value	0.105	0.546	0.279	0.039	0.017	0.610
REMOVAL: Package patient to end	**2.589**	**3.767**	**4.117**	**-1.178**	**-1.528**	**0.350**
SE	0.521	0.521	0.521	0.521	0.521	0.521
p-value	0.001	0.000	0.000	0.054	0.019	0.521

Appendix F: Statistical Analysis of Time to Task Data Patient Systemic Trauma Patient

Testing the Effects of ALS, Engine Placements, and Crew Size on Engine to Address Research Questions for the Trauma Analysis (Contrasts are in Minutes)						
TRAUMA Task:	**Q1: One ALS -- Engine vs. Ambulance**	**Q2: Two ALS: One Amb One Engine vs. Two on Ambulance**	**Q3: Value of 2nd ALS**	**Q4: Value of 3 vs. 2 Crew**	**Q5a: Value of 4 vs. 2 Crew**	**Q5b: Value of 4 vs. 3 Crew**
Spinal Motion Restriction – start	**-0.200**	**-0.106**	**0.064**	**-0.007**	**-0.092**	**-0.085**
SE	0.104	0.083	0.066	0.090	0.086	0.066
p-value	0.062	0.213	0.343	0.939	0.296	0.206
ABCs – start	**-0.026**	**-0.067**	**0.078**	**0.100**	**0.035**	**-0.065**
SE	0.041	0.065	0.039	0.046	0.051	0.044
p-value	0.536	0.313	0.052	0.037	0.503	0.149
ABCs – duration	**-0.130**	**-0.280**	**-0.234**	**-0.079**	**-0.157**	**-0.078**
SE	0.229	0.160	0.140	0.191	0.163	0.156
p-value	0.574	0.090	0.102	0.681	0.344	0.622
Patient Interview – start	**-0.017**	**-0.002**	**0.124**	**0.115**	**0.025**	**-0.090**
SE	0.056	0.104	0.059	0.070	0.068	0.078
p-value	0.767	0.986	0.043	0.111	0.715	0.257
Body sweep - – start	**-0.383**	**0.048**	**0.425**	**-0.247**	**-0.614**	**-0.367**
SE	0.274	0.509	0.289	0.425	0.376	0.233
p-value	0.170	0.925	0.151	0.564	0.112	0.125
Body sweep - duration	**-0.076**	**-0.248**	**-0.003**	**-0.093**	**-0.168**	**-0.075**
SE	0.245	0.365	0.220	0.317	0.280	0.197
p-value	0.759	0.501	0.990	0.771	0.552	0.706
O2 administration – start	**0.793**	**-0.724**	**0.414**	**0.347**	**-0.551**	**-0.899**
SE	0.404	0.543	0.338	0.457	0.377	0.404
p-value	0.058	0.191	0.229	0.453	0.153	0.033
Check Vitals – start	**0.065**	**0.165**	**0.596**	**-0.414**	**-0.932**	**-0.518**
SE	0.260	0.448	0.259	0.360	0.328	0.254
p-value	0.727	0.302	0.140	0.842	0.300	0.070
Wound Bandaged – start	**0.604**	**-1.239**	**0.045**	**-1.708**	**-1.064**	**0.644**
SE	0.618	0.714	0.472	0.548	0.607	0.578
p-value	0.335	0.092	0.924	0.004	0.089	0.273
Splint Leg – start	**-0.554**	**-0.650**	**0.385**	**-0.206**	**-1.099**	**-0.893**
SE	0.450	0.294	0.269	0.308	0.348	0.331
p-value	0.227	0.034	0.161	0.509	0.003	0.011
Splint Leg – duration	**0.830**	**-0.509**	**-0.277**	**-0.135**	**-0.340**	**-0.206**
SE	0.268	0.380	0.233	0.283	0.250	0.317
p-value	0.004	0.189	0.242	0.638	0.183	0.521
Back Board – start	**-0.250**	**-1.654**	**0.235**	**-0.293**	**-0.058**	**0.235**
SE	0.539	0.604	0.405	0.536	0.514	0.432
p-value	0.646	0.010	0.565	0.588	0.910	0.590
Back Board – duration	**0.063**	**0.330**	**-0.024**	**-0.340**	**-2.410**	**-2.069**
SE	0.426	0.535	0.342	0.427	0.484	0.330
p-value	0.883	0.542	0.944	0.431	0.000	0.000
Airway - intubation – start	**0.137**	**-1.389**	**0.194**	**-0.535**	**-2.558**	**-2.024**
SE	0.692	0.500	0.427	0.582	0.432	0.542
p-value	0.844	0.009	0.652	0.365	0.000	0.001
Airway - intubation – duration	**0.465**	**-0.437**	**-0.460**	**-0.775**	**-0.363**	**0.413**
SE	0.268	0.291	0.198	0.193	0.281	0.244
p-value	0.091	0.142	0.026	0.000	0.206	0.100
Bag Valve Mask – start	**-0.020**	**-1.487**	**0.031**	**-0.797**	**-2.603**	**-1.806**
SE	0.622	0.519	0.405	0.550	0.439	0.493
p-value	0.974	0.007	0.939	0.157	0.000	0.001
Package Patient / move fo r transport – start	**0.733**	**-2.089**	**-0.232**	**-1.525**	**-3.106**	**-1.581**
SE	0.763	0.692	0.515	0.641	0.589	0.660
p-value	0.343	0.005	0.656	0.023	0.000	0.022

Appendix G: Statistical Analysis of Time to Task Data Cardiac Arrest Patient

Testing the Effects of ALS, Engine Placements, and Crew Size on Engine to Address Research Questions for the Cardiac Analysis (Contrasts are in Minutes)

CARDIAC Tasks:	Q1: One ALS -- Engine vs Ambulance	Q2: Two ALS: One Amb and One Engine vs Two on Ambulance	Q3: Value of 2nd ALS	Q4: Value of 3 vs. 2 Crew	Q5a: Value of 4 vs. 2 Crew	Q5b: Value of 4 vs. 3 Crew
ABCs—start	**-0.019**	**0.020**	**0.029**	**-0.057**	**-0.069**	**-0.013**
SE	0.022	0.026	0.017	0.023	0.021	0.019
p-value	0.395	0.446	0.101	0.020	0.002	0.505
ABCs-- duration	**-0.009**	**0.028**	**-0.004**	**0.022**	**-0.026**	**-0.049**
SE	0.040	0.026	0.024	0.029	0.033	0.026
p-value	0.820	0.290	0.878	0.445	0.427	0.072
Patient Interview - start	**0.000**	**0.031**	**0.016**	**-0.024**	**-0.024**	**0.000**
SE	0.006	0.031	0.016	0.024	0.024	0.006
p-value	1.000	0.323	0.331	0.323	0.323	1.000
O2 administration- start	**-0.120**	**-0.039**	**-0.106**	**-0.121**	**-0.169**	**-0.049**
SE	0.140	0.111	0.089	0.095	0.120	0.113
p-value	0.396	0.729	0.246	0.210	0.166	0.669
Check Vitals – start	**-0.100**	**-0.031**	**0.086**	**-0.268**	**-0.286**	**-0.018**
SE	0.146	0.157	0.107	0.142	0.151	0.095
p-value	0.499	0.843	0.428	0.067	0.067	0.850
Check Vitals – duration	**0.024**	**0.230**	**-0.008**	**0.031**	**-0.208**	**-0.239**
SE	0.322	0.211	0.193	0.256	0.214	0.236
p-value	0.941	0.285	0.966	0.906	0.338	0.319
ALS Vitals 12-Lead - start	**-2.309**	**-2.330**	**-0.240**	**-0.235**	**-0.471**	**-0.236**
SE	0.277	0.239	0.183	0.233	0.222	0.216
p-value	0.000	0.000	0.198	0.321	0.041	0.281
Expose Chest - start	**-1.665**	**-1.404**	**-0.094**	**-0.593**	**-0.985**	**-0.392**
SE	0.447	0.490	0.331	0.392	0.397	0.428
p-value	0.551	0.113	0.081	0.476	0.358	0.811
Position Patient – start (difference from Arrest time)	**0.039**	**-0.044**	**-0.042**	**0.028**	**0.000**	**-0.028**
SE	0.029	0.024	0.019	0.023	0.022	0.025
p-value	0.183	0.077	0.034	0.229	1.000	0.265
ABCs – Start (difference from arrest time)	**0.000**	**-0.033**	**0.067**	**-0.079**	**-0.131**	**-0.051**
SE	0.072	0.122	0.071	0.093	0.093	0.071
p-value	1.000	0.786	0.352	0.402	0.170	0.473
Defib pads – Start (difference from arrest time)	**0.006**	**-0.056**	**-0.055**	**-0.086**	**-0.156**	**-0.069**
SE	0.120	0.119	0.084	0.120	0.118	0.061
p-value	0.963	0.642	0.521	0.477	0.195	0.265
Analyze / Shock #1 – Start (difference from arrest time)	**-0.078**	**-0.069**	**-0.071**	**-0.133**	**-0.179**	**-0.046**
SE	0.158	0.157	0.112	0.157	0.149	0.095
p-value	0.626	0.666	0.527	0.402	0.238	0.633

Appendix G: Statistical Analysis of Time to Task Data Cardiac Arrest Patient

Continued

Testing the Effects of ALS, Engine Placements, and Crew Size on Engine to Address Research Questions for the Cardiac Analysis (Contrasts are in Minutes)						
CARDIAC Tasks:	**Q1: One ALS -- Engine vs Ambulance**	**Q2: Two ALS: One Amb and One Engine vs Two on Ambulance**	**Q3: Value of 2nd ALS**	**Q4: Value of 3 vs. 2 Crew**	**Q5a: Value of 4 vs. 2 Crew**	**Q5b: Value of 4 vs. 3 Crew**
ABCs – Start – After Shock #1 (difference from arrest time)	**-0.098**	**0.026**	**-0.034**	**-0.178**	**-0.239**	**-0.061**
SE	0.153	0.214	0.132	0.187	0.182	0.098
p-value	0.526	0.904	0.796	0.349	0.198	0.539
CPR – CPR—Start (difference from arrest time)	**0.207**	**0.026**	**-0.057**	**-0.015**	**-0.021**	**-0.006**
SE	0.183	0.234	0.148	0.196	0.187	0.161
p-value	0.264	0.912	0.701	0.938	0.912	0.973
Airway Intubation- Start – (difference from arrest time)	**-0.359**	**0.128**	**-1.123**	**-0.207**	**-0.247**	**-0.040**
SE	0.438	0.254	0.253	0.321	0.256	0.347
p-value	0.418	0.618	0.000	0.524	0.340	0.908
Airway Intubation-- Duration	**0.081**	**-0.037**	**0.582**	**-0.172**	**-0.594**	**-0.422**
SE	0.346	0.315	0.234	0.319	0.301	0.232
p-value	0.681	0.097	0.009	0.135	0.021	0.328
Package Patient/Equip- Start (difference from arrest time)	**-0.606**	**0.991**	**-0.193**	**-0.733**	**-1.013**	**-0.279**
SE	0.551	0.583	0.401	0.538	0.450	0.480
p-value	0.279	0.098	0.634	0.182	0.031	0.565
Package Patient/Equip- Completion (difference from arrest time)	**-0.380**	**0.867**	**-0.190**	**-0.843**	**-1.394**	**-0.551**
SE	0.402	0.418	0.290	0.393	0.340	0.329
p-value	0.352	0.046	0.517	0.039	0.000	0.103

Regression Analysis Coefficients, Standard Errors and P-Values For Addressing Research Questions about Cardiac Time from Arrest (Coefficients are in Minutes) : Each Task Row Represents a Separate Regression

TRAUMA Tasks:	no engine	no engine & 2 ALS on ambulance	crew size 3 on engine	crew size 4 on engine	1 ALS on engine & 0 ALS on Ambulance	0 ALS on engine & 1 ALS on Ambulance	0 ALS on engine & 2 ALS on Ambulance	Constant
p-value	0.000	0.002	0.453	0.153	0.496	0.290	0.191	0.000
Check Vitals – start	**3.290**	**0.950**	**-0.414**	**-0.932**	**-0.646**	**-0.711**	**-0.165**	**2.754**
SE	0.501	0.611	0.360	0.328	0.384	0.419	0.448	0.474
p-value	0.000	0.130	0.259	0.008	0.102	0.099	0.715	0.000
Check Vitals – duration	**0.571**	**-0.572**	**-0.964**	**-1.311**	**-0.052**	**0.259**	**-0.028**	**2.784**
SE	1.458	1.434	0.601	0.546	0.524	0.574	0.687	0.658
p-value	0.698	0.692	0.118	0.022	0.922	0.654	0.968	0.000
Expose patient – start	**3.266**	**-0.317**	**0.067**	**-0.325**	**-0.187**	**-0.102**	**0.424**	**1.879**
SE	0.329	0.148	0.333	0.309	0.273	0.259	0.404	0.298
p-value	0.000	0.040	0.842	0.300	0.497	0.697	0.302	0.000
Wound Bandaged – start	**4.831**	**-1.533**	**-1.708**	**-1.064**	**0.876**	**0.272**	**1.239**	**3.763**
SE	2.074	2.549	0.548	0.607	0.764	0.667	0.714	0.677
p-value	0.026	0.551	0.004	0.089	0.260	0.686	0.092	0.000
Splint Leg – start	**4.250**	**-1.689**	**-0.206**	**-1.099**	**-0.337**	**0.217**	**0.650**	**4.027**
SE	1.142	1.128	0.308	0.348	0.441	0.278	0.294	0.271
p-value	0.001	0.144	0.509	0.003	0.450	0.442	0.034	0.000
Splint Leg – duration	**0.697**	**-0.700**	**-0.135**	**-0.340**	**0.946**	**0.117**	**0.509**	**2.281**
SE	0.650	1.018	0.283	0.250	0.266	0.226	0.380	0.192
p-value	0.291	0.496	0.638	0.183	0.001	0.609	0.189	0.000
Back Board – start	**4.438**	**-0.017**	**-0.293**	**-0.058**	**0.467**	**0.717**	**1.654**	**2.134**
SE	0.865	1.087	0.536	0.514	0.547	0.224	0.604	0.367
p-value	0.000	0.988	0.588	0.910	0.399	0.003	0.010	0.000
Back Board – duration	**4.283**	**-5.567**	**-0.340**	**-2.410**	**-0.109**	**-0.172**	**-0.330**	**6.661**
SE	1.165	1.465	0.427	0.484	0.419	0.438	0.535	0.506
p-value	0.001	0.001	0.431	0.000	0.796	0.697	0.542	0.000
Airway - intubation – start	**8.904**	**-5.561**	**-0.535**	**-2.558**	**0.569**	**0.432**	**1.389**	**9.057**
SE	1.753	1.755	0.582	0.432	0.696	0.417	0.500	0.493
p-value	0.000	0.003	0.365	0.000	0.420	0.308	0.009	0.000
Airway - intubation – duration	**0.293**	**0.772**	**-0.775**	**-0.363**	**0.911**	**0.446**	**0.437**	**2.296**
SE	0.481	0.706	0.193	0.281	0.229	0.305	0.291	0.250

Appendix H: All Regression Coefficients Continued

Regression Analysis Coefficients, Standard Errors and P-Values For Addressing Research Questions about Cardiac Time from Arrest (Coefficients are in Minutes) : Each Task Row Represents a Separate Regression

TRAUMA Tasks:	no engine	no engine & 2 ALS on ambulance	crew size 3 on engine	crew size 4 on engine	1 ALS on engine & 0 ALS on Ambulance	0 ALS on engine & 1 ALS on Ambulance	0 ALS on engine & 2 ALS on Ambulance	Constant
p-value	0.546	0.282	0.000	0.206	0.000	0.153	0.142	0.000
Bag Valve Mask – start	**8.867**	**-5.556**	**-0.797**	**-2.603**	**0.702**	**0.722**	**1.487**	**8.878**
SE	1.830	1.812	0.550	0.439	0.643	0.444	0.519	0.499
p-value	0.000	0.004	0.157	0.000	0.283	0.113	0.007	0.000
Package Patient / move for transport – start	**10.330**	**-5.544**	**-1.525**	**-3.106**	**1.643**	**0.909**	**2.089**	**11.670**
SE	2.542	2.644	0.641	0.589	0.738	0.546	0.692	0.611
p-value	0.000	0.044	0.023	0.000	0.033	0.105	0.005	0.000
Package Patient / move for transport – completion	**11.030**	**-5.039**	**-1.672**	**-3.390**	**1.806**	**0.915**	**2.267**	**12.520**
SE	2.612	2.760	0.657	0.597	0.773	0.565	0.704	0.617
p-value	0.000	0.077	0.016	0.000	0.025	0.115	0.003	0.000

Appendix H: All Regression Coefficients

Regression Analysis Coefficients, Standard Errors and P-Values For Addressing Research Questions about Cardiac Time from Arrest (Coefficients are in Minutes) : Each Task Row Represents a Separate Regression

CARDIAC Tasks:	no engine	no engine & 2 ALS on ambulance	crew size 3 on engine	crew size 4 on engine	1 ALS on engine & 0 ALS on Ambulance	0 ALS on engine & 1 ALS on Ambulance	0 ALS on engine & 2 ALS on Ambulance	Constant
ABCs—start	**3.017**	**-0.017**	**-0.057**	**-0.069**	**-0.048**	**-0.030**	**-0.020**	**0.316**
SE	0.047	0.041	0.023	0.021	0.027	0.025	0.026	0.028
p-value	0.000	0.687	0.020	0.002	0.084	0.249	0.446	0.000
ABCs-- duration	**0.012**	**-0.044**	**0.022**	**-0.026**	**-0.015**	**-0.006**	**-0.028**	**0.172**
SE	0.046	0.051	0.029	0.033	0.041	0.033	0.026	0.035
p-value	0.805	0.391	0.445	0.427	0.722	0.869	0.290	0.000
Patient Interview - start	**2.953**	**0.000**	**-0.024**	**-0.024**	**-0.031**	**-0.031**	**-0.031**	**0.047**
SE	0.046	0.000	0.024	0.024	0.031	0.031	0.031	0.046
p-value	0.000	0.358	0.323	0.323	0.323	0.323	0.323	0.311
O2 administration- start	**3.207**	**0.044**	**-0.121**	**-0.169**	**0.065**	**0.185**	**0.039**	**0.815**
SE	0.283	0.452	0.095	0.120	0.132	0.123	0.111	0.094
p-value	0.000	0.922	0.210	0.166	0.625	0.141	0.729	0.000
Check Vitals – start	**2.728**	**-0.050**	**-0.268**	**-0.286**	**-0.120**	**-0.020**	**0.031**	**1.005**
SE	0.133	0.052	0.142	0.151	0.130	0.141	0.157	0.128
p-value	0.000	0.340	0.067	0.067	0.360	0.886	0.843	0.000
Check Vitals – duration	**0.335**	**-0.689**	**0.031**	**-0.208**	**-0.094**	**-0.119**	**-0.230**	**1.948**
SE	0.410	0.399	0.256	0.214	0.229	0.300	0.211	0.218
p-value	0.419	0.094	0.906	0.338	0.683	0.695	0.285	0.000
ALS Vitals 12-Lead - start	**2.789**	**0.678**	**-0.235**	**-0.471**	**0.250**	**2.559**	**2.330**	**1.394**
SE	0.437	0.472	0.233	0.222	0.346	0.240	0.239	0.255
p-value	0.000	0.160	0.321	0.041	0.474	0.000	0.000	0.000
Expose Chest - start	2.772	-0.433	-0.593	-0.985	-0.037	1.628	1.404	2.267
SE	0.583	0.479	0.392	0.397	0.496	0.501	0.490	0.470

Appendix H: All Regression Coefficients Continued

Regression Analysis Coefficients, Standard Errors and P-Values For Addressing Research Questions about Cardiac Time from Arrest (Coefficients are in Minutes) : Each Task Row Represents a Separate Regression

CARDIAC Tasks:	no engine	no engine & 2 ALS on ambulance	crew size 3 on engine	crew size 4 on engine	1 ALS on engine & 0 ALS on Ambulance	0 ALS on engine & 1 ALS on Ambulance	0 ALS on engine & 2 ALS on Ambulance	Constant
Airway Intubation-- Duration	**1.768**	**1.106**	**-0.696**	**-1.083**	**-1.889**	**0.619**	**0.298**	**4.199**
SE	0.958	1.398	0.563	0.570	0.783	0.761	0.809	0.893
p-value	0.074	0.434	0.225	0.066	0.021	0.422	0.715	0.000
IV Access – start	**0.382**	**-0.578**	**-0.194**	**-0.243**	**0.080**	**0.282**	**-0.361**	**1.785**
SE	0.462	0.410	0.270	0.261	0.253	0.351	0.222	0.260
p-value	0.414	0.168	0.476	0.358	0.755	0.428	0.113	0.000
IV Access – duration	**0.394**	**-0.261**	**0.028**	**0.000**	**0.083**	**0.044**	**0.044**	**0.072**
SE	0.259	0.272	0.023	0.022	0.032	0.021	0.024	0.021
p-value	0.138	0.343	0.229	1.000	0.015	0.040	0.077	0.002
Position Patient – start (difference from Arrest time)	**0.104**	**-0.383**	**-0.079**	**-0.131**	**-0.050**	**-0.050**	**0.033**	**0.307**
SE	0.364	0.336	0.093	0.093	0.113	0.108	0.122	0.141
p-value	0.776	0.261	0.402	0.170	0.660	0.645	0.786	0.036
ABCs – Start (difference from arrest time)	**0.345**	**-0.378**	**-0.086**	**-0.156**	**0.085**	**0.080**	**0.056**	**0.555**
SE	0.247	0.265	0.120	0.118	0.093	0.130	0.119	0.117
p-value	0.171	0.163	0.477	0.195	0.364	0.544	0.642	0.000
Defib pads – Start (difference from arrest time)	**0.242**	**-0.194**	**-0.133**	**-0.179**	**0.067**	**0.144**	**0.069**	**0.991**
SE	0.283	0.269	0.157	0.149	0.142	0.189	0.157	0.174
p-value	0.399	0.475	0.402	0.238	0.641	0.449	0.666	0.000
Analyze / Shock #1 – Start (difference from arrest time)	**0.089**	**-0.189**	**-0.178**	**-0.239**	**-0.028**	**0.070**	**-0.026**	**1.522**
SE	0.331	0.239	0.187	0.182	0.188	0.226	0.214	0.256
p-value	0.790	0.434	0.349	0.198	0.883	0.757	0.904	0.000
ABCs – Start – After Shock #1	**0.477**	**-0.356**	**-0.015**	**-0.021**	**0.148**	**-0.059**	**-0.026**	**0.779**
SE	0.459	0.460	0.196	0.187	0.191	0.182	0.234	0.186
p-value	0.306	0.445	0.938	0.912	0.444	0.746	0.912	0.000
CPR – CPR—Start (difference from arrest time)	**1.545**	**0.183**	**-0.207**	**-0.247**	**0.880**	**1.239**	**-0.128**	**1.244**

Regression Analysis Coefficients, Standard Errors and P-Values For Addressing Research Questions about Cardiac Time from Arrest (Coefficients are in Minutes) : Each Task Row Represents a Separate Regression								
CARDIAC Tasks:	**no engine**	**no engine & 2 ALS on ambulance**	**crew size 3 on engine**	**crew size 4 on engine**	**1 ALS on engine & 0 ALS on Ambulance**	**0 ALS on engine & 1 ALS on Ambulance**	**0 ALS on engine & 2 ALS on Ambulance**	**Constant**
SE	0.588	1.163	0.321	0.256	0.313	0.374	0.254	0.236
p-value	0.013	0.876	0.524	0.340	0.008	0.002	0.618	0.000
Airway Intubation- Start and duration – (difference from arrest time)	**-0.244**	**-0.078**	**-0.172**	**-0.594**	**-0.522**	**-0.604**	**0.037**	**2.800**
SE	0.417	0.453	0.319	0.301	0.322	0.286	0.315	0.260
p-value	0.562	0.865	0.593	0.057	0.114	0.043	0.907	0.000
Meds (Epi)- Start (difference from arrest time)	**0.632**	**-0.542**	**-0.228**	**-0.508**	**-0.504**	**-0.394**	**-1.022**	**2.751**
SE	0.957	1.262	0.339	0.303	0.365	0.390	0.408	0.430
p-value	0.513	0.671	0.506	0.103	0.177	0.318	0.017	0.000
Analyze / Shock #2 -- Start time	**-0.070**	**-0.300**	**-0.442**	**-0.479**	**-0.009**	**-0.137**	**-0.133**	**4.003**
SE	0.394	0.237	0.216	0.208	0.245	0.255	0.250	0.315
p-value	0.860	0.214	0.049	0.027	0.970	0.594	0.597	0.000
Medis (Lidocaine) - Start (difference from arrest time)	**2.054**	**-2.278**	**-0.440**	**-0.721**	**0.293**	**0.424**	**-0.596**	**4.763**
SE	0.424	0.404	0.287	0.297	0.296	0.359	0.350	0.258
p-value	0.000	0.000	0.135	0.021	0.329	0.246	0.097	0.000
Package Patient/Equip- Start	**1.444**	**0.328**	**-0.733**	**-1.013**	**-0.606**	**0.000**	**-0.991**	**5.795**
SE	0.673	1.375	0.538	0.450	0.554	0.530	0.583	0.480
p-value	0.039	0.813	0.182	0.031	0.282	1.000	0.098	0.000
Package Patient/Equip- Completion	**2.173**	**-0.072**	**-0.843**	**-1.394**	**-0.433**	**-0.054**	**-0.867**	**7.327**
SE	0.610	1.248	0.393	0.340	0.365	0.458	0.418	0.402
p-value	0.001	0.954	0.039	0.000	0.244	0.907	0.046	0.000

NOTES: