Model-Driven Data Integration for Emergency Response

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Model-Driven Data Integration for Emergency Response

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Dedicated to my children

Anushrutha Srinivas Yemula

and

Adhvaith Srinivas Yemula

Summary

Over the past decades, lots of emergencies such as natural and technological and man-made emergencies have been happening all around the world, every day and even every single hour. When any one of these emergencies happen, they create massive impacts on people, property, and environment. To lessen the emergency impacts, a complex network of Emergency Responders (ERs) from various Emergency Response Organizations (EROs) such as police service, fire and rescue service, health care, municipality, military, and non-governmental organizations, work together in teams and dispersed at different geo-locations to carry out different tasks depending on the type of an emergency.

In order to perform different tasks, ERs first need plenty of information to share within or among (intra-inter) teams in a timely manner to obtain a common operational picture of the emergency situation. However, during any kind of emergency, enormous amount of information is generated and available at various places. This generated and available information is collected manually or semi-automatically by distinct ERs and then stored in their respective organizations' data sources after the emergency occurrence. Although plenty of information is available, the information utilization by ERs is not optimal. The reason for this is that the available information is heterogeneously distributed, in different formats, with different semantics, stored in different EROs' data sources, and technically not accessible to one another. As a result, searching and finding the relevant information become time consuming. In such a situation, ERs face difficulties in obtaining a sufficient understanding of the emergency situation and poor decisions may be made.

Another problem faced by the ERs is lack of semantic understanding of the emergency domain concepts and their relationships that are being exchanged between separate information systems during an emergency response. Despite improvements made in the information systems' development in the emergency management domain, the existing information systems have not still completely solved the semantic heterogeneity problem across different EROs' data sources. In addition, different data exchange formats are being used to exchange information between or among ERs. As a result, misunderstandings among the ERs could happen thereby making ERs'

decision making process slow, which results in inefficient emergency management. Hence, the semantic heterogeneity problem needs to be solved.

One more problem that ERs are often confronted with is information overload. This is due to the fact that ERs are often engaged with performing various tasks during an emergency response. The delay in accomplishing response tasks may be caused by poor information presentation which is highly undesirable as it can result in causalities, property damage, and economic losses. This adds the point why the presentation of the information aspect is also an important problem which needs to be considered and solved.

In order to enhance the emergency response operations, the importance of access to the relevant information must be realized by different EROs. If relevant information is available, it is possible to achieve a common operational picture for making better decisions which is key to a better emergency response. Therefore, overcoming the above mentioned challenges need to be investigated. The use of information technology for integrating and handling data from existing data sources with different data formats via a unified system can be a good solution.

In this Ph.D dissertation, our research focuses on bringing the available heterogeneously dispersed information together to improve the information accessibility for ERs. To do so, we proposed a framework based on a model-driven data integration approach for solving the semantic heterogeneity problem in order to support various ERs for improving access to the needed and relevant information from different existing data sources. This is considered as a main contribution of this dissertation.

The proposed framework consists of three main components. The first component is the semantic model. The second component is the data source handling, and the third component is the information presentation. To test the applicability of the proposed framework, an indoor fire emergency use-case scenario in a multiple storey building has been considered. Using this case, a building fire emergency response (BFER) ontology has been developed to explore the semantics of fire emergency response in a building domain. The developed BFER ontology enables data exchange and knowledge sharing among different ERs and across heterogeneous EROs' data sources during the search and rescue operation. A semantically-enhanced mediator-based approach has been used to connect the existing data sources with the developed information model. To make the data accessible and available in a reliable way to ERs, web services have been utilized to present the relevant information on a graphical user interface (GUI).

The evaluation of the prototype was done in a workshop session with nine participants i.e., six from fire and rescue service, three from police service to evaluate the prototype against user requirements, and to evaluate the usability and performance of the prototype. The results of the workshop session revealed that the implemented framework can solve the data access problem faced by participants' i.e., access to the critical information and reduces their time for the information search. In addition, the developed prototype also solves the information overload problem by presenting the needed information in a systematic way on the developed GUI. When it comes to usability evaluation, the participants informed that the developed prototype was easy to learn how to use. However, the participants recommended that adding extra information such as mobile number to the victims' details and the room dimensions could have been beneficial for them on the GUI which will improve their decisions making process during the search and rescue operations.

As the applicability of the proposed framework is tested with integrating different information systems of university by solving the semantic heterogeneity problem in an indoor fire emergency in a public building, we believe that this proposed framework and the used methods can be extended and applied in other emergencies and cases for providing access to the needed information from various data sources in a unified way by solving the semantic heterogeneity problem.

Preface and Acknowledgments

This dissertation is the result of a research work carried out from February 2013 to February 2017 at the Department of Information and Communication Technology (ICT), Intelligent systems and Centre for Integrated Emergency Management (CIEM), research groups of the University of Agder (UiA), Grimstad, Norway. The task of completion of this dissertation would have not been possible without the supports from several individuals to whom I would like to express my deepest gratitude.

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Vimala Nunavath
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Grimstad, Norway

List of Publications

As the outcome of this research, the author of this dissertation is the main contributor and the first author of all the papers listed below. Papers A-E are selected and presented in Part II of this dissertation as the author's main research achievements. Papers F-L are not included in this dissertation.

Papers Included in the Dissertation

Paper A: Vimala Nunavath, Andreas Prinz, and Tina Comes, "Identifying First Responders Information Needs: Supporting Search and Rescue Operations for Fire Emergency Response", in *an international Journal of Information Systems for Crisis Response and Management*, Vol.8(1), pp.25–46, December 2016, DOI: `http://dx.doi.org/10.4018/IJISCRAM.2016010102`.

Paper B: Vimala Nunavath, Andreas Prinz, Tina Comes and Jaziar Radianti, "Representing Fire Emergency Response Knowledge through a Domain Modelling Approach", in *the proceedings of the NOrsk Konferanse for Organisasjoners Bruk av IT (NOKOBIT) conference*, Vol.24(1), pp.1–14, Bergen, Norway, 28–30 November 2016.

Paper C: Vimala Nunavath, and Andreas Prinz, "Data Sources Handling for Emergency Management: Supporting Information Availability and Accessibility for Emergency Responders", in *the 19th International Conference on Human-Computer Interaction*, pp.1–20, Vancouver, Canada, July 2017, DOI:`http://dx.doi.org/10.1007/978-3-319-58524-6_21`.

Paper D: Vimala Nunavath, and Andreas Prinz, "LifeRescue: A Web Based Application for Emergency Responders during Fire Emergency Response", in *the third International Conference Information and Communication Technologies for Disaster Management*, pp.1–8, Vienna, Austria, December 2016, DOI:`http://dx.doi.org/10.1109/ICT-DM.2016.7857204`.

Paper E: Vimala Nunavath, and Andreas Prinz, "LifeRescue Software Prototype for Supporting Emergency Responders during Fire Emergency Response: A Usability and User Requirements Evaluation", in *the 19th International Conference on Human-Computer Interaction*, pp.480–498, Vancouver, Canada, July 2017, DOI:`http://dx.doi.org/10.1007/978-3-319-58077-7_39`.

Other Publications Not Included in the Dissertation

Paper F: Vimala Nunavath, and Andreas Prinz, "Reference Architecture for Emergency Management Operations", in *the 8th IADIS International Conference on Information Systems*, pp. 243–247, Madeira, Portugal, March 2015.

Paper G: Vimala Nunavath, and Andreas Prinz, "Norwegian Emergency Management Process by using Business Process Modelling Notation", in *the 8th IADIS International Conference on Information Systems*, pp. 205–210, Madeira, Portugal, March 2015.

Paper H: Vimala Nunavath, Jaziar Radianti, Tina Comes, and Andreas Prinz, "Visualization of Information Flows and Exchanged Information: Evidence from an Indoor Fire Game", in *the 12th International Conference on Information Systems for Crisis Response and Management*, pp. 1–8, Kristiansand, Norway, May 2015.

Paper I: Vimala Nunavath, Jaziar Radianti, Tina Comes, and Andreas Prinz, "The Impacts of ICT Support on Information Distribution, Task Assignment for Gaining Teams' Situational Awareness in Search and Rescue Operations", in *the Second International Symposium on Signal Processing and Intelligent Recognition Systems*, pp. 443–456, Trivandrum, India, December 2015, DOI:`http://dx.doi.org/10.1007/978-3-319-28658-7_38`.

Paper J: Vimala Nunavath, Andreas Prinz, and Tina Comes, "Qualitative and Quantitative Study on Videotaped Data for Fire Emergency Response", in *an International Conference on Leadership, Innovation and Entrepreneurship (ICLIE)*, pp. 160–170, Dubai, UAE, April 2016, DOI:`http://dx.doi.org/10.1007/978-3/-319-43434-6_13`.

Paper K: Vimala Nunavath, and Andreas Prinz, "Taking the Advantage of Smart-phone Apps for Understanding Information Needs of Emergency Response Teams' for Situational Awareness: Evidence from an Indoor Fire Game", in *the*

18th International Conference on Human-Computer Interaction, Toronto, Canada, pp. 563–571, July 2016, DOI:http://dx.doi.org/10.1007/978-3-319-39513-5_52.

Paper L: Vimala Nunavath, and Andreas Prinz, "Visualization of Exchanged Information with Dynamic Networks: A Case Study of Indoor Fire Search and Rescue Operation", in *the 7th IEEE International Advance Computing Conference*, pp. 1–6, Hyderabad, India, January 2017, DOI:http://dx.doi.org/10.1109/IACC.2017.0068.

Contents

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Abbreviations

API	Application Programming Interface
AJAX	Asynchronous JavaScript and XML
BFER	Building Fire Emergency Response
CAP	Common Alerting Protocol
CIM	Computational Independent Model
CIQ	Customer Information Quality
CM	Crew Manager
CSS	Cascading Style Sheets
COP	Common Operational Picture
DM	Disaster Management
EDXL-DE	Emergency Data Exchange Language Distribution Element
EDXL-HAVE	Emergency Data Exchange Language Hospital Availability Exchange
EDXL-SitRep	Emergency Data Exchange Language Situation Reporting
EM	Emergency Management
ERs	Emergency Responders
EROs	Emergency Response Organizations
ESB	Enterprise Service Bus
ETL	Extract-Transform-Load
FC	Fire Chief
FS	Felles Studentsystem
GAV	Global-As-View (GAV)
GML	Geography MarkupLanguage
GLAV	Global and Local-As-View
GUI	Graphical User Interface

HTML5	Hyper Text Markup Language5
HTTP	HyperText Transfer Protocol
HCDP	Human Centered Design Process
IT	Information Technology
IDE	Integrated Development Environment
ICT	Information and Communication Technology
JDK	Java Development Kit
JMS	Java Message Service
JSP	Java Server Page
LAV	Local-As-View
LRC	Local Rescue Center
MDD	Model Driven Development
MySQL	My Structured Query Language
MDA	Model Driven Architecture
NIEM	National Information Exchange Model
OASIS	Organization for the Advancement of Structured Information Standards
OSC	On-Scene Commander
PC	Police Chief
PFIF	People Finder Interchange Format
PIM	Platform Independent Model
PSM	Platform Specific Model
REST	REpresentational State Transfer
SA	Situational Awareness
SAR	Search and Rescue Operation
SD	Smoke Diver
SDL	Smoke Diver Leader
SL	Smoke Leader

SOA	Service-Oriented Architecture
SOAP	Simple Object Access Protocol
SQL	Structured Query Language
UDEF	Universal Data Element Framework
UiA	Universitetet i Agder
UML	Unified Modelling Language
VDB	Virtual Database
VDI	Virtual Data Integration
W3C	The World Wide Web Consortium
WSDL	Web Service Description Language
XML	Extensible Markup Language

Glossary

- *Coordination:* Coordination is defined as “aligning one’s actions with those of other relevant actors and organizations to achieve a shared common goal” [1].
- *Collaboration:* Collaboration is used interchangeably with cooperation and coordination. It is defined as “an interaction between participants with capabilities to accomplish organizational goals, but choose to work together, within existing structures and policies, to serve individual interests” [2].
- *Decision making:* Decision-making can be defined as “ a process of taking important decisions by several entities to achieve a common goal by utilizing a combination of resources, information, and management tools” [3].
- *Data Integration:* Data integration is “a process of combining data residing in different sources and providing users with a unified view of these data” [4].
- *Data exchange:* Data exchange is “the process of taking data structured under a source schema and transforming it into data structured under a target schema, so that the target data is an accurate representation of the source data” [5].
- *Disaster:* Disaster is defined as “a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources” [6].
- *Emergency:* Emergency is defined as “a state in which normal procedures are suspended and extra-ordinary measures are taken in order to avert a disaster” [7].
- *Emergency Management:* Emergency Management is defined as “the organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps” [6].

- *Human-center design process:* Human-center design process is "a process focusing on usability throughout the entire development process and further throughout the system life cycle" [8].

- *Information model:* Information model is defined as "a notation by which the structural properties of information from a certain domain can be described in a precise but implementation independent manner" [9].

- *Information sharing:* Information sharing is defined as "the process of making information available to other individuals, teams, or organizations in the alliance" [10].

- *Meta-model:* A meta-model is "a model of a model which captures a particular domain's essential properties and a list of relevant relationships between these concepts. These include the concepts it supports, its textual and/or graphical syntax and its semantics" [11].

- *Mitigation Phase:* Mitigation phase is defined as "the lessening or limitation of the adverse impacts of hazards and related disasters" [6].

- *Ontology:* An ontology is " the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary" [12].

- *Preparedness Phase:* Preparedness phase is defined as "the knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions" [6].

- *Response Phase:* Response phase is further defined as "the provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected" [6].

- *Recovery Phase:* Recovery phase is defined as "the restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors" [6].

- *Search and rescue operation:* The purpose of search and rescue operation is to "prevent loss of life and injury through search, locate and rescue persons in distress by alerting, responding, and aiding activities using public and private resources" [13].

- *Semantics:* Semantics is defined as the "meaning and the use of data". In the information systems context, it can be considered as "a mapping between an object modeled, represented and/or stored in an information system and the real-world objects it represents. This mapping represents the semantics of the modeled object by describing or identifying the meaning and the use perspectives" [14].

- *Situational awareness:* Situational awareness is defined as "all knowledge that is accessible and can be integrated into a coherent picture, when required, to assess and cope with a situation" [15].

- *Web service:* A web service is defined as "a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-processable format (specifically Web Services Description Language (WSDL)). Other systems interact with the Web service in a manner prescribed by its description using Simple Object Access Protocol (SOAP) messages, typically conveyed using hypertext transfer protocol (HTTP) with an extensible markup language (XML) serialization in conjunction with other web-related standards" [16].

PART I

Chapter 1

Introduction

This chapter starts with presenting the background and the motivation of the Ph.D research study. In Sub-section 1.2, the problem is stated. The research questions are presented in Sub-section 1.3. The use case that we used to address the stated research questions is described in Sub-section 1.4. The research approach and methods that were used for the Ph.D study are presented in Sub-sections 1.5, and 1.6 respectively. In Sub-section 1.7, limitations of the research scope are reported. Our contributions to knowledge, the connection between the papers and the research questions are sketched in Sub-section 1.8. The structure of the dissertation is outlined in Sub-section 1.9.

1.1 Background and Motivation

Over the past decades, various kinds of emergencies such as natural and technological and man-made have been happening all over the world every day and even every single hour [17]. These emergencies are increasingly threatening people, infrastructure, environment, and economy. If we consider worldwide natural disasters' statistics, in the past 16 years (2000-2016), a total of 7029 disasters occurred with a total of 1.2 million causalities and 19.2 billion US dollar economic damages. When it comes to technological and man-made disasters, in the past 16 years (2000-2016), 4613 disasters occurred with a total of more than 140 thousand causalities and losses of 3.5 billion US dollars [18]. Given the devastating impacts caused by all kinds of emergencies every year, all over the world, an effective emergency management has become a compulsory issue to reduce the emergency impacts.

In this dissertation, Emergency Management (EM) also known as disaster management is defined as "the managerial function charged with creating the framework within which communities reduce vulnerability to hazards and cope with all kind of emergencies" [19]. In other words, disaster management can be defined as “the process of planning and taking actions to minimize the social and physical impact of disasters and reduce the community’s vulnerability to the consequences of disasters” [20]. The EM actually includes four main phases: *Mitigation phase, Preparedness phase, Response phase, and Recovery phase* [19]. In this Ph.D research, the focus is on response phase of the emergency management.

In the literature, an emergency response includes "providing emergency aid and assistance, reducing the probability of secondary damage, and minimizing problems for recovery operations" [21]. An emergency response consists of several activities such as placing emergency personnel and resources, searching and rescuing, first-aid victims, placing the victims in temporary shelters or places, evacuation, reporting, and dispatching resources [22].

To perform different emergency response activities, a complex network of diverse Emergency Responders (ERs) from different Emergency Response Organizations (EROs) such as police, fire and rescue service, health care, and municipality are involved. These ERs have to act rapidly in a coordinated manner to manage an emergency efficiently [23]. The engaged ERs usually have different roles, responsibilities, and backgrounds while responding to an emergency. The ERs are normally dispersed at different geographic locations i.e., some work at the emergency site, and some work at the operational center (i.e., command and control or support center) and handle different tasks either individually or in teams [24, 25].

During an emergency response, information sharing plays a significant role. For an efficient emergency response, the involved ERs should have access to the right information and share it with the right persons at the right time and in a right format for both intra-and-inter organizational coordination, for achieving a common operational picture, and for decision making [26, 27]. To achieve an efficient information sharing, the involved ERs need access to both static and dynamic information to perform tasks effectively and efficiently during an emergency response. The example static information might be information related to resources, and buildings. The example dynamic information might be information related to location of the victims, and location of the emergency responders.

To be proactive and lessen the emergency impacts, ERs should share relevant and needed up-to-date information with one another as quickly as possible, because the involved ERs often work at different geo-locations, and are confronted with time pressure, uncertainty, and complexity due to dynamic changing of the emergency situation [28]. With this, the information sharing becomes more frequent in order to gain an adequate understanding of the emergency situation and to make better decisions [29].

During an emergency response, ERs can coordinate well only if they have a common understanding of meanings of the terminologies, and their semantic relationships that are being exchanged among different information systems. If ERs do not have a common semantic understanding of the meanings of the terminologies related to the situation, the emergency situation is subjected to misinterpretation [30–32]. Poor information sharing and coordination in the inter-agency emergency response situations result into a poor emergency response [33–36]. Besides, the involved ERs face both communication and operational load during an emergency response.

Evaluation of past big disasters such as the 9/11 terrorist attacks in the United States in 2001 [37], the Indian ocean tsunami in 2005 [38], the Haiyan typhoon disaster in 2013 [39, 40], the 22 July 2011 Norway massacre [41], the Gudvangatunnel accident in 2013 Norway [42], the 1984 Bhopal incident [43], the Hurricanes Katrina in 2005 [44] consistently pointed out that one of the main challenges that frequently hampered ERs' emergency response activities was lacking access to timely information and finding precise information from the available information. In [45], the authors reported that during the 9/11 disaster, access to the inter-agency information needs to be improved to support inter-agency coordination. In addition, Dawes et.al mentioned that "in some cases, needed information existed but was not accessible" [33]. In brief, getting information access and awareness was always a challenge for ERs.

Another barrier is the difficulty to develop a common operational picture, which stems from the fact that ERs follow their own organization's policies, applications, procedures, and documents [1, 46]. ERs of one organization (e.g. police) generally are more interested in receiving information than in providing information to other organizations' ERs (e.g. fire and rescue service) and vice-versa [47]. In addition, power struggles, and shifting relationships can also play an important role [48]. The involved ERs use their own applications and data exchange formats. In such a case, ERs get a syntactic understanding, but face the semantic heterogeneity problem. As a result, ERs encounter difficulty in obtaining a common operational picture [49].

Additionally, ERs use a lot of time to gather information from various sources manually and semi-automatically. This collected information is stored in their individual data sources which are isolated. Whenever ERs of one organization (e.g. police) need information (e.g. geographic information) from other organization (e.g.

fire protection service), the needed information is obtained either face-to face or with the help of hand-held devices. This type of information sharing can prevent ERs from performing the emergency response activities (e.g. evacuation, causality count, and victim transportation) effectively as the obtained information cannot be remembered due to the emergency responsibilities and stress. Yet, there might be chances that supply and demand can be mismatched in such an unpredictable emergency environment [47].

Due to the dynamic environment of an emergency, time is an important factor that has to be considered, because information that is collected at a particular time may become outdated after some time [1] [50]. If sharing of information is delayed, it is difficult for ERs to achieve a common operational picture as well as may be difficult to make decisions. Therefore, all the above-mentioned factors are motivation factors which invoked us to study and implement efficient ways for accessing the relevant information and provide information awareness in order to support ERs for information access and sharing, for obtaining a common operational picture, for decision making, and for conceptualization of the emergency response concepts.

1.2 Problem Statement

An emergency response is a complex situation which requires different emergency responders (ERs) from various emergency response organizations (EROs), and a need to access and share different types of information in a timely manner [51]. In current practices, when an emergency happens, a vast amount of large and heterogeneous data is generated. This generated data is gathered manually or semi-automatically by different EROs and some of the information is only stored in their respective data sources in different formats with different semantics after an emergency occurrence.

As an illustrative example, we show in Figure 1.1, how the involved ERs (from two different EROs) need access to various types of information for performing different tasks at the emergency site. When ERs from Emergency Organization (EO) A and EO B work together, they have to perform numerous tasks (i.e., task1....task n) at the emergency site. To actually perform various tasks, ERs **need heterogeneous information** from both EO A's data source A (represented as DA1 to DAn (blue circles)), and EO B's data source B (denoted as DB1 to DBn (green circles)).

For example, in Figure 1.1, to perform task 2, the ERs of EO A need some information such as DB1 and DB2 from EO B's data source B. To perform task 3, ERs of EO B need some information such as DA2 and DAn from EO A's data source A. This situation may hinder these two organizations to cooperate and perform their tasks, as ERs of EO A and EO B do not have access to each others information. This can occur due to the fact that ERs of EO A and EO B use their own applications (data sources) and these applications contain **different data sets, representations, semantics, and information models**. This means that each individual information system's information is often understandable by only one specific organization i.e., either to EO A or to EO B.

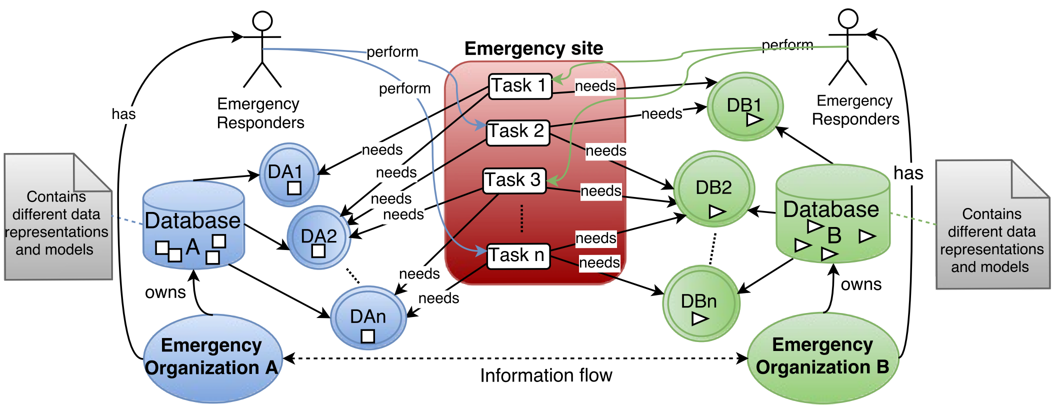

Figure 1.1: Information Access Problem during an Emergency Response

Further, when EO A and EO B exchange information with one another, the receiver and sender should have a common understanding of the meanings of the exchanged information. But, in reality, as these two organizations are different entities, they use different concepts and terminologies to represent the same terms i.e., the entities in the ERO A's data source are represented in "square" and entities in EO B are represented in "triangle". As a result, the **semantic heterogeneity** problem occurs. To make EO A and EO B's data accessible, a **semantic data integration** is needed. Semantic data integration can be possible only when ERs understand the semantics of the information that is integrated and being exchanged and understood by the communicating information systems during an emergency response.

The integrated information should be accessible and available to the ERs in a reliable way and presented in such a way that the information help to meet the ERs' goals during an emergency response. This is due to the delay in accomplishing response tasks caused by poor information presentation which is highly undesirable as it can result in a lot of causalities, property damage, and economic losses. This adds the point why the **presentation of the information** aspect is also an important problem that needs to be considered and solved.

This research work aims in contributing to solve the semantic heterogeneity issue of various existing data sources to support quick, real-time access to relevant information during the search and rescue operation (SAR) by using information and communication technologies. The main research challenge addressed in this research is as follows: *"How to make relevant information available and accessible from diverse information sources to support ERs for improving the efficiency of performing emergency response activities?"*. To solve the main research problem, we consider the Model-Driven Development (MDD) approach, because it facilitates modeling, design, implementation, and integration of different applications in a simple manner by developing the software mainly at the model level [52]. More details on the MDD approach are given in the Sub-section 1.5.

1.3 Research Questions

To solve the main research challenge, the following research questions were taken into consideration, because to provide quick access to the relevant information, first it is necessary to know ERs' information needs, where the information is stored, and how the information can be provided. Thus, the research questions are stated as follows.

- **RQ1**: What are the critical information categories needed by the emergency responders during an emergency response?
- **RQ2**: How to solve the semantic heterogeneity issue that hinders information exchange among different information systems and eventually different emergency responders during an emergency response?
- **RQ3**: How to provide relevant information from existing various emergency response organizations' data sources into a single operational model during an emergency response?
- **RQ4**: How and what information can be accessed in a reliable way and presented to the emergency responders to meet their information needs during an emergency response?

The first research question in the above list is to understand and know the **information needs** and requirements of the ERs during an emergency response. The information needs are studied from the perspective of ERs who are at the emergency site. The emphasis is put especially on the information content. The second research question is targeting at the **semantic heterogeneity** challenge that ERs are facing, while the third research question is to address the **semantic data**

integration challenge. The last research question is to address/understand the **information presentation** challenge. As the problems that are stated in the above research questions contains exactly the same problems that are identified in the Sub-section 1.2, it is clear that solving these research questions answer the main research challenge.

Based on the above research questions, detailed literature reviews were performed, existing solutions were studies, potential information and communication technologies were investigated, and a tailored approach was proposed. The results of the research were presented in twelve research papers. However, we considered only five papers in this dissertation. The reason for selecting the five papers is that these papers include answers to the research question that are stated above and can be seen in the Sub-section 1.8. The detailed explanation of these papers is given in Chapter 3.

1.4 A Case Study

The research questions that are stated in the Sub-section 1.3 are very generic and have to be answered depending on a domain. So, we need a specific case in addition where a solution can be applied. Therefore, in this research, to test solution's applicability and validity, a use-case is considered. The investigated use-case is an indoor fire emergency in a public building (i.e., in university) which is used to study the information needs of ERs, to develop, and evaluate the solution.

The reason for selecting fire emergencies is, because major fire and explosion is the most frequent man-made emergency that occurs worldwide in daily life [53]. Even in some natural disaster events such as earthquake or volcanic eruption, building fires can be a significant part of the emergency which needs an urgent response. If we consider world statistics for the fire emergencies, for the year 2014, almost 28 million fire emergencies occurred with a total of 21000 fatalities and losses of 110 billion US dollars worldwide [54]. In addition to that, statistics of the fire emergencies in public buildings such as universities reveal that in the USA, for example, from 2000-2015, 89 fires have occurred on a college campus which killed 126 people.

Fire in a building can represent a complex scenario, because many dimensions are involved when responding to a fire:

- Rescuing people from areas filled with smoke and fire might get decreased due to unavailability of needed information.
- In a wider scenario such as fire in public buildings with many occupants,

local EROs may have to increase their response capacity by initiating inter-organization collaboration.

- During the SAR, the information needs of different ERs will increase due to uncertainty of people's location.
- In the SAR, the ERs face numerous challenges due to not having access to the available information.

Thus, an indoor fire emergency scenario is an interesting, complex, solid, and acceptable as a basis for developing a proof-of-concept of the proposed solution in this dissertation. The considered use-case scenario description is outlined below.

"Imagine there is a big fire in the university building. The fire starts in the ground floor of the building A at the university. But, unfortunately the fire alarm sensor and sprinkler system do not work and alert the security officials. As a result, the ground floor of the building is filled with smoke and then the fire started to spread from one room to the other. After a few minutes, students on the first floor alert the security personnel.

Immediately, the sprinkler system gets activated manually and, within a minute, security guards activate the fire alarm. As everyone knows that, this time, it is not a drill, tensions are high and some students begin pushing other people to get to the exit. However, due to the fast fire spread, the flame is beginning to escalate to the other parts of the building. Due to the high risk of potential additional hazards, no one is allowed to take elevators for self-evacuation.

There are 50 vulnerable persons among the people who are at the university (vulnerable are old people, pregnant, allergic to smoke and heat, physically-challenged persons). These vulnerable people cannot reach the exit quickly and are spread all over the building. Visitors are not aware of the evacuation procedures and exit routes. Due to structural collapse and poor visibility, they are also being stuck inside the building. Some other people are suffering from severe burns and smoke inhalation.

The roof collapsed in the neighboring classrooms of the room where the fire originated. There is also heavy smoke coming out of the building and electricity damage occurred. Thus, evacuating occupants from multiple floors of a high-rise building involves a lot of time. The vast majority of the occupants are self-evacuated, but 50 victims are still trapped in each floor of the university building. As the university building has several floors, at least 10 victims got stuck inside each floor. However, fire fighters are unaware of the total number of the victims and also the number of persons inside each floor of the building and their exact location to get an overview of the situation and to evacuate them" [55].

Based on this considered use-case, we have reformulated the generic research questions which are stated in the Sub-section 1.3 as follows. The formulated research questions are:

- **FRQ1**: What are the critical information categories needed by the emergency responders during an indoor fire emergency SAR?
- **FRQ2**: How to solve the semantic heterogeneity issue that hinders information exchange among different information systems and eventually different emergency responders during the fire emergency response?
- **FRQ3**: How to provide relevant information from existing various emergency response organizations' data sources into a single operational model during an indoor fire emergency SAR?
- **FRQ4**: How and what information can be accessed in a reliable way and presented to the emergency responders to meet their information needs during an indoor fire emergency SAR in order to perform better?

In the aforementioned use-case, to perform the SAR efficiently, ERs need information such as victims' location, fire related information, and resources inside the building information from diverse data sources. However, at the emergency site, the needed information is available at various places i.e., in different university information systems. But, in reality, ERs face two challenges to use these information resources: 1) ERs don't have access to the information, 2) even if they get access, the information can be retrieved only from one single system at a time, and this information do not necessarily provide actionable information. Hence, there is a necessity to integrate the needed information by solving the semantic heterogeneity problem from the various university information systems to give a unified way to access the information.

Figure 1.2 depicts information flows among different ERs during an indoor fire emergency at the university building. The arrows in Figure 1.2 represent the inter-organizational and intra-organizational information flows. Here, intra-organizational information flows mean "information sharing within one organization". Inter-organizational information flows mean "information sharing among two different organizations". As we mentioned earlier, when information is needed, the information is collected manually and semi-automatically. The collected and manually processed information is then shared with the ERs who have requested it. The information sharing between two different ERs are usually done via face-to-face or by using hand-held devices such as either mobile phones or walkie-talkies.

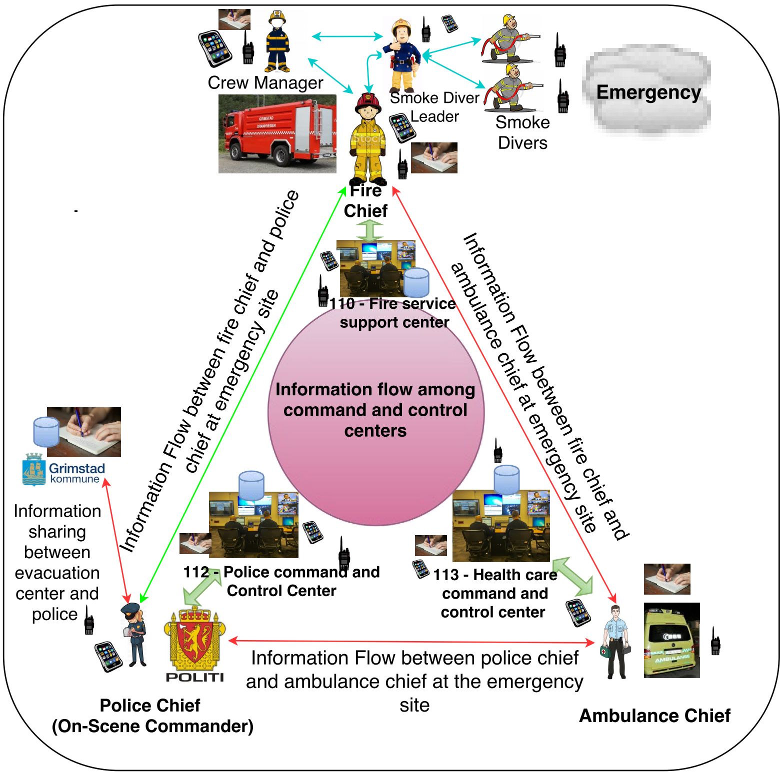

Figure 1.2: Information Flows among Different Emergency Responders during an Indoor Fire Emergency Search and Rescue Operation

With this kind of information collection, a lot of time is being used for information search instead of rescuing people. Hence, in the above-mentioned case, it is important that ERs should get access to real-time information which are available at various university information systems. Therefore, in this research, we propose a methodology to answer the above-stated formulated research questions (FRQ1-FRQ4). The solutions and results of the formulated research questions (FRQ1-FRQ4) are presented in papers A-D. Note, in this dissertation, we investigate the information flow between the police and fire and rescue services, and use different university information systems for testing the applicability of our proposed solutions, but not various EROs' information systems. This is because, at the time we started this research, we did not get access to the EROs' data sources (or applications) due to organizational, political, and legal restrictions.

Table 1.1 summarizes the papers included in this dissertation and how each of them tackles each formulated research question. The goal of the paper A was to answer the research question FRQ1 by identifying the critical information needs (which are referred to in this dissertation as 'user requirements or information requirements') of the emergency responders who are involved during an indoor fire emergency response SAR. In paper B, the goal was to answer the research question FRQ2 by developing an information model for solving the semantic heterogeneity problem which can be used during a fire emergency response.

The objective of paper C was to answer research question FRQ3 by implementing a solution for solving the data integration problem by connecting existing data sources with the developed information model. In paper D, the goal was to answer the research question FRQ4 by implementing a solution to access and make the needed information available in a reliable way to ERs by developing a graphical user interface (GUI) to support ERs during an indoor fire emergency response SAR. The objective of paper E was to evaluate the developed prototype against the user requirements and also to evaluate the usability of the GUI which contributes in achieving the research objective by validating and verifying the developed system.

Table 1.1: The Published Scientific papers and the Related Research Questions

Paper	**Scope**	**Formulated and addressed Research Questions**
A	To identify the information needs of emergency responders during an indoor fire emergency SAR	FRQ1
B	To solve the semantic heterogeneity problem by developing an information model which can be used for a fire emergency response	FRQ2
C	To solve the data integration problem by connecting existing data sources with the developed information model	FRQ3
D	To make information accessible and present relevant information on the developed graphical user interface for supporting emergency responders during an indoor fire emergency SAR	FRQ4
E	To evaluate the developed prototype against the user requirements and the usability and performance evaluation	-

1.5 Research Approach

In this dissertation, we approach the problem by employing a Model-Driven Development (MDD) approach.

MDD is sometimes also referred to as model-driven software development. This is an approach to system development, which increases the power of models in system development. It is model-driven because it provides a means for using models to direct the course of understanding, design, construction, deployment, operation, maintenance, and modification. The MDD process is depicted in Figure 1.3. This approach has been used to solve the main research question which embraces the following models of a system [56, 57]. We adapt the MDD approach (see Figure 1.3) to our situation.

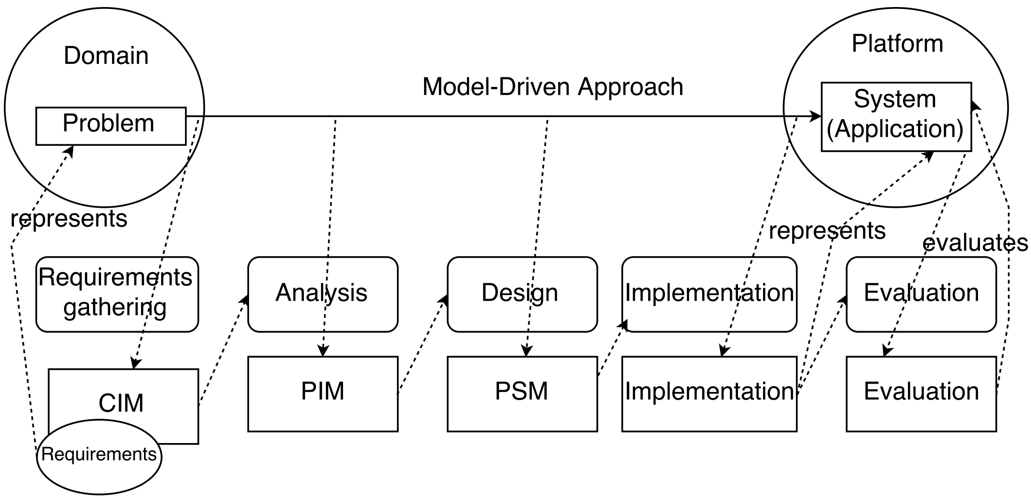

Figure 1.3: Foundational Concepts of the MDD (adapted from [56])

- **Computational Independent Model (CIM):** The requirements of the system and the domain concepts are described in the CIM. It consists of a model which acquires information about the data of a system from the informational viewpoint. The conceptualization perspective's requirements model is harmonized with this model. The requirements are defined and presented in Chapter 3.

- **Platform-independent Model (PIM):** The system independent operations of any platform are described in the PIM. It consists of a model which holds information about the data of a system from the informational viewpoint, and a model which captures information about the processing of a system from the computational viewpoint. It is independent of any platform. In order to achieve platform independence, a technology-neutral virtual machine may be targeted by a model. A virtual machine is a collection of parts and services. In any specific platform, these parts and services remain independent and unaffected by any underlying platform. Further, PIM corresponds to a model for specification perspective's analysis. This part is not considered in this dissertation due to time limitations.

- **Platform Specific Model (PSM):** In this, PSM uses one or more specific platforms to describe the operation of the system. It consists of a model which captures information about the data of a system from the informational viewpoint, and a model which captures information about the processing of a system from the computational viewpoint. It is based on a specific platform. It uses the features of the specific platform specified by a platform model as it targets a specific platform. Further, it corresponds to a model for specification perspective's design. This part is presented in Chapter 3.

- **Implementation**: The implementation represents a specification that contains all of the information for developing and putting a system into operation. This part is presented in Chapter 3.

- **Evaluation:** The evaluation is done on several things. First, the developed prototype is evaluated against the information requirements and then proposed framework against framework requirements that are posed in the Sub-section 3.1.1. Next, the proposed framework is evaluated against the formulated research questions that are stated in the Sub-section 1.4. The proposed framework is evaluated against the research questions that are posed in the Sub-section 1.3. The complete evaluation part is presented in Chapter 4.

1.6 Research Methods

To answer the formulated research questions, different research methods have been taken into account. The reason for considering the different research methods in this research is that, we want to solve the main research problem in different aspects in order to achieve a holistic perspective. The first research method is methontology [58], the second method is mediator-based data integration [59], and the third method is the human-centered design process (HCDP) [8]. In addition, qualitative and quantitative methods have also been used.

1.6.1 Methontology

In this Ph.D research, we used the methontology [60] framework to construct an information model for answering the formulated research question FRQ2. Methontology is a well-structured methodology to build domain models from scratch [61]. This methodology highly recommends the use of existing models. It consists of the following 6 tasks:

- **Build a requirements specification document:** In this phase, knowledge about the scope of an ontology, intended uses, level of formality, and intended end users should be gathered and specified.
- **Acquire knowledge:** In this phase, knowledge is elucidated and acquired from various sources such as domain experts, books, handbooks, figures, tables, and even from other ontologies by using different conjunction techniques such as brainstorming, interviews, formal and informal analysis of texts, and knowledge acquisition tools.
- **Conceptualize the meta-model:** In this phase, the domain knowledge in a conceptual model is structured to describe the problem and its solution in terms of the domain vocabulary which are identified in the ontology specification activity. A conceptual model consists of domain concepts, their meanings, attributes, and instances.
- **Implement the meta-model:** In this phase, an ontology is codified into a formal language.
- **Evaluate during each phase:** In this phase, evaluation has to be done in order to carry out a technical judgment of the ontologies, their software environment, and documentation with respect to a frame of reference (in our case the requirements specification document). It is done during each phase and between phases of their life cycle.
- **Documentation after each phase:** In this phase, each phase of the ontology development has to be documented.

1.6.2 Mediator-based Data Integration

In order to answer the formulated research question FRQ3 i.e. handling various data sources, we have used a semantically-enhanced mediator-based data integration approach. This approach provides users with a virtual data warehouse without moving the data from its original sources and schematically mapping the data with the developed ontology [59, 62].

1.6.3 Human-centred Design Process

In order to implement the prototype and answer the formulated research question FRQ4, we have used HCDP methodology which was proposed in [8]. The process includes the following steps.

- **Step 1 - Understand and specify the context of use:** In this step, theoretical and practical studies were conducted in order to get an in-depth understanding about emergency response operations, involved ERs, information flows, challenges that ERs are facing for information sharing, situational awareness, and for decision making.

- **Step 2 - Specify the user requirements:** Emergency responders from police service, and fire and rescue service were involved in the design process especially to specify their information needs, and best way to present the information to the ERs. In this step, information needs, GUI requirements, and framework requirements were elicited and presented in Chapter 3.

- **Step 3 - Produce design solutions to meet user requirements:** Having taken information and GUI requirements into consideration, design and implementation were carried out and described in Chapter 3.

- **Step 4 - Evaluate the developed prototype:** In this step, evaluation of the developed prototype against user requirements and the usability of the GUI have been done and presented in Chapter 4.

1.6.4 Qualitative and quantitative Methods

The main beneficiaries of this work are different ERs who are at the emergency scene, hence their opinions have a considerable impact either positively or negatively on the proposed solution. Thus, different qualitative research methods such as surveys, semi-structured interviews, participants observation were used and applied to obtain an in-depth understanding and to collect data regarding an indoor fire emergency SAR. The same methods were used for understanding the information flows among different ERs, challenges that ERs are facing for information access and sharing, obtaining a common operational picture, and for decision making. These methods were being used for answering certain parts of the research questions FRQ1, FRQ2, and FRQ4.

The quantitative method such as survey method was used for evaluating the developed prototype against user requirements and for usability.

1.7 Limitation of the Research Scope

It is very important to clarify, identify, and describe the limitations of this Ph.D research scope. Therefore, the scope of this study is described as follows.

- The focus of this dissertation is restricted to the response phase of the emergency management.
- In this study, the explorations are limited to only fire and rescue and police services' personnel's information needs who work at the emergency site instead of all the involved organizations' ERs due to time limitations.
- The research is focused on information accessibility during the SAR in case of an emergency.
- Interviews were carried out only for the most important roles of fire and rescue and police services such as fire chief, crew manager, smoke diver leaders, smoke divers, and police chiefs.
- Strategic level, tactical level, and command and control center personnel of all EROs, operational level of municipality and ambulance personnel's information needs are not covered in this dissertation due to time limitations.

1.8 Contributions of the Scientific Papers

The high level view on our solution and the contributions (C1-C4) of this Ph.D dissertation are illustrated in Figure 1.4. The main contributions of this dissertation are summarized as follows.

- **C1:** The dissertation presents an information technology (IT) framework for data integration to support ERs during an emergency response. The framework aims at providing a reliable access to the needed and relevant information for obtaining a common operational picture, and for decision making. The framework allows integrating existing different data sources within the EROs into a unified system and providing information to various ERs.

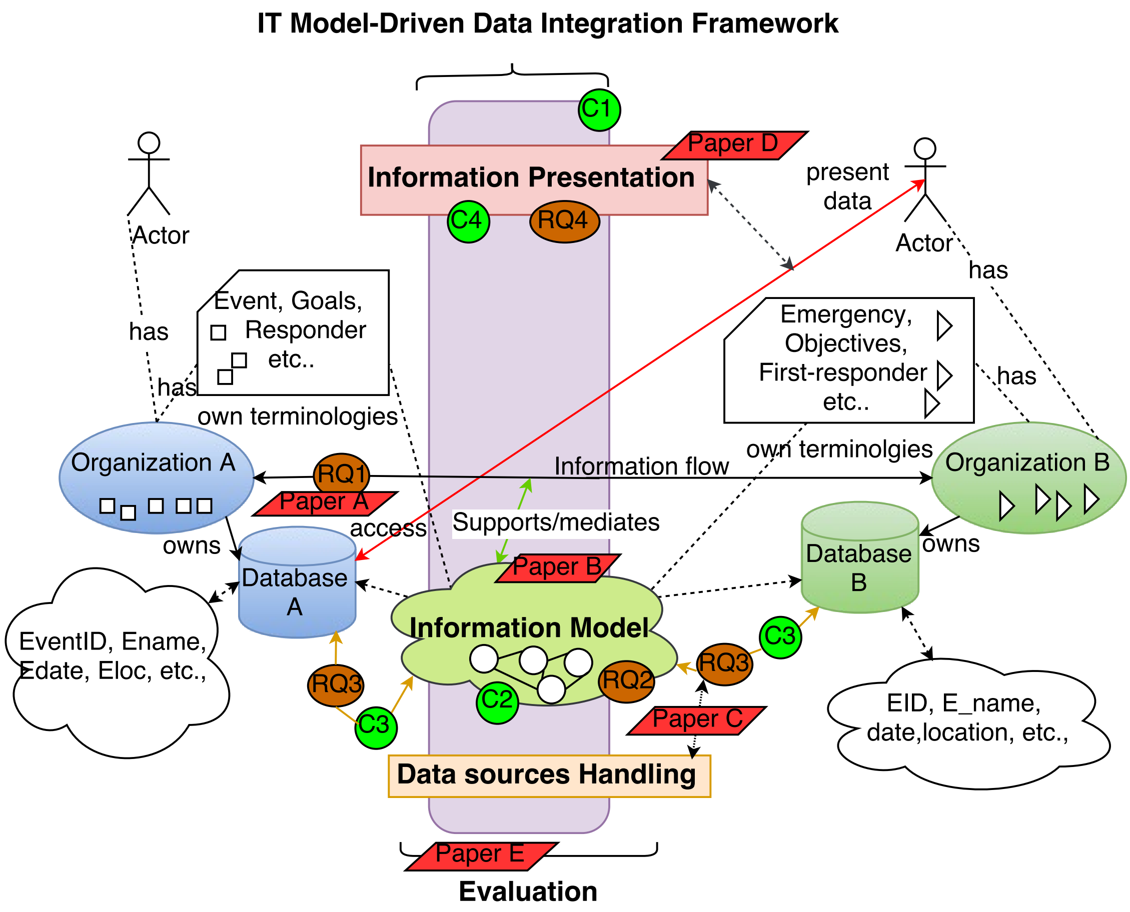

Figure 1.4: Overview of the Research Contributions

- **C2:** In this dissertation, an information model has been developed and presented to manage the fire emergency response information in a semantic way. The development of the information model has been done with the help of an indoor fire emergency use-case scenario.

- **C3:** In this dissertation, a method for handling multiple structured data sources and connecting with the developed information model has been developed and presented. However, to test the applicability, we have used an indoor fire emergency SAR as a case.

- **C4:** A method for providing relevant information for fulfilling different ERs' information needs has been developed. However, we have used an indoor fire emergency SAR as a case to test the applicability of the method.

1.9 Structure of the Dissertation

This dissertation is organized as a compilation of scientific papers. It consists of two parts. Part I provides an overview of the work carried out throughout the Ph.D research and Part II includes a collection of five published scientific articles which are mentioned in the list of publications.

Part I is organized as follows.

- **Chapter 1** presents the following points: background and motivation of the research work, research questions and formulated research questions that we want to answer in this dissertation, description of the use-case scenario that we have considered to answer the formulated research questions, the research approach that we have followed to achieve the objective of this dissertation, different research methods to tackle the formulated research questions individually, limitations of this research, and the contributions of the research to the knowledge.
- **Chapter 2** describes the state-of-the-art concepts and technologies that lay the foundation for this work, including related works that have been conducted earlier by other researchers.
- **Chapter 3** presents the proposed solutions to solve the issues addressed in Chapter 1.
- **Chapter 4** presents the discussion on the results achieved throughout the research work, including an evaluation of the developed prototype against the user requirements, evaluation on the usability of the GUI, an evaluation of the framework against framework requirements, and an evaluation of the framework against research questions, and formulated research questions that are presented in Chapter 1.
- **Chapter 5** briefly summarizes the contributions we have presented in this dissertation. Concluding remarks, and future outlook are then presented.

Part II includes five appendixes A-E which presents the selected publications as described in the Sub-section 1.4.

Chapter 2

Background and State-of-the-Art

This chapter is divided into two parts i.e., 1) background, and 2) related work. The first part starts with giving an overview of the concepts that act as the building blocks of the main contributions of this dissertation. Then current technologies and paradigms that enable the author to proceed with the design and development of the proposed solution in the next chapter are presented. In the second part, related works that have been carried out by other researcher are outlined.

2.1 Background

2.1.1 Emergency Management

In the literature, sometimes the terms disaster, emergency, catastrophe, and crisis are being used interchangeably with slight differences by many scholars and practitioners [22]. In order to understand the emergency management domain, these concepts are defined as follows. According to the United Nations [6], *disaster* is defined as “a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources”.

The Federal Emergency Management Agency defines *catastrophe* as “any natural or man made incident, including terrorism, that results in extraordinary levels of mass casualties, damage, or disruption severely affecting the population, infrastructure, environment, economy, national morale, and/or government functions” [63, 64]. According to the World Health Organization, an *emergency* is defined as “a state in which normal procedures are suspended and extra-ordinary measures are taken in order to avert a disaster" [7]. The *crisis* is defined as "a decisive crucial event, or a great danger or trouble with the possibilities of both good and bad outcomes" [65]. In this dissertation, we use the term emergency as it fits to our work.

All emergencies are caused either by natural and technological and man-made emergencies. Here, *natural emergency* is the emergency "that exist in the natural environment and pose a threat to human populations and communities" [17]. *Technological and man-made emergency* is defined as "a human induced emergency is the result of a failure of human hand or in human-made products" [66]. From the definitions, it is obvious that if any kind of disasters or emergencies occur, it may result in substantial harm to environment, economy and societies [67].

2.1.1.1 Emergency Management Phases

Emergency Management (EM) is defined as "the organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps" [6]. Generally, emergency management is described as consisting of four phases: "mitigation, preparedness, response, and recovery" [6, 68], and can be seen in Figure 2.1.

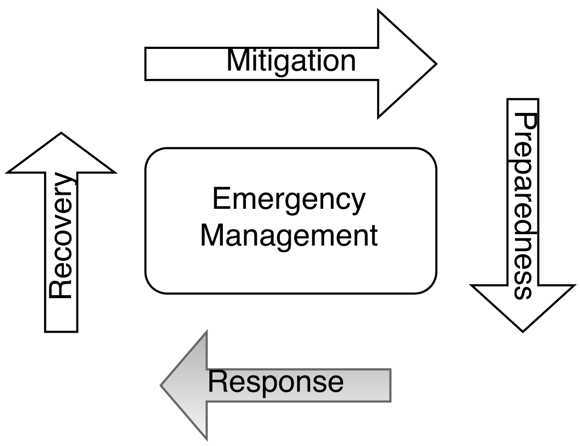

Figure 2.1: Emergency Management Cycle

The *mitigation* phase is defined as "the lessening or limitation of the adverse impacts of hazards and related disasters" [6]. The *preparedness* phase is defined as "the knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions" [6].

The *response* phase is further defined as "the provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected" [6], while the *recovery* phase is defined as "the restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors" [6].

In each EM phase, thorough planning and execution is needed. An efficient coordination of activities in all four phases results in a successful EM. To avoid overlapping among these four phases, clear boundaries should be defined at each level such as where one phase should start and where one should end. However, often overlapping occurs during execution of these phases. Generally, in EM, different emergency response organizations take part in each phase i.e., preparedness, mitigation, response and recovery [69]. In the next section, the response phase of the EM is discussed in detail since it is the focus of this Ph.D research.

2.1.1.2 Emergency Response

In emergency management, the response phase is considered as one of the core phases [68,70]. During this phase, emergency responders (ERs) are the key personnel who are responsible for having the preparedness and ability to intervene instantly and rapidly for responding to an emergency [70, 71]. The ERs belong to various Emergency Response Organizations (EROs). From the involved ERs, some work at the emergency site and some work at the command and control center. ERs (who are also called as first-responders) are the personnel who are trained and equipped to operate during an emergency response. The first-responders are the persons who work at the emergency site [72].

During an emergency response, ERs are often confronted with stressful situations in unfamiliar and hazardous work environments [73] making response more complex than other phases [74]. The six major functions that are performed by Emergency response organization are coordination, policy-making, response operations, information gathering, dispersal of public information, and hosting visitors [75].

If the emergency occurrence is large, to provide immediate response, a temporary organization structure is formed to mitigate an emergency [76, 77]. ERs in the temporary structure have individual roles, tasks and responsibilities [70]. Due to the unique characteristics of an emergency response situation, the information that is required by ERs may be different from case to case while responding to an emergency [73]. Emergency response operations comprise of many specific work rhythms [78] and temporal structures [79].

After drawing from the work of [80, 81], Landgren [70] outlines five specific characteristics that make work unique during the response phase of an emergency. The first time-critical aspects are related to the reactive nature of the emergency response work for example *time-pressure*, because, ERs always confronted by time-pressure during an emergency response to physically intervene in a sudden event as fast as possible [82]. Second, the time-critical aspects are also related to uncertainties and ambiguities caused by *incomplete information* [83]. Third, the immediate actions are dependent on *team-based collective actions* and are to a large extent fixed and irreversible [84]. Fourth, the situation is *dynamic and uncertain*, leading to changing and sometimes competing goals [84–86]. Fifth, the involved actors are *working on different time-scales* [87] depending on their role and responsibility [88].

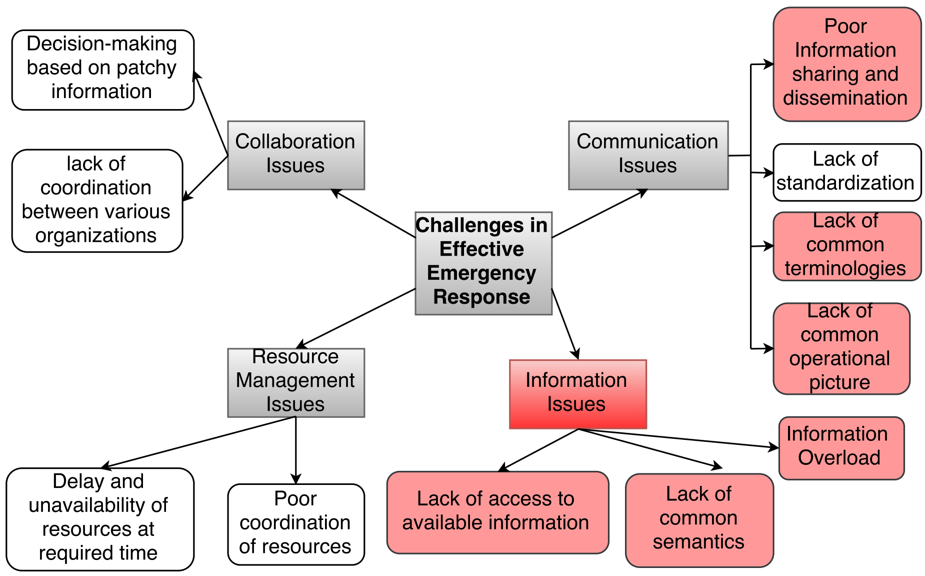

Figure 2.2: Barriers to an Effective Emergency Response ([73])

The time-critical nature and adverse conditions during the response phase often lead to an inadequate emergency response [89, 90]. One of the essential elements of emergency response that is particularly important to large-scale emergencies is *information flow* [91]. Managing information flows is important during the emergency response, because decision making is critical which depends on time and distributed information [92]. A key challenge in an effective emergency response operation is to accurately access the existing situation to collect accurate and relevant data from the emergency scene, and to analyze and transmit it to the right personnel at the right time [73]. The information which is gathered at one particular time may become outdated after some time due to changes in the emergency conditions [93].

Furthermore, during an emergency response, ERs face numerous challenges such as information overload, the availability of fewer communication channels, and the omitting, delaying, and filtering of information, processing of incorrect information [94, 95], lack of access to available information [96], and misunderstanding due to difference in terminologies [73]. With these challenges, ERs at individual, team, and organizational levels are unable to achieve a common operational picture and make decisions in an appropriate manner [73, 97, 98].

To manage emergencies in an efficient and highly coordinated manner, updated emergency information must be collected, analyzed, and distributed vertically and horizontally among different ERs in a timely manner [98, 99]. Various challenges exist for an effective emergency response which are summarized and documented in [73]. Those challenges are related to collaboration, communication, and resource management. In this research, we include the barriers for an effective emergency response that were found in [73] and add some more challenges as shown in Figure 2.2 i.e., information issues. In Sub-section 2.1.2, we discuss the information issues during an emergency response in detail which is the main problem that this dissertation contributes to.

2.1.2 Information Issues in Emergency Response

During an emergency response, lots of information sharing is done among various ERs. Information sharing is defined as "exchanging or otherwise giving other agencies access to required information" [100]. This means, it is a process where different ERs deliberately decide on which information should be exchanged to other entities and in what manner in order to achieve the objectives in an emergency response [101]. Hence, information sharing is considered as a foundation for inter-organizational collaboration and coordination, pivotal for increasing efficiency and performance of ERs during an emergency response [102, 103].

The ERs require various kinds of information at the emergency site in order to share information with one another. However, at the emergency site, different types of data is collected from various places. Managing such a large scale information is challenging due to diversity, large amount, dynamic behavior, and geographical distribution [104]. In order to manage an emergency, the optimal provision of detailed, precise, and up-to-date information concerning the situation is essential for ERs [105, 106]. Otherwise, ERs face information overloading problems [28]. The up-to-date information must be exchanged upstream and downstream within and among organizations in real-time. In order to do so, the need arises for an integrated information system to provide efficient, reliable, and secure exchange and processing of relevant and updated information [104, 105]. However, during an emergency response, it is challenging to provide relevant and up-to-date information to ERs since it might be dispersed across a hierarchy of storage i.e., the information is stored in heterogeneous databases with heterogeneous data formats [104]. These heterogeneous data sources belong to autonomous organizations [107] and these information systems are designed for each individual emergency response organization needs.

Furthermore, during an emergency, network disconnections and data failures become the rule rather than exception [71]. The heterogeneous systems must also respond to the users as quickly and as efficiently as possible with the most updated information [104]. Otherwise, lack of access to relevant information from these diverse information sources or systems causes hindrances in developing a common operating picture for ERs [102]. To make the information that are stored in diverse information sources or systems accessible and available, information integration is a good solution. However, to integrate the data, there are various challenges existed such as diversity, data heterogeneity, and data sources distribution [108]. Here, diversity means multiple autonomous organizations (governmental, non-government organizations, individuals, communities, and industry). Data heterogeneity is characterized with three main constituents: syntactic, schematic, and semantic [109].

- Syntactic heterogeneity: Syntactic heterogeneity occurs when there are differences between data models (entity-relationship, relational, object oriented).

- Schematic heterogeneity: Schematic heterogeneity is also called as structural heterogeneity. It occurs when different structures are used to store the same data in different information systems.

- Semantic heterogeneity: Semantic heterogeneity occurs when the database schemas and data sets of the same domain are developed by independent parties, they will be always quite different from each other. These differences are referred to as semantic heterogeneity. In order to achieve semantic interoperability, the meaning of the information that is interchanged must be understood across the systems [110]. Goh et al. [111] identify three main causes for the semantic heterogeneity. The first one is *confounding conflicts* which occur when information items seem to have the same meaning, but differ in reality e.g., due to different temporal contexts. The second one is *scaling conflicts* which occur when different reference systems are used to measure a value. The third and final cause is *naming conflicts* which occur when naming schemes of information differ significantly. A frequent phenomenon is the presence of homonyms and synonyms.

In order to solve above-mentioned challenges, there are different data integration approaches existing in the literature which are presented and discussed in Subsection 2.1.3.

2.1.3 Existing Data Integration Approaches

In this section, we first discuss different existing data integration approaches and then present the available state-of-the art technologies for supporting data integration that we used in this research i.e., Web services, and Enterprise Service Bus (ESB).

2.1.3.1 Data Integration

Data integration is sometimes also referred to as information integration which aims at combining the data that reside in multiple autonomous and heterogeneous data sources which are distributed at different physical places and provide the users with a uniform access to these data. As a result, users' can have improved information accessibility and availability. Data integration is not a recent issue. When database systems were first introduced, this issue is actually arisen shortly after it [112]. Data integration is still a challenging task, although there are many proposed solutions to solve it. With recent technologies, there is an introduction of more and more data integration solutions, improvements in the existing solutions, and proposal of new solutions.

In the literature, to classify the data integration approaches, several methods and architectures are currently in use, for example, data warehousing, and data mediation approaches [112]. Data warehouses contain a large amount of integrated data from different data sources. Data from several data sources are extracted, transformed, and loaded (ETL) into a data warehouse. Then, data analysis can be performed on integrated and aggregated data [112]. Data warehouses are mostly designed for supporting decision-making purposes [113]. There exists some data integration tools that use data warehousing approach. Those are Talend Data Integration [114], Pentaho Data Integration [115], and Microsoft SQL Server Integration Services [116].

When it comes to the data mediation approach which is also called as virtual database approach, a mediated schema over data sources to answer users' queries is used. In this approach, the mediation is implemented by wrappers [4] which can be used to establish an interface of the schema to the various data sources [117]. An advantage of this approach is that data which needs to be integrated remain at the original place and need not to be moved to a common data storage. With this, building and maintaining costs of a common database can be saved and also real time data delivery can be possible. There exist some data integration tools that use the data mediation approach. Those are Teiid Data Integration [118], IBM InfoSphere Federation Server [119], and MASTRO [120]. The data warehouse approach is different from the data mediation approach, because of the data location.

In the data mediation approach, a mapping between a mediated schema and the data sources is done. According to the query answering settings, the mappings can be classified into three ways. Those mappings are: the global-as-view (GAV) [121], the local-as-view (LAV) [122], and the global/local-as-view (GLAV) [123]. In the GAV mapping approach, each element of a mediated schema (global schema) is linked with a view over a data source. All the mappings in the GAV are written with respect to the global schema. When it comes to the LAV mapping approach, each data source is defined as a view over the the mediated schema and the mappings are written with respect to the data sources [4]. One more difference between the GAV and the LAV approaches is that query processing in the GAV can be based on unfolding techniques, while in the LAV, query processing requires the involvement of reasoning. The GLAV approach is a combined approach where both the GAV and the LAV assertions are allowed in the mapping [122].

Data integration solutions are classified according to the handling of the heterogeneity i.e., syntactic heterogeneity, schematic (structural) heterogeneity, and semantic heterogeneity. To handle syntactic and schematic heterogeneities, there exists some traditional integration solutions which typically use shared information models in formats such as XML, developing common XML interfaces. However, these solutions cannot resolve the semantic conflicts between the heterogeneous data sources. So, in order to solve the semantic heterogeneity issue in the data integration, ontology-based data integration approaches are widely used, in which ontologies are employed. In this dissertation, we consider the widely used definition which was proposed by Gruber [124]: *"An ontology is an explicit specification of a conceptualization"*. The ontologies are being used to explicitly define concepts, properties, relations, functions, constraints, and axioms of a specific domain. In an ontology-based data integration approach, the ontologies are considered as mediators between the users' queries and the data sources. The ontology-based data integration can be classified into: single ontology, multiple ontologies, and hybrid approaches [125].

- *Single ontology approach:* In this approach, all the information sources are directly related to a global shared ontology which provide a shared vocabulary for the specification of the semantics. However, to apply this approach, all the information sources should have a same view on a domain. The advantage of this approach is that any changes to one data source will not affect other data sources. However, when any changes to the data sources happen, then the global ontology must also be changed. To avoid such an issue, domain experts' knowledge on the semantics of all data sources should be gathered for building a global ontology.

- *Multiple ontologies approach:* In this approach, each information source is described by its own local ontology and all these ontologies are mapped with each other for data exchange. Any changes to a local ontology might lead to changes of other ontologies that are connected to it. To solve this issue, an additional representation formalism defining the inter-ontology mappings is necessary. Besides, changes to local ontologies may not affect the mapping.

- *Hybrid approach:* This approach is used to overcome the problems of the two preceding approaches. Local ontology is built for each information source and connected to a global shared ontology. An advantage of this approach is that new sources can be easily connected to the global shared ontology with no need for existing mappings modification.

In next Sub-sections, we present the technologies that we used for data integration in this research i.e., Service-Oriented Architecture (SOA), Web services, and Enterprise Service Bus (ESB).

2.1.3.2 Service-Oriented Architecture

In the context of data integration, Service-Oriented Architecture (SOA) is not one of the data integration approaches, but it is a software architecture, in which functionality is grouped around business processes and packaged as interoperable services. The objective of SOA is to achieve loose coupling among interacting different software components within a distributed environment such as operation systems, programming languages, and other technologies, which underlie applications [126]. The functionality of SOA are gets separated into distinct units, or services. A service is a self-contained unit of functionality that is well-defined, can be discovered and composed. It does not depend on the state or context of other services [127, 128].

Services are described in a standard definition language and have a published interface. To collectively support a common business task or process, services communicate with one another by requesting execution of their operations [129]. Consequently, each service is built as a discrete piece of code in order to provide a

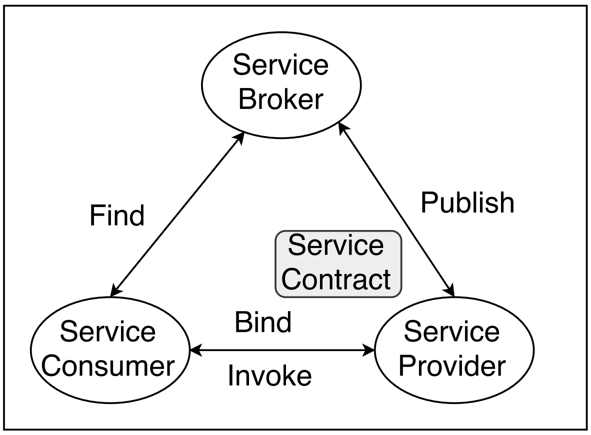

Figure 2.3: Basic Components of a Service-Oriented Architecture

possibility to be reused in several ways during the complete application. However, the only thing that needs to be changed is an individual service which interoperates with other services that create the application. The basic components of a traditional SOA are shown in Figure 2.3 which contains three major elements. Those are *service provider, service consumer, and service broker* [130–132].

Service provider implements the services, and their descriptions are published to a service broker (or registry). Information about services is organized by the service broker. Service broker provides facilities for the service provider to publish descriptions of their implemented services. In addition to that, service broker provides facilities for the service consumer to discover available services that can be used. To find a particular service, the service broker is being queried by the service consumer. If the particular service is found, the location of the service is being retrieved by the service consumer, then binds with the service endpoint, and then service operations are invoked. However, in software systems, the publish-find-bind/invoke cycle, as shown in Figure 2.3, is not commonly applied [132]. In most cases, the service broker is being left as optional by leaving only the service provider and the service consumer interacting with each other.

Whether the service broker is being used or not, as depicted in Figure 2.3, the traditional SOA adopts a point-to-point integration model between the service provider and the service consumer. The point-to-point integration approach is depicted in Figure 2.4. Even though the point-to-point approach looks simple and straightforward to be deployed, there are some disadvantages of this integration style i.e, it is not scalable. This means, when the number of applications are increased, the complexity of the whole system increases. In addition, any change in one application will make changes in the whole system. With this, new connections need to be

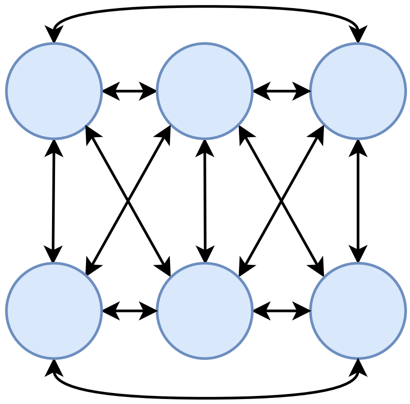

Figure 2.4: Point-to-point Integration

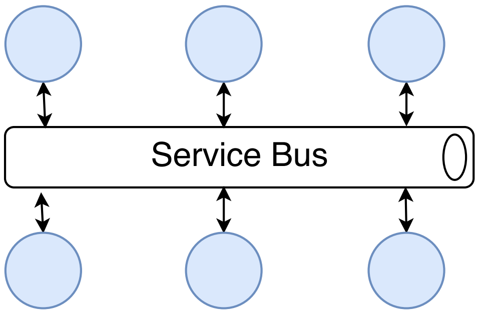

Figure 2.5: ESB Integration

reestablished between the applications. When it becomes necessary to make changes, it results in high maintenance costs and a lack of flexibility [133]. To overcome the issues that are caused by using the point-to-point approach, an enterprise service bus concept was introduced which is depicted in Figure 2.5. An enterprise service bus is a centralized service bus middleware which is usually employed to avoid direct contacts between communicating services to remove the hard wiring between the service provider and the service consumer. More information on an enterprise service bus can be found in Sub-section 2.1.3.4.

2.1.3.3 Web Services

Web services can be viewed as programming paradigm for extracting and integrating data from heterogeneous information systems. Web services denote one important technology for realizing SOA. According to the World Wide Web Consortium (W3C), a web service is defined as: *"a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-processable format (specifically Web Services Description Language (WSDL)). Other systems interact with the web service in a manner prescribed by its description using Simple Object Access Protocol (SOAP) messages, typically conveyed using hypertext transfer protocol (HTTP) with an extensible markup language (XML) serialization in conjunction with other Web-related standards"* [16].

Standards such as WSDL, SOAP, and Universal Description, Discovery and Integration registry (UDDI), together with HTTP and XML, are the most popular type of services available today utilized by the web services with maximum service sharing, reuse, and interoperability. To recall, here, SOAP is a standard for messaging over HTTP and/or other internet protocols. WSDL is a language for describing the programmatic interfaces of web service. UDDI is a look-up business registry or database standard for indexing and publishing web services, to register and locate web service applications.

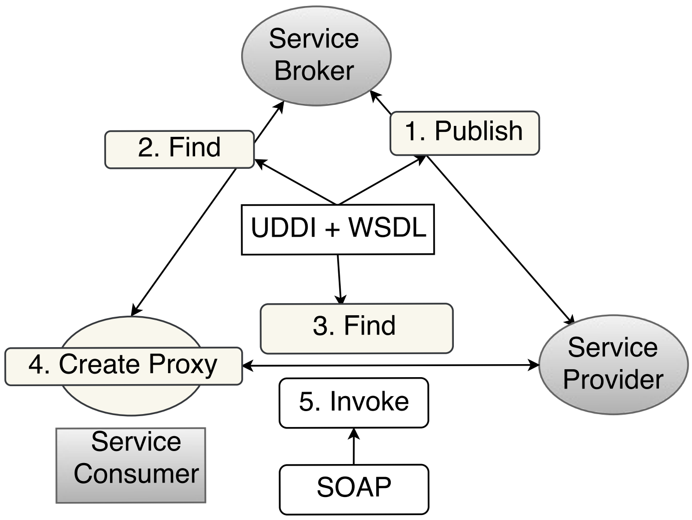

Figure 2.6: The Web Services Realization of SOA

Figure 2.6 shows how web services realize the SOA paradigm. The major advantages of implementing an SOA using web services are that web services are pervasive, simple, and platform-neutral. It supports the interaction of a web service requester with a web service provider and the potential discovery of the web service description. The provider typically publishes a WSDL description of its web service, and the requester accesses description using a UDDI or other type of registry, and requests the execution of the provider's service by sending a SOAP message to the consumer [126].

Representational State Transfer (REST) is another type of web service technology, which has been accumulating tremendous attention in the recent years mainly due to its simplicity for publishing and consuming a service [134]. A REST defines "a set of architectural principles to design and develop web services that focus on a system's resources" [135]. It primarily focuses on the roles of components, the constraint of interaction with other components, and their interpretation of significant data elements, but ignores the details of component implementation and protocol syntax [136]. It utilizes HTTP methods (i.e. GET, POST, DELETE, PUT) explicitly with a one-to-one mapping between a set of four operations i.e., Create, Read, Update, and Delete (CRUD) [134]. Every interaction with a resource is stateless i.e. request messages are self-contained, and all session state is held in the client or alternatively, all session state can be transferred to another service such as the database [135]. In RESTfulweb services, resources are identified by uniform resource identifiers, which provide a global addressing space for resource and service discovery [135]. Resources are decoupled from their representations so that their contents can be retrieved in different formats (e.g. JSON, XML) [135].

2.1.3.4 Enterprise Service Bus

An Enterprise-Service-Bus (ESB) is a software architecture for middleware that is based on SOA. It uses a standard-based software component in order to provide dynamically integrating loosely-coupled services in heterogeneous distributed environments [137], and is depicted in Figure 2.5. A combination of SOA and Event-Driven Architecture (EDA) has been used for the implementation of an ESB [138]. The goal of an EDA is that if any remarkable event happens inside or outside a business, it disseminates immediately to all interested parties. An example of this could be using a publish/subscribe mechanism in an EDA to enable a real-time information provisioning. This is to say, whenever new data arrives, the data is immediately published to a channel and the relevant notifications will be sent to subscribers instead of letting subscribers query for information every once in a while. An EDA is used to complement SOA as it is extremely loosely coupled and highly distributed [139].

An ESB provides a mechanism for managing access to applications and services via a simple and consistent interface. It is considered as a communication backbone between different applications. It provides transports, events, and mediation services to facilitate the integration of large-scale heterogeneous applications. The idea of an ESB concept is that every application needs to be connected to a bus and then all applications can share information by producing or consuming information on the bus [140]. The following features are provided by an ESB.

- An ESB is a loosely coupled architecture. This means, whatever changes in an application happens, it will not affect other applications in the whole system;
- It has increased flexibility. This means, if there are any changes in the requirements, then it is easier to change;
- It is a standardized platform for integration;
- It shares common services such as security, error management, and reporting;
- With an ESB, more configuration has to be done rather than integration coding;
- It is a mediation to expose REST-based or SOAP-based services;
- It is used for service orchestration and automation.

An evaluation on existing both open source and commercial ESBs has been done and documented in [141] and the examples of open source ESB frameworks are Mule ESB, Fuse ESB, PEtALS ESB, ServiceMix, Open ESB. Among the available ESBs, in this dissertation, Mule ESB has been considered due to its solid track record in organizations that have deployed it into production. Mule ESB is a lightweight integration framework based on Java. It supports quite a number of transport protocols and connectors. XML-based configurations are used for creating message flows, which can be configured manually or through a friendly Integrated Development Environment (IDE) called MuleStudio.

2.2 Related Work

2.2.1 Existing Information Models for Emergency Management

In this section, first we discuss the existing information exchange standards for the emergency management and then present the existing ontologies for an emergency response.

2.2.1.1 Existing Information Exchange Standards For Emergency Management

Approved standards are recommended to use in order to make the information sharing unambiguous. There have been several efforts made for relevant data standards for inter-agency data exchange such as the Common Alerting Protocol (CAP) [142], the Emergency Data Exchange Language (EDXL-RM) [143], the Emergency Data Exchange Language Hospital Availability Exchange (EDXL-HAVE) [144], the EDXL Distribution Element (EDXL-DE) [145], the Emergency Data Exchange Language Situation Reporting (EDXL-SitRep) [146], and the Customer Information Quality (CIQ) [147]. All these standards are developed by the Organization for the Advancement of Structured Information Standards (OASIS).

Here, the CAP is a data interchange standard for alerting and event notification and the EDXL-RM data standards are mainly used for routing messages including requesting or deploying resources or communicating their status. The CIQ contains a set of specifications for person and organization and their relationships. The EDXL-HAVE data standard is for messaging the hospital information. The EDXL-DE is a standard to encapsulate and disseminate emergency management information. The Emergency Data Exchange Language Situation Reporting (EDXL-SitRep) describes a set of standard reports and elements that can be used for data sharing among emergency information systems, and that provide incident information for situation awareness on which incident command can base decisions.

Another data standard called the National Information Exchange Model (NIEM) [148] developed by the U.S. Department of Justice and the Department of Homeland Security. This framework is developed for sharing critical information across all levels of the U.S homeland security. The main part of this exchange framework is its metadata repository. The core concepts in this framework include a set of data standards for emergency management such as person, address, organization, etc. The data standards in the NIEM emergency management supports only alarm events, resource, and message distribution element [149]. The limitation of this data standard is that it does not address other aspects such as incident command, response operation, risk assessment, incident setting.

There are also various geo-spatial standards exist such as the Geography Markup Language (GML) for the exchange of geographical information [150]. The People Finder Interchange Format (PFIF) [151] encodes information about missing or displaced people in disasters. The ISO/IEC 11179 is an international standard for metadata registry [152]. It provides a guideline for definition and representation of data elements in a hierarchical schema. Among the frameworks using ISO/IEC 11179, the notable ones in the domain of emergency management is the Universal Data Element Framework (UDEF) which is developed by the Open Group consortium [153].

The UDEF categorizes objects in an enterprise into high-level concepts such as entity, asset, document, enterprise, etc. It also classifies attributes of these objects, such as amount, graphic, picture, date, etc., in a separate hierarchy. It then assigns a number or alpha character to the nodes of both hierarchies and uses this structure to generate identifiers for uniquely labeling data elements in an enterprise. The identifiers are derived by concatenation of the assigned numbers or alpha characters [154].

From the above-mentioned international existing information exchange standards, none of them allow us to capture the information that is necessary for our case, specially not in the semantic way. That is why, these information standards and models do not fit to our problem.

2.2.1.2 Existing Ontologies for Emergency Response

When it comes to domain specific models, in the literature, different types of meta-models and ontologies have been developed in order to define the concepts and their relationships for improving the information interoperability across ERs' functions within the emergency response domain. However, the developed information models [155] are restricted either to one organization [156] or to a specific case [157–163] or to a specific goal [164, 165] or to a specific purpose [166–168]. The existing models are reviewed based on the information entities that involved in an emergency response such as *Who* (who are involved: both victims and actors), *Where* (location of the event(i.e. emergency)), *What* (type of the event, needed resources, and what kind of activities are involved), *When* (date and time of the event), and *How* (cause of the event and performing tasks).

In [155], the world wide web consortium (W3C) emergency information model represents the concepts and relationships that define an overall context for sharing of coordination information in an emergency. The model contains information about "Who (organizations or people) does What (activity) and Where" as a basis to derive high-level concepts and relationships. This is developed based on data schema from existing emergency information systems. However, they did not look into "When and How". In [160], the authors have reused the W3C Emergency information model by adding "When" for developing an information system.

Zlatanova [169] used formal modelling to model the tasks to support geo-information in an emergency response in order to give deep understanding about the spatial data structures and corresponding terminology to the emergency experts. In the work [164, 170], Dilo and Zlatanova built a data model to capture and manage both operational and situational information along with spatial data structures in emergency response, but did not include in the model about the required resources for an emergency response.

Onorati [165] has developed an ontology named SEMA4A for managing knowledge about accessibility and evacuation guidelines during the emergency situations. The main classes of the ontology include "Evacuation, Location, Personnel, Procedure and Transportation". Chen [159] has created a data model for the fire emergency response. This data model is applied to chemical fire emergencies. In [171], a geo-data model is developed to specify the components to determine the application schemas of geo-data themes and to harmonize geo-data to enable semantic interoperability. In this model, the authors focused on spatial data structures, particularly on the emergency actors and their tasks.

In [172], an ontology is developed to model the emergency management domain. In this model, the authors included incident classification, agents, roles and profiles, geographical objects, map symbols, time, space, resources, infrastructure, spatial point objects, communication objects, activities (task and movement), but not the severity or emergency impacts and escalation. Barros [166] along with other researchers, developed an EDXL-RESCUER ontology for semantic integration. The developed model uses EDXL (Emergency Data Exchange Language) to model the coordinating and exchanging of information with legacy systems. The concepts included in the model were "alert, info, resource, incident, response type, area, category, message type, status, and scope". In this model, the authors mainly focused on alerting the people. This model however, does not cover the time and spatial information.

Bitencourt [158] proposed an ontology for the emergency response protocols, in particular, for fires in buildings. The developed ontology supports the knowledge sharing, evaluation and review of the protocols used, contributing to the tactical and strategic planning of organizations. This model, however, is restricted only to fire emergency and not applied to other emergencies. In this work [173], an ontology called DIRES is suggested to describe emergency situations and the key factors that are associated with response activities to the incident. It also defines terms related to scenario, people, and organization.

Babitski [174] developed an ontology called SoKNOS, which includes resource planning, damages, and geo-sensor information. In [175], a meta-model called ISyCri is proposed to conceptualize the crisis coordination. The developed model includes categories of entities affected by crises, the treatment system, and the crisis description. Othman and Hassan [176] suggested a meta-model for each phase of the emergency management domain to define the concepts and to serve as a representational layer of the emergency management expertise. The classes that exist in the meta-model were: "Event, Organization, Procedure, Requirement, Policy, Actor, ElementsAtRisk, Team, Domain Knowledge, Resource, ActorRole and MessageCommunication". However, this model did not cover the '"Where" aspect of an emergency.

In [156, 177], an ontology is developed for an emergency shared situational awareness. The main components of the model are: "Event, Mission, Resource, Context, and Actor". In this model only "What" and "Who" were included, but not "When, Where and How" of the W3Consortium [155]. In [178], the authors developed a context ontology for humanitarian assistance in crisis response. This context ontology includes two parts: global ontology and local ontology. The classes in the global ontology are: "crisis identification, place, and crisis need". The classes in the local ontology are: "event, actor, time, impact, and place". Fan and Zlatanova [179] proposed a model to explore the semantic interoperability of the terms and spatial information to be used by different emergency response organizations. The proposed model consists of dynamic data ontology for assisting responders in decision making.

Table 2.1: The Existing Ontologies for Emergency Response

Author	Who	Where	What	When	How	Literature
W3C	✓	✓	✓	×	×	[155]
Li et al.	✓	✓	✓	✓	×	[160]
Zlatanova	✓	✓	✓	×	×	[169]
Dilo et al.	✓	✓	✓	×	×	[164, 170]
Onorati et al.	✓	✓	✓	×	✓	[165]
Chen et al.	✓	✓	✓	✓	×	[159]
Aydinoglu et al.	×	✓	✓	×	×	[171]
Azcona et al.	✓	✓	✓	✓	×	[172]
Barros et al.	✓	✓	✓	✓	×	[166]
bitencourt et al.	✓	✓	✓	×	✓	[158]
Brewster et el.	✓	✓	✓	×	×	[173]
Babitski et al.	✓	✓	✓	×	×	[174]
Benaben et al.	✓	✓	✓	×	×	[175]
Othman et al.	✓	✓	✓	×	✓	[176]
Kirillov et al.	✓	×	✓	×	×	[156, 177]
Jihan et al.	✓	✓	✓	✓	×	[178]
Fan et al.	✓	✓	✓	×	×	[179]

When it comes to case specific models, the existing ontologies' information entities are summarized and presented in Table 2.1. The existing models that are summarized in Table 2.1 do not fit to our problem, because we have considered different use-case in this dissertation i.e., an indoor fire emergency in a public building. Therefore, for developing an ontology for our case, we reuse the existing information models from the previous work and at the same time extend the existing models with our new findings.

2.2.2 Existing Data Integration Solutions for Emergency Response

This section reviews some of the significant previous work related to the design and development of the information systems for providing access to the multiple data sources in a unified way to support various ERs during an emergency response. This review includes literature on information systems, frameworks, architectures which were developed by integrating several data sources. It also pays attention whether the developed systems, frameworks, architectures solve the semantic heterogeneity problem.

In the last 16 years (2000-2016), researchers have proposed and developed various information systems by using different integration approaches to solve the semantic heterogeneity problem. In [180], Casado et al. proposed and developed a data interoperability software solution for cross-border collaboration. The main goal of their work is to translate emergency related terms and symbols from one language to an other language and also to translate emergency related symbols from one country to an other country with the help of a common and modular ontology called EMERGency in case of a border fire. For data interoperability, service-oriented architecture technologies have been used for solving mediation issues. In their work, semantic mapping for different predefined information artifacts, information representations, and languages between countries in Europe is considered. In their study, the semantic mapping of the incident information is left out and end-user requirements were not identified. This means that the solution is technology-driven rather than human-centered.

Balogh et al. [181] proposed to use an agent-based infrastructure for supporting interoperability as part of the SECRICOM project. SECRICOM is a four year project started in 2008, which aims to create a Seamless Communication for Crisis Management for EU safety by gathering, managing and distributing information among various ERs by integrating various data sources. The authors have used agent-based integration approach. The limitation of their work is that they did not gather information needs of ERs. There is no evidence provided that their developed systems has been evaluated with the end-users. Romanowski et al. [182] implemented a web-based decision support tool for emergency managers by using data fusion, data mining, and data integration techniques. The purpose of this developed system is to build scenarios based on the integrated data (historical data). In this work, the drawback is that the authors did not look into the semantic differences of the data sources.

Fahland et al. [106] developed a prototype system called HUODINI for the flexible integration and visualization of heterogeneous data sources for disaster management. HUODINI collects information from several freely available data sources on the web, such as news feeds, personal blogs, tagged images, and seismographic information. In their work, textual and multimedia data is integrated. There is no evidence provided that this developed systems has been evaluated with end-users. Ashish et al. [183] developed an information system that provides integrated access to a wide variety of information sources. With this developed system, both previous data and real-time information are integrated. However, the purpose of the developed system is to provide information related to the location such as maps of the location and facility, floor plans of buildings in the area, hazardous material location information, and other potentially useful information such as work schedules and shift timing information. Moreover, real-time sensor data such as surveillance cameras in a building at the incident site also made available to the fire brigades. However, in their work, the authors looked into the geo-spatial aspects, but neglects the deep semantics of an emergency.

The ALADDIN [184] is a five year project started in 2006. The objective of this project is to model, design, and build decentralized systems that can bring together information from a variety of heterogeneous sources to take informed action. In this project, different aspects such as data fusion, decision-making, machine learning, and system architecture have been considered. The drawback of their study is that the authors did not look into solving the semantic heterogeneity problem. Li et al. [160] proposed and implemented a decision support system by integrating diverse EROs data sources to enable the collaborative information sharing among community-based NGOs, public, and private organizations within a community. They used a peer-to-peer integration approach. The disadvantage of this type of data integration is that it slows down the performance for the user and it is difficult to recover the data in case of any network failure. In addition, they proposed a distributed hash tables (DHT)-based P2P overlay to resolve queries efficiently for locating desirable data to construct a mapping between data sets. The disadvantage of using DHT approach is that it does not provide absolute guarantees on data consistency and integrity. In addition, there is no evidence provided that this developed system has been evaluated with the end-users.

Mecella et al. [185] proposed and developed a two-layered peer-to-peer service-oriented software infrastructure to support decision making during the emergency situations. It provides a decentralized, event-driven information integration environment. In this project, a task analysis technique called hierarchical task analysis is used to identify the task requirements for various emergency scenarios. The developed solution partially solves the semantic mapping of the geo-data, but neglects the deep semantics of the emergency. Christman et al. [186] proposed a methodology to integrate tactical level information integration from two systems i.e., civil information management, and data processing system. For data interoperability, a data exchange format called the national information exchange model (NIEM) is used. However, the used NIEM data model solves the semantic heterogeneity problem partially.

Alamdar et al. [187] integrated geo-spatial data of different sensor databases and used them for a flood use-case. Lezcano et al. [188], proposed an archetype approach for integrating different sensor data sources for solving the semantic heterogeneity problem. However, both these solutions, tried to solve the semantic heterogeneity of different types of sensor data. In [189–193], the authors integrated different spatial data sources for providing spatial data to ERs. Kou et al. [194] proposed a heterogeneous data integration framework for providing video and audio data. However, there is no evidence that this framework has been developed and tested with any use-case. Raman et al. [195] proposed and developed a web-based disaster management system called CEMAS for providing resource related information to ERs. The information provision is done by integrating different data sources. The main objective of their system is to provide emergency alert about the surrounding area via SMS or email to ERs in case of natural disasters.

Subik et al. [196] provides multi-disciplinary rescue teams with an integrated and intelligent communication and information system for an efficient data sharing and emergency process management before, during, and after major incidents. Their developed system allows mapping internal onto an external data structures and vice versa for achieving technical and the syntactical interoperability. However, their work completely neglects the semantic heterogeneity problem. SINTEF [197] proposed and built a middleware which allows data, system and network interoperability for multi-agency emergency collaboration and decision making. In their project, multimedia information has been integrated by using SOA paradigm and web services technology. For requirement analysis, a participatory design methodology and ethnographic studies were being used. In addition, they use the EDXL standard for information exchange. This project provides data from the social media to the involved ERs for situational awareness social media data integration. However, in their work, the semantic mapping is done on unstructured data i.e., social media data.

Apisakmontri [198] proposed and developed an ontology to integrate different humanitarian aid information and disaster management systems. However, in their work, the semantic mapping is done on unstructured data i.e., social media data. Erskine et al. [199] used a hybrid approach for aggregating data from social networks for natural disasters. Here, a hybrid approach means utilizing automated data mining tools and crowd-sourcing to optimize the information. In this study, solving the semantic heterogeneity aspect is not considered. Careem et al. [200] developed a software application called SAHANA for managing resources and information in disaster response, but does not address the semantic integration of content.

Peng et al. [201] proposed a information integration framework to support decision makers during an emergency response. The proposed framework consists of three major components i.e., data integration module, data mining module, and multi-criteria decision-making module. However, in their work, the authors did not look into addressing the semantic heterogeneity problem. Hu et al. [202] proposed a system architecture for the development of fire-fighting information integration system. However, in this work, the authors do not address the semantic heterogeneity problem. There is no evidence provided that this developed system has been evaluated with the end-users.

Although various information systems have been developed by introducing novel ideas, architectures, frameworks, and systems to provide information to ERs in order to support them during an emergency response, there are still gaps exist: i.e., (1) deep analysis of semantics of the technological and man-made emergency domain, (2) the majority of the above studies have not shown any interest in understanding and identifying the end-user information needs and requirements, and 3) providing the identified needed and relevant information to the involved ERs at the right time to the right persons at the right time. Therefore, in this research, our study will fill these gaps that are identified and listed.

2.3 Chapter Summary

This chapter started with introducing the emergency management domain and its phases. Then, an emergency response which is one of the core phases was described.

Later, we discussed problems for accessing information to the available information in an emergency response domain. Afterwards, we briefly discussed existing data integration approaches. In this work, we selected mediator-based data integration approach by including ontologies to solve the data integration issue in the emergency response domain. The state-of-the-art SOA and web services have been presented. The combination of SOA and web services solve the data sources handling issue in data integration. Next, we presented the review on various information exchange standards for the emergency management and existing information models for an emergency response. Finally, the existing data integration systems, architectures, and frameworks have also been reviewed, discussed, and presented. The concepts, technologies, and related works presented in this chapter act as the stepping stones for the proposed solutions that will be presented aiming to fulfill the requirements listed in the next Chapter.

Chapter 3

Emergency Response Data Integration

This chapter presents a model-driven data integration framework for emergency response for answering the research questions that are posed in Sub-section 1.3. The chapter begins with eliciting the requirements for an information technology (IT) framework and then presenting the framework. After that, by using an indoor fire emergency scenario, we identify and present the emergency responders (ERs) who are involved during the fire emergency response. Then, the same indoor fire emergency is used to identify the first-responders' information needs. Afterwards, the proposed framework and its components, and implementation details are presented. At last, the chapter concludes with a summary of the main achievements.

3.1 The Data Integration Framework

In this section, we present the requirements for an IT framework and then the proposed IT framework.

3.1.1 The Framework Requirements

Based on the problems identified and described, and the stated research questions on the semantic heterogeneity, the semantic data integration, and the information presentation in Sub-section 1.2, we have elicited some general requirements in order to make sure that the proposed framework is applicable to solve these problems. The elicited requirements are divided into two categories. The first category is functional requirements and the second category is non-functional requirements. The functional requirements (FR) describe what the framework should do and the non-functional requirements (NFR) describe what properties the framework should have [203]. Both functional and non-functional requirements for an IT framework are listed below.

Functional Requirements:

- **FR1:** During an emergency response, lots of information sharing is done among different ERs. As stated in Sub-section 1.2, to avoid ambiguity and misunderstanding on the terminologies and their relationships that are being exchanged between two different emergency response organizations' applications, semantics should be exploited. Hence, the framework should provide a common understanding on domain concepts, terminologies, and relationships and a possibility to resolve the semantic ambiguity concerning emergency related data that is stored in multiple data sources.

- **FR2:** As mentioned in Sub-section 1.2, for an efficient emergency response, to make relevant information accessible and available from various different existing data sources for supporting different ERs, semantic data integration is necessary. Hence, the framework should provide a common platform for data exchange between or among different ERs by integrating the existing data sources.

- **FR3:** Data from multiple data sources should be made available in a reliable way and presented in such a way that the information helps to meet the ERs' goals during an emergency response. To be specific, the framework should provide a reliable way to access, present, and visualize the needed and relevant information during an emergency response.

- **FR4:** Data from emergency response organizations' applications or data sources should be made available in terms of services such that other ERs from various EROs can easily get access to the services and request for the needed data depending on the situation. To be specific, the framework shall provide the publish/subscribe feature which sends the information to all interested subscribers.

Non-functional requirements:

- **NFR1:** The framework should be platform independent.

- **NFR2:** The framework should be flexible enough for further extension.

3.1.2 The Proposed Framework

Information accessibility and availability is vital during an emergency response. In order to obtain a common operational picture, making efficient decisions, and performing different emergency response activities, timely access to needed information from various structured data sources is necessary for ERs. However, due to the heterogeneity of both data and individual information systems of ERs, it is challenging to integrate data which is stored in EROs' data sources. Considering Norway as an example, like other countries, there are many government organizations and their respective first-responders are involved in case of any emergency.

While responding to an emergency, the involved ERs collect numerous information and store some of the information in their respective organizations after an emergency. This is because, the ERs collect the information on a paper and then store that information in their respective organizations later on. In such a situation, the needed information is shared either face-to face or over hand-held devices. As an emergency response is a complex process and requires plenty of information, ERs may face several challenges in remembering the received information.

To have a common agreement and understanding on the terminologies and their relationships that are being exchanged between two different emergency response organizations' applications, we have looked into the literature and found out that the most suitable method is developing an ontology. So, from this, the FR1 leads directly to the semantic model which is considered as a central requirement for our solution. When we have the semantic model, it needs to be connected with different data sources (FR2) and presented to ERs (FR3). Therefore, in this research, we propose an IT framework i.e., Model-Driven Data Integration Framework (MDIF) for an emergency response to support various ERs' for performing different emergency response activities. The proposed MDIF based on Model-Driven Architecture (MDA) to integrate different EROs' legacy systems by solving the semantic heterogeneity problem.

The proposed MDIF for an emergency response is depicted in Figure 3.1 which is based on the requirements specified in Sub-section 3.1.1. In Figure 3.1, the framework consists of three parts. Part 1 of the proposed framework provides all data sources from different EROs, such as fire and rescue service, police service, health care service, and municipality. Sensor data from different sensor vendors is also used to integrate within this proposed framework. Part 3 contains the information about for what purposes the framework can be used. Part 1 and part 3 in Figure 3.1 are connected by part 2. Part 2 of the proposed framework consists of three components i.e., the first component is the semantic model (also called as an information model),

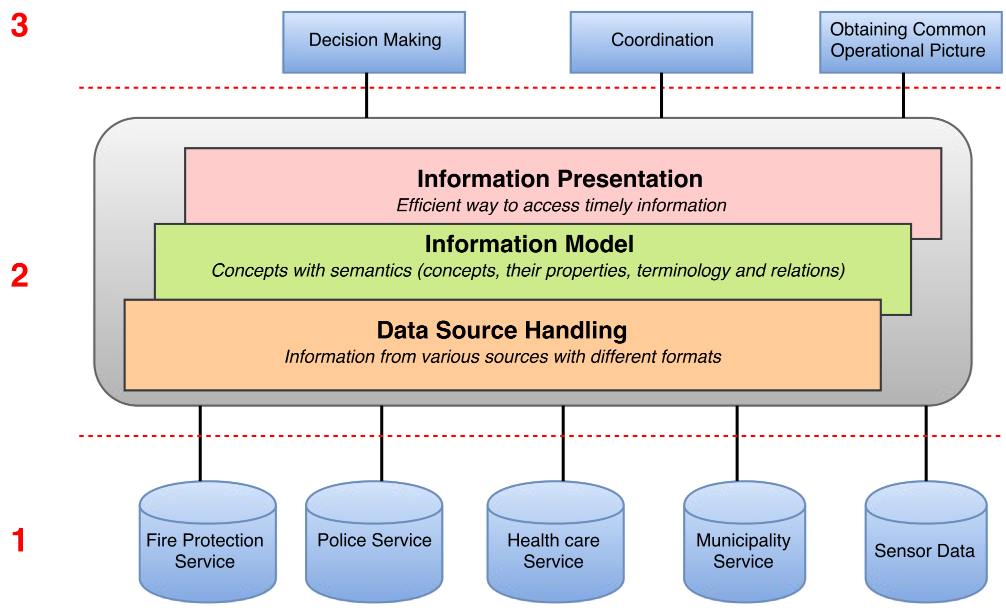

Figure 3.1: The Proposed Model-Driven Data Integration Framework for Emergency Response

the second component is the data source handling, and the third component is the information presentation. Note that, in this research, we refer to part 2 as the framework since the entire implementation is done for part 2. The description of each component is as follows. The *semantic model component* represents the key concepts in the emergency response domain and their semantic relationship. By using this information model, a virtual database (VDB) will be used in order to store the integrated information. Further details on this component development can be found in Sub-section 3.2.3.

The *data source handling component* collects information from different EROs' applications or data sources. Information from this component will be processed and provided to the developed information model. More details on this component development can be found in Sub-section 3.2.4.

In the *information presentation component*, information from the VDB is accessed in a reliable way and provided to ERs for different purposes such as getting overview of the situation, for decision making, setting up shelters, and arranging ambulances for victim transportation, and coordination. The acquisition of the needed information supports ERs in managing an emergency efficiently and effectively. Further details on this component development can be found in Sub-section 3.2.5.

The architectures of each framework component of part 2 are depicted in Figure 3.2. Recall that, to prove the applicability of the above-proposed framework, we did not get access to different EROs' databases or applications due to organizational,

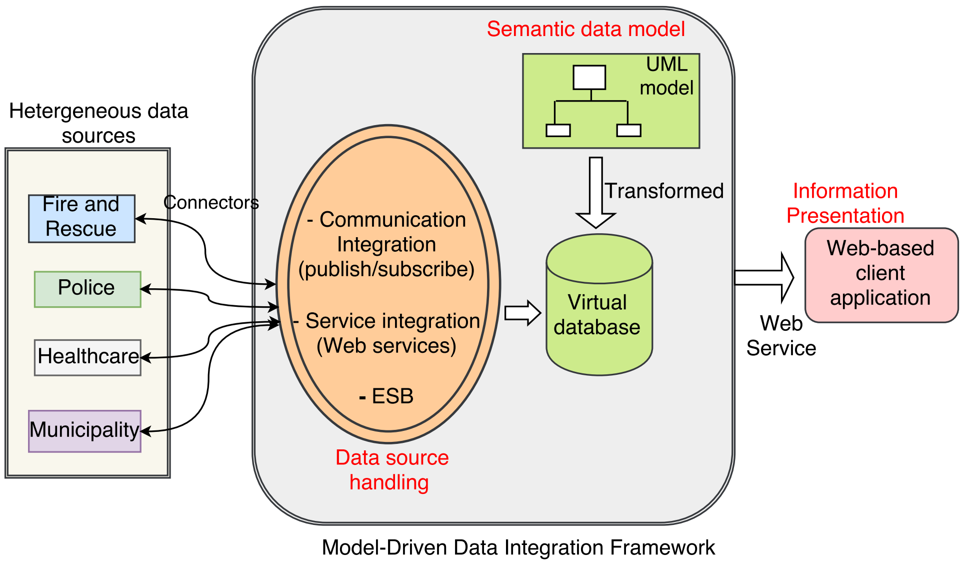

Figure 3.2: The Components of the Model-Driven Data Integration Framework

political, and legal restrictions. To apply the proposed framework as a proof of concept, we adapt the framework into an indoor fire search and rescue case. Section 3.2 presents the development of these three components of the framework in detail.

3.2 A Proof-of-Concept

To test the applicability and the validity of the proposed framework, we consider an excerpt from the use-case scenario that is described in Sub-section 1.4, "....... *After lots of people self-evacuated, 50 victims are still trapped in each floor in the university building. As the university building has several floors, at least 10 victims got stuck inside each room. However, first-responders are unaware of the total number of victims and also the number of persons inside each floor of the building and their exact location to get an overview of the situation and to evacuate them*".

By using this use-case scenario, in the next sub-sections, we identify the ERs who are involved in the emergency response operations and their information needs. Then, we develop the three components of the framework to support ERs during an indoor fire emergency response search and rescue operations (SAR).

3.2.1 First-responders in an Indoor Fire Emergency Response

In any domain, to understand the domain and implement an IT framework, identification of the stakeholders is the first step that needs to be done. This is because the involved stakeholders can see the problem from their own perspective and express their opinions and challenges that they face while performing any tasks in their respective organization [204]. In this dissertation, stakeholders are defined as “the actors who are affected by the problem directly and have passive and active influence on decision making and implementation of any processes” [205]. In our research, the stakeholders are the first-responders.

The first-responders who respond to the above-mentioned case are: firefighters from fire and rescue service, police personnel from police service, ambulance staff from health care service, and municipality staff. From fire and rescue service, the first firefighters who go to the emergency site immediately after receiving the emergency fire alarm or call from either the support center (110) or from the emergency location (in our case, the location is university) are one Crew Manager (CM) and two Smoke Divers (SDs). In our case, CM is the person who is responsible for taking decisions and look after his crew’s safety. The SDs are the ones who enter the building and perform SAR when necessary. After reaching the site, CM and SDs evaluate the situation by collecting the information manually from those who are at the emergency scene (victims, witnesses or the owner of the place).

Collected information is then passed to their leader (Fire Chief, who is at the fire station) with a hand-held device such as either mobile phone or walkie-talkie to provide an overview of the situation and to make decisions. The CM acts as an On-Scene Commander (OSC) until the Fire Chief (FC) arrives at the emergency site. The FC arrives at the emergency location only if he or she thinks that the emergency is not minimal and will create a major impact on population, property and environment. When FC arrives at the emergency site he or she takes over the OSC responsibilities from the CM and acts as an OSC until ERs from police and ambulance services arrive at an emergency scene.

When police staff arrive at an emergency site, the leader of the police takes over the OSC responsibilities from the FC and acts as an OSC. The OSC makes all the decisions at an emergency site and guides other EROs such as fire and rescue service, health care service, and municipality staff. In Table 3.1, emergency response organizations and their tasks at the emergency site are documented. From their roles and responsibilities, it can be concluded that the involved first-responders have a significant amount of tasks to deal with. In order to perform the tasks, first-responders need timely information from various data sources.

Before integrating information from various existing data sources, it is necessary to identify the information needs of different ERs to understand their requirements for developing an information system. Furthermore, based on the identified information needs, it is important to build an information (semantic) model for solving the semantic heterogeneity problem and to integrate the knowledge that can be used in fire emergency response SAR inside the building. In the next Sub-sections (3.2.2, 3.2.3, 3.2.4, 3.2.5, and 3.2.6.2.6), we present the development of the three components of the proposed framework which are published in papers A-D. The results of the three components of the proposed framework development answer the research questions from FRQ1 to FRQ4 which are stated in Sub-section 1.4.

Table 3.1: The Involved Emergency Response Organizations and their Tasks during the Fire Emergency Response

Emergency Response Organization	**Tasks at Emergency Site**
Fire and Rescue Service	- Extinguish fires - Save lives, avert danger, and limit damage - Evacuate victims from buildings
Police Service	- Save lives, avert danger, and limit damage - Maintain peace, order, and security on site - Assist with salvage of cargo, the service, and circumstances warrant - Issue death notification of accidents, disasters, and criminal acts - Register fatalities, injured, and missing - Provide information to media and others
Health Care Service	- Provide first-aid - Transport victims to health centers
Municipality Personnel	- Note down the details of incoming victims - Provide details about saved victims to police

3.2.2 Information Needs of First-responders

This section is intended to answer research question FRQ1 posed in Sub-section 1.4. During an emergency response, a lot of information sharing is done between or among different ERs in order to perform diverse tasks (activities) and to make decisions. Here, information means the content of the communication that takes place within the framework of an emergency response. As mentioned in previous sections, the search and rescue operation (SAR) is one of the emergency response activities. To perform the SAR, the involved first-responders need heterogeneous information. In this section, we identify the information requirements that are needed and shared by different ERs during the SAR.

To perform the SAR, ERs should have an overview of an emergency situation. The aim of the SAR is "to protect and evacuate the victims, extinguish the fire, prevent the fire from spreading, and coordination of the available resources in a timely manner" [13]. As part of the SAR, ERs initially retrieve the emergency plans and procedures that have to be followed at the emergency site. After reaching the emergency site, in order to obtain an overview of the building, ERs gather building map and information related to the university building such as number of floors, number of emergency exists, number of labs, and safest route to enter. This information assists ERs in making decisions such as sending their crew from the safest entrances.

After entering the building, ERs need information about the persons who are inside the university building, their presence and location. The persons could be students, employees, and visitors. This information helps ERs in obtaining a common operational picture of the emergency situation. In addition, ERs also need information related to the fire such as location, size, condition, and duration of the fire. The condition of the smoke is a necessary information item required by search and rescue teams. Information gathering is performed on hazardous goods inside the building such as type, amount, and impacts, to take decisions such as which areas are safe or should be avoided during the evacuation, and rescue people. Resource information such as fire extinguisher, location of available fire hoses, coverage length, which floor they are in, is also required by firefighters to help them in extinguishing fire and rescuing people.

If ERs are provided with medical information of the students, employees, and visitors such as disabilities, allergenic to smoke or heat, it would help them to prioritize in the rescue process. Occupants' identification information such as name and social security number is needed for search and rescue teams as it helps them to recognize the persons after rescuing them. Information about victims' family is useful for the first-responders to inform immediate contacts in case of any fatalities and injuries. Information about first-responders (who are inside the building to perform the SAR) is also considered as vital information during the SAR.

Thus, from the above-described SAR procedure, it can be concluded that different types of information categories and items are needed by ERs. The identified information categories and items which are needed by ERs are shown in Table 3.2. This information is most often available, but in reality the identified information is

Table 3.2: The Identified Information Categories and Items

Needed Information Categories	**Detailed Information Items**
University Building Information	Type of building Name of the building block Number of exits Number of elevators Type of labs Number of rooms Room numbers Type of material used Accessibility Risk areas inside the building Building map Number of floors Year of construction
Hazardous Goods Inside the Building	Amount Location Type and impacts
Information about Occupants	Count on number of occupants inside the building such as students, employees, and visitors. Occupants' location in specific time periods.
Occupants' Personal Identification Information	Full name and social security number
Occupants' Medical Information	Allergenic Disabilities Pregnancy Asthma
Fire Related Information	Cause of the fire Location Size Duration Condition of smoke Condition of fire
Resource Information Inside the Building	Location of available fire hoses Coverage length and floor
Occupants' Family Information	Full name Relation Mobile number Social security number Address

distributed heterogeneously (i.e., stored at different university information systems and these information systems might be located inside and outside the building). Further details on the information identification, and methodology that we used for data collection can be found in paper A.

3.2.3 The Semantic Model

This section presents the content and development of the semantic model (also referred as an information model) and its use to fulfill the framework requirement FR1 and answer the formulated research question FRQ2 that is stated in Sub-section 1.4.

3.2.3.1 Information Model Content

During an emergency response various ERs work simultaneously to coordinate their goals and actions by sharing their resources, information, and process for achieving a common goal [206]. When ERs exchange information between different information systems, the sender and receiver should have a common understanding of the meanings of the exchanged information. If not, the received information is misinterpreted, hence resulting in the semantic heterogeneity problem.

To explain the semantic heterogeneity problem, we provide the following example: the term "event" which is used by fire and rescue service means "emergency", and the term "accident" could mean "hazard". The term "accident" which is used by police service could mean "emergency" and the term "event" could mean "action". When ERs of both fire and rescue and police services exchange these terms, the meaning of the terms can be misinterpreted which results in serious decision-making problems during an emergency response. Therefore, developing a dedicated information model (ontology) for fire emergency response in public building can be considered as a primary step for modelling domain concepts, their properties, terminology, and relations between them to solve the semantic heterogeneity problem.

An ontology is a formal, explicit specification of a shared conceptualization [207] [208]. However, meta-models are also called "simplified ontologies" and can be characterized as a domain ontology, since the concepts such as objects, classes, and relations which can be defined in an ontology are similar to a meta-model [209] [210]. In this research, we believe that model-driven approaches are well suited for solving the semantic heterogeneity problem of the information [211].

In this research, a building fire emergency response domain model has been built for conceptualizing the fire emergency response domain concepts and their semantic relationships. This model facilitates structuring and integrating the knowledge that can be used in fire emergency response SAR inside the building. Furthermore, it represents the Computational Independent Model (CIM) of the MDD approach. The objective of the proposed information model (also referred as a semantic model) is providing a way to interpret data in an emergency situation while making the gathered information formalized enough for computed exploitation. This exploitation is dedicated to contribute to information sharing and coordination of the involved ERs. The explicit and formal definition of each concept of the fire emergency management may help existing applications to share the information with different ERs with high accuracy [212]. The meta-model development process is described below in Sub-section 3.2.3.2.

The semantic model serves the following purposes:

- It explicitly expresses the building fire emergency domain concepts and the relationships between them.
- It ensures the domain terms are consistent, and it can be reused in the domain.
- It is formal enough to be understood and manipulated by a computer.
- It provides technologies that document the exchange protocol between ERs on information exchange, in particular, what information exchange formats to use and what kinds of information to exchange.
- It serves as a common base for the information used in some existing information systems.

3.2.3.2 Information Model Development

In this section, we first present the development process for the meta-model (i.e. an ontology) which has been used for characterizing the fire emergency response domain concepts. This meta-model has been built manually on the basis of the extracted knowledge from the existing emergency meta-models and studied fire emergency response domain. The development of meta-model has been done using the methontology method [61]. As suggested by [213–215], the Unified Modelling Language (UML) can be used to build the meta-model. Based on recommendations in previous literature, we use UML to give an overview of the fire emergency response process by showing its classes and the relations among them.

The proposed meta-model consists of four components: Emergency, Goal, Actor, and Building components. The description of each component is given below and the main classes of the developed information model are presented in Figure 3.3. A

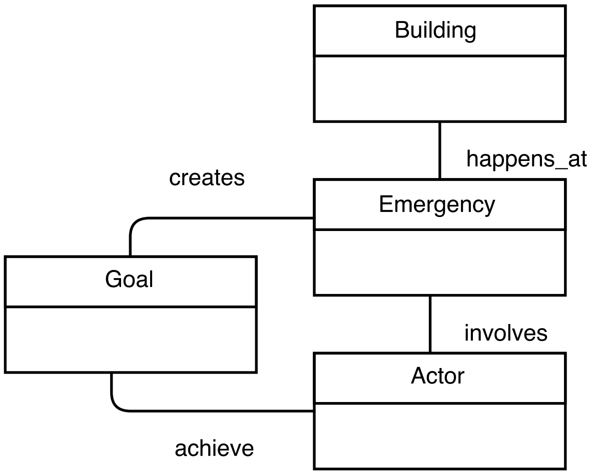

Figure 3.3: The Main Classes of the Developed Domain Model

more detailed description of each component and its classes, and the methodology can be found in paper B.

- *Emergency Component:* The emergency component is none other than an event component which includes all the elements related to the emergency elements that permit to describe the building fire emergency characteristics and links between them.

- *Goal Component:* The goal component which contains the information related to the goals to achieve based on the procedure and alternative plans by ERs even if the responders face any obstructions due to weather conditions.

- *Actor Component:* The actor component incorporates all the elements that specify either the responders' properties (role, task, team, organization, resources, status, etc.) or causality or witness properties.

- *Building Component:* The building component depicts the information related to the characteristics of the building and links between them.

After developing the meta-model, a logical data model is derived manually from the meta-model to be used for our considered use-case. To deal with information which come from different data sources and for storing the large amounts of integrated information, development of a logical data model is necessary. This data model can contribute abstract conceptualizations of domain data that can serve as common modeling for different existing databases. This semantic data model serves to represent the information structures on the collected information needs. The main advantage of the information model development is that information models are considered as a proven technology for many years in numerous software projects for representing the information structures [9].

When information is stored in individual databases, then these databases are simple and good enough to handle queries against them. But, when it comes to integrate these individual databases into different systems or vice versa, there are problems with mapping different database structures due to a mismatch in naming domain concepts. For example, "emergency" in one database can be named as "Emergency_name", but in another database, it can be named as "accident_name". It is obvious that these concepts have the same semantic i.e., information about the "emergency". But syntactically, they are different. Moreover, it is also not an easy task for a machine to integrate. Therefore, resolving the semantic heterogeneity problem not only helps machines understand the domain concepts, but also gives users a unified understanding and a way to access distributed information. Therefore, the information model can be used as a basis for data integration.

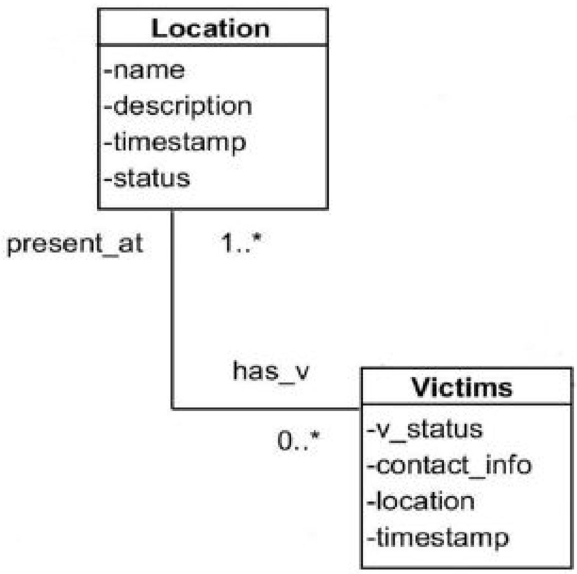

Figure 3.4: An Excerpt of the Derived Information Model

To provide information to the involved ERs to manage the above-described use-case, ERs need information related to the victims, and their locations. To fulfill this need, information from different information systems of the university should be integrated. The logical data model is depicted in Figure 3.4 which is an excerpt of the proposed information model. In Figure 3.4, the relationship between the *Victims* class and the *Location* class represents the bi-directional relationship. The relationship between the *Victims* and the *Location* classes represent that the association is navigable from both sides i.e., victims are present at a specific location and location has victims.

Paper A presents a detailed description of the information needs, the methodology that we used, and the other classes, their attributes, and the relationships among the classes of the proposed information model.

3.2.4 The Data Source Handling

The results of this component fulfill the framework requirements FR2 and FR4, and answers the research question FRQ3 that is stated in Sub-section 1.4. To enable ERs' information sharing by providing access to several data sources, in this section, we present another component of the proposed framework i.e., the data source handling component. To address the need for semantic information integration in emergency response, several technologies and approaches have been applied to ensure data integration such as Service Oriented Architecture (SOA), Enterprise Service Bus (ESB), and Computational Independent Model (CIM).

In Figure 3.2, the data source handling component contains three layers i..e, communication integration, ESB, and service integration. Here, communication integration provides various communication approaches, for instance publish/subscribe allowing to access information through a message exchange pattern. An ESB is used as a hub for exchanging information between different applications. RESTful web services are used to support interoperable machine-to-machine interaction over a network. To enable more flexible cross-facility information access, the information as a service (IaaS) capability will be used. IaaS enables loose coupling to data sources and data model [216]. It also enables business processes and users to work with up-to-date information in critical applications.

3.2.4.1 Data Sources

To fulfill information needs of the ERs in the above-mentioned scenario, information from different information systems of the university have to be integrated. The considered six different applications for data integration are *Felles student (FS) system, SAP (Systems, Applications and Products) system, Syllabus(raptus2) system, UiA system, Sensor database (Sensordb), and Cisco Prime Infrastructure Application (Cisco).* To integrate information of these six applications, we consider a semantically-enhanced mediator-based data integration pattern for handling data sources in an ESB. The detailed description of the mediator-based data integration approach can be found in [59].

The description of each application used is given in Table 3.3. While, the illustration of how these data sources will be used in the SAR is shown in Figure 3.5. In this figure, to perform different activities, we show which information is needed by which EROs and where this information is stored in which database. Figure 3.5 contains four boxes. The first left hand side box represents the tasks that ERs have to perform at the emergency site. The second left hand side box contains the involved EROs during an indoor fire emergency response. The third box represents the information needs of various EROs to perform different tasks. The final box contains the university information systems which own the information that are needed for different EROs.

Table 3.3: Data Sources used for Data Integration

Used Applications	Description
FS system	Contains information related to students who have registered to courses and programs at the university.
SAP portal	Contains information related to full time and part time employees.
Syllabus system	Contains information related to time plans of scheduled courses.
UiA system	Contains information related to university building information, resources information, and hazardous material information.
Sensor database	Contains information related to the smoke, fire, and temperature inside the room.
Cisco Prime Infrastructure application	It contains information related to the connected users over Wi-Fi.

3.2.4.2 Data Mapping

To integrate information from different university information systems, a few rules are used. Here, rules mean the descriptions of how the information from different data sources should be mapped. These rules are used to map the information and to make a query plan for retrieving information from different data sources. For data mapping, we considered a one-to-one and a one-to-many mappings. To retrieve information, we used local schemas and global schema. Local schemas are the

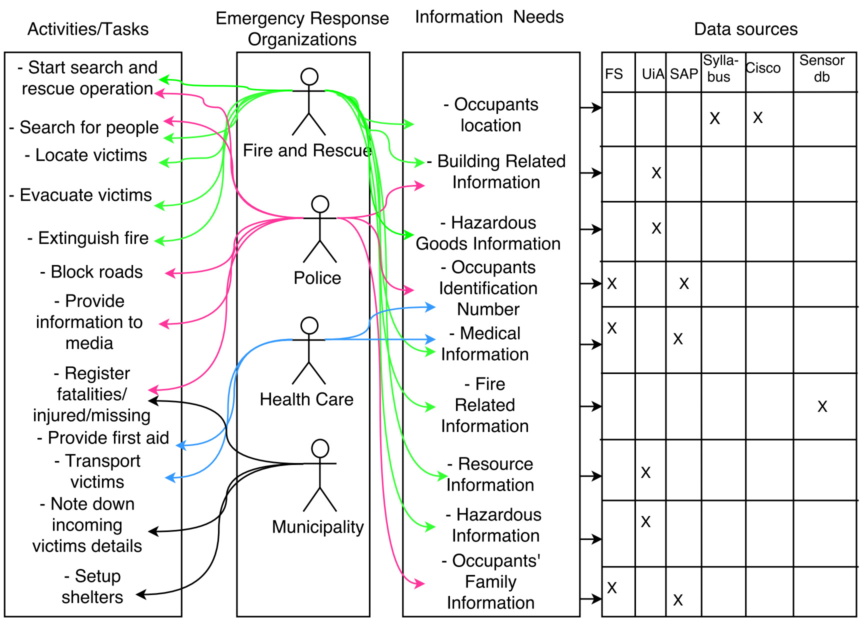

Figure 3.5: Information Needs for Performing Tasks during an Indoor Fire Emergency Search and Rescue Operation

schemas that were used to extract information from local databases i.e., FS, SAP, Cisco, Syllabus, UiA, and Sensordb.

Global schema is the schema that was used to extract information from VDB. Here, VDB is a database which stores the integrated information according to the proposed information model. The extracted information from local databases are mapped with the suggested information model that we used and stored in the centralized database i.e., cloud server. The information that is stored in VDB gets updated once in two minutes in order to give real-time information to the involved ERs.

A sample data mapping from local databases to virtual database is as follows.

- Victim_ID in VDB = User_name in FS, U_name in SAP and U_ID in Cisco (this is a one-to-many mapping).
- Victim_status in VDB = status in FS, P_status in SAP (this is a one-to-many mapping).
- Device_type in VDB = d_id in Cisco (this is a one-to-one mapping).
- Network_id in VDB = Accesspoint_ID in Cisco (this is a one-to-one mapping).
- Network_name in VDB = AP_location in Cisco (this is a one-to-one mapping).

The detailed description of the rules that are used for data mapping and the system implementation is presented in paper C.

3.2.5 The Information Presentation

Information provisioning component of the proposed framework (see Figures 3.1 and 3.2) fulfills the requirement FR3 presented in Sub-section 3.1.1 and answers the research question FRQ4 stated in Sub-section 1.4.

An important requirement of an effective information system is that useful information should be integrated and needed and relevant information should be presented in an understandable way to the end-users. Hence, both the content and presentation are equally important. During an emergency response, to obtain a common operational picture and make effective decisions, it is important to present the needed information without creating information overload. Therefore, in this section, the third component of the proposed framework (see Figure 3.2) is presented i.e., the information presentation. It presents the needed information by accessing the information from different data sources in a reliable way.

To provide relevant and reliable information to different ERs under time pressure in a complex and uncertain environment, the information presentation component consists of three layers 1) the service layer, 2) the business layer, and 3) the presentation layer. The service layer provides consumers with sufficient details to invoke the business functions exposed by the provider of the service. In a business layer, all business work-flows are handled. The presentation layer provides an user-friendly human-computer interface called LifeRescue to ERs. In this dissertation, an end-user centric approach is considered instead of a technology-centric approach for designing LifeRescue web portal. The end-user centric approach is "organizing the technology around the users' goals, tasks and abilities" [217]. The technology-centric approach is "developing many complex applications without involving and considering users' perspectives, which results in difficulties in understanding the systems" [217].

During LifeRescue development process, different ERs from both police and fire and rescue services have been involved at several stages (for example, scenario creation of an indoor fire in a university building, extracting user requirements for performing the SAR, mock-up graphical-user interface (GUI) design) to increase the usefulness and acceptance of the system, and to provide feedback and their requirements for the GUI features with us. More details on the developed prototypes are given in Sub-section 3.2.6.2.

3.2.6 Framework Implementation

We prove the applicability of the proposed framework by developing prototypes. We present different parts of the developed prototypes in papers A, B, C, and D. The prototypes described in papers A and B support our proposal of the semantic model presented in Sub-section 3.2.3. The prototype presented in paper C is used for data source handling presented in Sub-section 3.2.4. Finally, our proposal of the information presentation component, which is presented in Sub-section 3.2.5, is proved by the prototype described in paper D.

This section first presents technologies that are used in the prototype development. Afterwards, an implementation of the framework is described.

3.2.6.1 Technology Selection

Modern information and communication technologies are used to make the systems interoperable. That is the reason to have several technologies and approaches to ensure data integration in this research. The selected technologies and approaches are: Service Oriented Architecture (SOA), Enterprise Service Bus (ESB), and Model-Driven Development.

Among the existing ESB open source frameworks such as JBoss Fuse ESB, Talend ESB, Petals ESB, and Mule ESB, we choose Mule ESB, a lightweight Java-based ESB that connects applications together quickly and easily, enabling them to exchange data [218]. Mule ESB is provided together with an IDE (Integrated Development Environment), namely Mule studio, which makes the process of flow design much easier. Mule ESB also provides many connectors such as endpoint-based or operation-based, many transports, for instance REST, SOAP, and JMS (Java Message Service).

AJAX technology is used to handle requests and responses between server and client. A jetty server is used to provide a HyperText Transfer Protocol (HTTP) web server, and JDK 1.8 (Java Development Kit) for supporting Java application. JSP (Java Server Page) [219], HTML5 [220], CSS [221], JQuery [222] have been used for the web application development. In addition, JFreeChart [223] has been used for displaying the information in a pie-chart form on LifeRescue web application. We used the Oracle SQL Server and the MySQL for creating and managing the different relational databases i.e., FS, SAP, Cisco, UiA system, Syllabus, and Sensordb.

3.2.6.2 Prototype Implementation

To present information on the GUI, we created a prototype system as shown in Figure 3.6. The horizontal dashed lines divide the figure into three parts that are marked with numbers (1), (2), and (3). These parts correspond to Part(1), Part(2), and Part(3) presented in Figure 3.1.

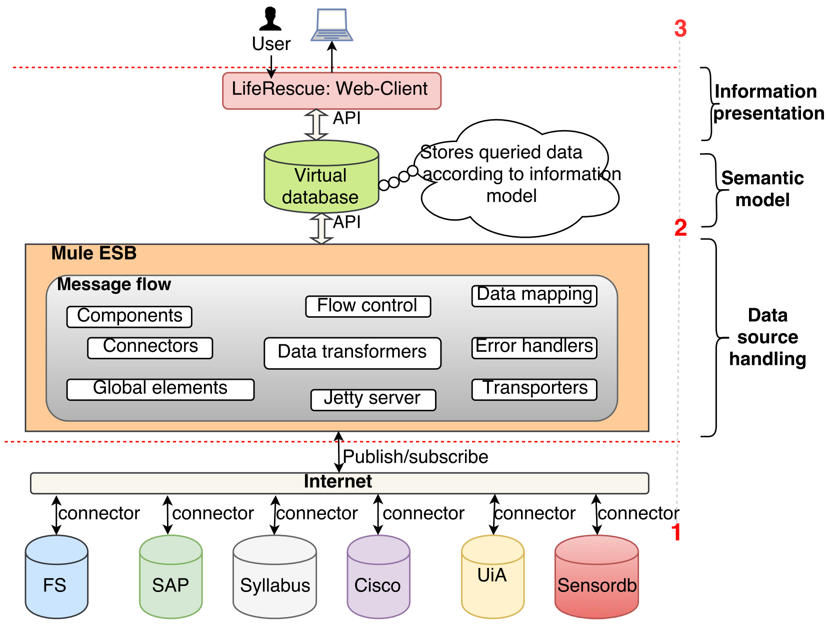

Figure 3.6: A Data Integration Prototype

The relevant information is made available through web services and the information are pushed to our system over the Internet from the data providers FS, SAP, Syllabus, Cisco, UiA and Sensordb. Schemas are used to pull and push the information on web-based application. The virtual database is a cloud server (Salesforce cloud server), where the queried and integrated information is stored.

In our implemented system, a message flow was created to specify how a service request is to be parsed in the system. Mule uses message flows to plug together a series of message processors. A typical message flow has a message source (usually connectors), which accepts messages from an external source (e.g., databases or applications or third party APIs) either via a standard protocol i.e., HTTP and triggers the execution of the flow. It also typically includes a series of message processors which transform (i.e., convert message payload data to a format which another application can understand), filters, and enriches messages. The message flow for the implementation included an HTTP endpoint component as message source, which made the flow available as an HTTP service. In addition, there are two types of endpoint-based connectors i.e., inbound endpoints and outbound endpoints in Mule

ESB. Here, inbound endpoints serve as a message source for a flow and outbound endpoints send information to the external systems (i.e., web services or files or databases).

In Mule ESB, the HTTP endpoint connector is used along with the Simple Object Access Protocol (SOAP) component, where the service was configured with an appropriate jetty transport representing the different operations that could be invoked on the service bus. The SOAP component would make the service available for cross-computer communication.

Transformers and jetty transport were being used to perform data conversion (i.e., from JSON to Object) and to expose Mule services over HTTP using a jetty HTTP server. A data mapper takes data in a specific format and outputs the same data in the format of our choice. Therefore, we have used this component to resolve the semantic heterogeneity problem. A data Sense is a feature which is offered by Mule to use message metadata to facilitate application design [218]. With this functionality, Mule ESB proactively acquires information such as data type and structure, to prescribe how to accurately map or use this data in our application.

The web application prototype is shown in Figure 3.7 and Figure 3.8. The developed GUI is a user-friendly human machine interface which enables efficient ways to access reliable data by the ERs. The integrated data sources in Table 3.3 are made available to the ERs who are at the on-site and at the command center through secured web services. Making information available through web applications increases the availability of information due to platform independence and easy access. The log-in page of LifeRescue web application can be seen in Figure 3.7.

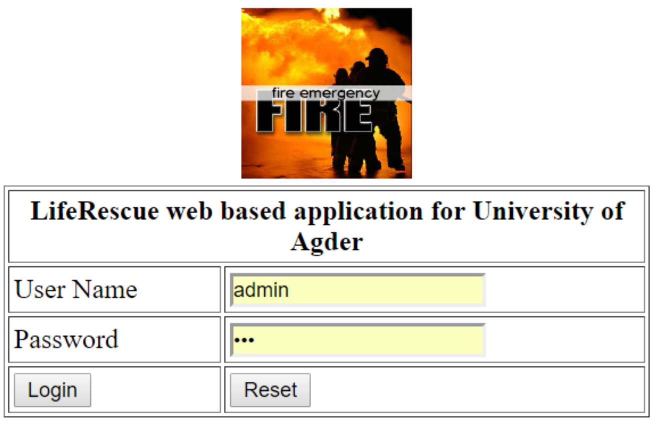

Figure 3.7: The Log-in Page of LifeRescue Prototype Graphical User Interface

LifeRescue application provides both static and dynamic information to the ERs. Dynamic information means the information which changes over time during the fire emergency and static information means the information which remains unchanged all the time.

To demonstrate the information presentation component, an example case is considered i.e., if ERs request the following information on the GUI: "showing the information about the persons who are inside the building during fire emergency which occurred between 9 to 10 am". In this emergency situation, the GUI presents victim information such as the total number of victims (both normal and persons with disabilities) still inside the university to the ERs through a web browser in a pie chart format. In Figure 3.8, the pie chart with the total number of victims inside the building can be seen. Further details on the features and the information that are available on the GUI can be found in papers D and E.

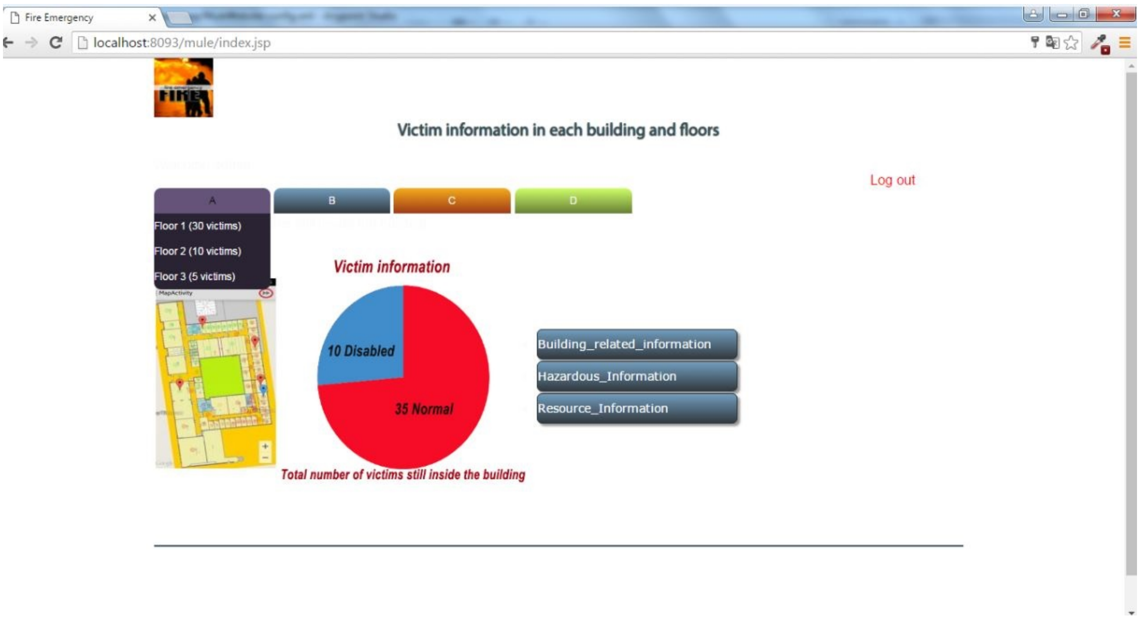

Figure 3.8: The Main Page of LifeRescue Prototype Graphical User Interface

3.3 Chapter Summary

In this chapter, to support different ERs during the emergency response, a data integration framework is proposed for providing information accessibility and availability from various existing data sources. The proposed data integration framework for an emergency response can be considered as our main original contribution to knowledge. The proposed framework is composed of three components i.e., the semantic model, the data source handling, and the information presentation.

To develop all these three components, a use-case of indoor fire emergency in a university building has been developed. For this use-case, information needs of different ERs during the SAR have been identified. After identifying information needs, a semantic model has been proposed. The semantic model covers key concepts in the emergency response domain (i.e., fire emergency in building) and their semantic relationships. It defines the basic agreements on data exchange format and what kind of data to exchange. Data source handling focuses on acquiring data from existing different sources, and the sensor database. Data source handling component consists of three layers: service integration, ESB, and communication integration. Finally, the information presentation component contributes in providing relevant information in a timely manner. With all of these framework components, the requirements for the proposed framework have been matched.

Chapter 4

Evaluation and Discussion

This chapter presents the evaluation of the developed prototype against the usability and performance of the system and against the information requirements. Afterwards, the evaluation of the proposed framework against the framework requirements are discussed. Next, the evaluation of the proposed framework against the formulated research questions that are stated in Sub-section 1.4 is described. Later, we explain how our proposed framework answers the research questions that are presented in Sub-section 1.3. The chapter finally ends with a discussion on findings, the contributions, and comparison of our solution with alternative solutions.

4.1 Evaluation of the prototype

In this section, we present the results of usability evaluation of the developed prototype and information requirements fulfillment. As mentioned in Chapter 3, to test the applicability of the proposed framework, a prototype with a Graphical User Interface (GUI) called LifeRescue has been implemented. The human-centered design process method (see Sub-section 1.6.3) was used to develop LifeRescue prototype. The development process and used technologies are presented in Sub-section 3.2.6. After developing the prototype, a formal evaluation of LifeRescue has been done to check whether LifeRescue satisfies information requirements of various emergency responders (ERs) and also to check the usability and performance of the system.

For evaluating the developed LifeRescue prototype, we conducted a workshop session with nine participants i.e., three from police, and six from fire and rescue services. Among the participated 6 ERs of fire and rescue service, one works as fire chief (FC) who acts as an on-scene commander, one person as crew manager (CM), one as smoke diver leader (SDL), and three persons as smoke divers (SD).

Among the participated three ERs of police service, two work as police chief (PC) and have experience in working at the emergency site, and one works as a control room supervisor (CRS) at the control and command center. The experience of the involved participants in responding to the emergency situations ranges from 4 to 20 years.

The entire workshop session was carried out for 2 hours (120 minutes). However, the number of involved participants in the conducted workshop was relatively small. But, in [224], the author stated that "*a small number of participants can be sufficient for having valid result for testing a developed system*". Hence, keeping this point in mind, in this dissertation, we believe that the results we got from the workshop session are considered as valid results.

In the workshop session, the evaluation started with narrating a use-case scenario i.e., an indoor fire emergency in a university building and followed by demonstration of the developed prototype. Next, the involved participants used the prototype.

After using the prototype, the participants were given a system usability scale (SUS) questionnaire [225] to collect data on their opinion on the usability and the performance of the system. Here, the SUS-questionnaire used as a survey scale which was developed by Brooke and can be found in [225]. This SUS-questionnaire helps to find out how efficiently and easily users can access and use a given product or service.

After getting the participants' responses via a SUS-questionnaire, we have conducted a semi-structured interview with the participants to understand deeper whether the developed prototype meets their requirements or not.

4.1.1 Usability and Performance Evaluation

In this section, we present the results of the SUS-questionnaire. As mentioned above, a SUS-questionnaire was given to the participants to rate their opinion on the usability and performance of the developed prototype. The given SUS-questionnaire was composed of 10 statements that are scored on a 5-point Likert scale of strength of agreement. The results of the overall SUS-scores are shown in Figure 4.1.

To calculate the overall SUS score, in this research, we adapt the same scale that was used in the literature [226, 227] called adjective scale. The division of the SUS scores was done as follows: score of 0–25: *worst*, score of 25–39:*poor*, score of 39–52: *OK*, score of 52–85: *excellent*, and score of 85–100: *best imaginable*.

The results show that all the participants have given an overall rating above 60%.

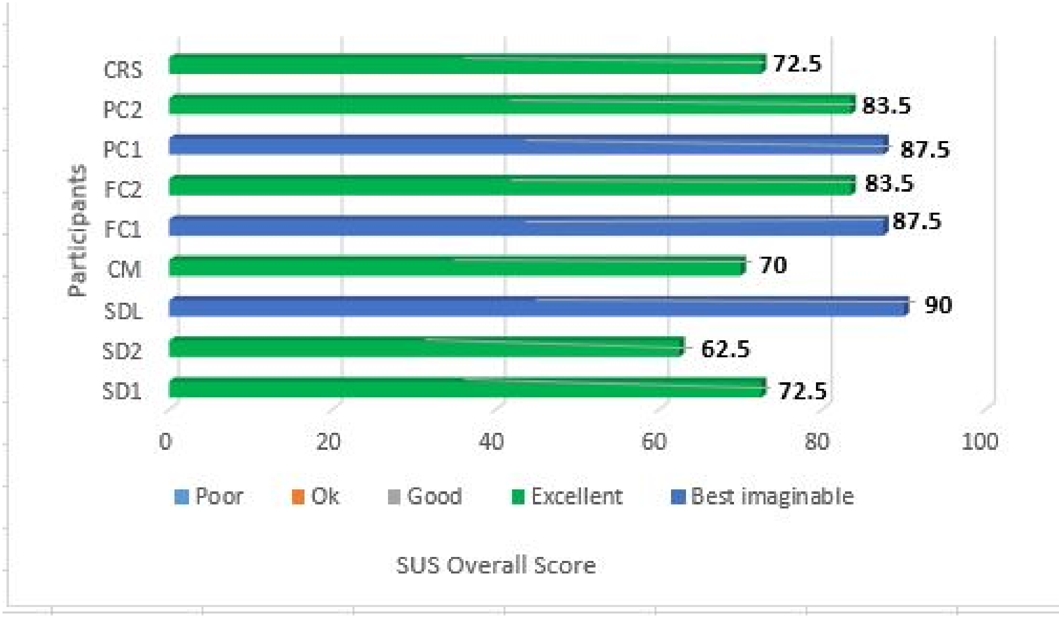

Figure 4.1: The Overall SUS Scores

Therefore, LifeRescue achieved an "Excellent and Best imaginable" SUS overall score. The SUS scores calculation can be found in [225]. From Figure 4.1, it is observed that SDL (Smoke Diver Leader), FC1 (Fire Chief 1), PC1 (Police Chief 1) and PC2 (Police Chief 2) rated LifeRescue as "*best acceptable*" system which can be used to support their work during an indoor fire SAR. Other participants rated the system as "*excellent*" to be used to support their work during an indoor fire emergency SAR. More details on usability and performance evaluation can be found in paper E.

4.1.2 Evaluation of Information Requirements

When it comes to evaluate the prototype against the information requirements, the participants used the developed system. After getting access to the system, the participants went through the GUI features thoroughly. Then, we collected the participants' opinions through a semi-structured interview on whether the information requirements (see Table 4.1) got matched with the developed system or not.

The semi-structured interview was audio recorded and the audio recordings were transcribed into an excel sheet. Later on, the data from an excel was exported and encoded using a Nvivo tool for analyzing the data.

To recap, the identified information needs of fire and rescue and police services' personnel are presented in Table 4.1 where ✓represents the needed requirements and × represents the requirements which are not needed by the ERs.

Table 4.1: The Used User Requirements of different Emergency Responders

User Requirement ID (UID)	**User Requirement Description**	**Emergency Responders**	
		Firefighters	**Police**
1	The user can connect to the system from any place and at any time.	✓	✓
2	The user can get data from diverse sources in a structured form.	✓	✓
3	The user can know the count and location of victims who are inside the building.	✓	✓
4	The user can know the resources' location and their details.	✓	×
5	The user can get building related information.	✓	✓
6	The user can get the hazardous materials' location and its details.	✓	✓
7	The user can get access to information from other emergency response organizations' databases in real time.	✓	✓
8	The user can get access to victims' family information.	×	✓
9	The user can get access to information related to victims' details.	✓	✓
10	The user can get trustworthy information.	✓	✓
11	The users can not face information overload on the screen.	✓	✓
12	The users can understand the language that is visualized on the GUI including acronyms, signs and symbols.	✓	✓
13	The user can see the rescuers location inside the building.	✓	×

From the same table it can be seen that ERs from both fire and rescue and police services would like to be supported by getting the listed features and information via an information system.

The User Requirement ID (UID) 2 got matched since the information that got integrated and presented on the GUI was from diverse existing information systems of university. The pie chart feature and the floor map of the GUI matches with the UID 3.

The resources information and building related information and hazardous information tabs in the GUI matches with the UID 4, UID 5, and UID 6. However, UID4 is not needed for the police as the resources information is irrelevant for them during the SAR.

The requirements UID 8 and UID 9 are met since the floor map feature of the GUI provides the victims and their family details. However, UID8 is not needed by firefighters as the family related information is irrelevant for them during the SAR. The pie chart feature and the floor map feature of the GUI meet the UID 3.

As the presented information on the GUI is the integrated information of existing university systems, the information is considered as trustworthy information. Thus, UID 10 gets matched.

During the GUI development process, both fire and rescue and police services' personnel got involved. Therefore, the symbols and text of the GUI were discussed during the development process. With this, the UID 12 got satisfied. As additional data sources can be added to the system, UID 7 got satisfied.

Given that the GUI features are systematically arranged and provide only the relevant data, UID 11 got satisfied. The UID 1 got matched as the users were provided with the log-in details and can access the system from anyplace. The details of ERs who entered the building can also be seen in the GUI, which satisfies the UID 13.

During the interview, the involved participants stated and agreed that *"the system was very well integrated and gives relevant information to us"*. Furthermore, FC and PC mentioned that *"it was easy to log-in to the GUI and the screen was useful to get an overview of the inside situation i.e., victims and their location"*.

When linking the participants statements with the GUI features, it can be concluded that the results of the semi-structured interview show that the information requirements that are listed in Table 4.1 of both fire and rescue and police services got satisfied by the developed LifeRescue prototype. More details on the user requirements evaluation can be found in paper E.

4.1.3 Recommendations from the Participants

Although we have received positive comments on the developed GUI, we have also received some recommendations for improving the current GUI features by adding some extra information i.e., adding phone number to the victim details. With this information, either police or fire personnel can send mass messages to the trapped victims. Furthermore, the participants also mentioned that adding information related to room and corridor dimension (such as width, breadth and length size) will be helpful for the firefighters.

During the interview, participants also stated that displaying all information in a single browser with a single click was an outstanding idea, because it doesn't burden their operation as ERs have already diverse tasks to perform simultaneously at the emergency site. So, if they were given information with multiple browser windows, that would be overloading for them to remember the information that they got from LifeRescue GUI. More details on the recommendations for GUI improvement can be found in paper E.

4.2 Evaluation of the Proposed Framework against Framework Requirements

In this section, we evaluate the proposed framework against the framework requirements which were stated in Sub-section 3.1.1. The semantic model component in Figure 3.2 fulfills the requirement FR1 which is intended to solve the semantic heterogeneity problem. The results of this component were presented in Sub-section 3.2.3 and in paper B. The framework requirements FR2 and FR4 which were stated in Sub-section 3.1.1 have been fulfilled by the data source handling component which was shown in Figure 3.2. The results of this component were presented in Sub-section 3.2.4 and in paper C. In Figure 3.2, the information presentation component fulfills the framework requirements FR3. The results of this component were presented in Sub-section 3.2.5 and in paper D.

The non-functional requirements NFR1 and NFR2 are fulfilled since the framework is platform independent and some parts of the proposed ontology are reusable and extensible. Besides, the framework can be applied to other emergencies such as natural and man-made emergencies. The applicability of the framework is presented with the help of the use-case in Section 3.2. The applicability of the proposed framework in other emergencies is presented in Section 4.4. The information and communication security part is not covered in the framework due to limitation of the project period.

4.3 Evaluation of the Prototype against Formulated Research Questions

This research work focused on providing easy access to relevant information from the various existing information sources in order to support emergency responders during an emergency response. The research questions raised in Sub-section 1.4 are answered as follows.

1. *What are the critical information categories needed by the emergency responders during an indoor fire emergency search and rescue operation?*

   We answered the formulated research question by identifying the basic critical information needs of different emergency responders during an indoor fire emergency in a university building case. To do so, qualitative research approaches such as survey, interviews, and drill participation have been used. The complete answer to this research question has been described in the Sub-section 3.2.2.

2. *How to solve the semantic heterogeneity issue that hinders information exchange among different information systems and eventually different emergency responders during an indoor fire emergency search and rescue operation?*

   We answered this research question by using semantic technologies. In particular, an ontology was used to describe the fire emergency response in a building concepts and their relationships. So, we developed a building fire emergency response ontology which was used to discover the semantic mappings between various existing data sources. The complete answer to this research question has been described in Sub-section 3.2.3.

3. *How to provide relevant information from existing various emergency response organizations' data sources into a single operational model during an indoor fire emergency search and rescue operation?*

   We answered this research question by using an Enterprise Service Bus (ESB). An ESB plays a middleware role to connect different existing university data sources in our system. Connectors in Mule ESB platform were used to handle differences in data format of different data sources. In Sub-section 3.2.4, more explanation on the answer to this question has been given.

4. *How and what information can be accessed in a reliable way and presented to the emergency responders to meet their information needs during an indoor fire emergency search and rescue operation in order to perform better?*

   We answered this research question by using web services to make data accessible and available in a reliable way. By using a human-centered design process approach, a web based application called LifeRescue has been developed to provide relevant information from various existing data sources. The detailed answer to this question has been presented in Sub-section 3.2.5.

4.4 Evaluation of the Framework against Research Questions

In this section, we evaluate the framework against the research questions (RQ1-RQ4) that are stated in Sub-section 1.3. We want to mention that the success of implementing the framework in a specific case will lead to answer the general research questions that will work on other scenarios too.

1. *What are the critical information categories needed by the emergency responders during an emergency response?*

   To develop a new information system for supporting the actors who are involved in a particular domain, the first step that needs to be done is analyzing the domain where an information system will be built and applied. Here, domain analysis aims at extracting, identifying, capturing, organizing and making reusable information of a specific domain. Therefore, in this research, analysis of the emergency management domain was done to gain the deep knowledge of the domain to develop a better system and for faster development. The analysis was about emergency type, emergency response organizations (EROs) who are involved in a particular emergency, the emergency responders (ERs) of EROs and their information needs, bottlenecks, tasks to perform and so on.

   In order to answer this research question, a general answer does not exist due to the diversity of the emergency domain. So, to know the basic information categories of ERs for each new or extended emergency type, the first basic step is to perform domain analysis. The domain analysis approach that we have followed for answering the formulated research question (FRQ1) will be used for answering the RQ1. The used approach for answering the FRQ1 has been summarized as follows: First choose a particular use-case (i.e., knowing the emergency type) where the intended solution needs to be applied. Then, identify the involved EROs, then ERs, and next their information needs by using different qualitative methods such as "*surveys, open or semi-structured interviews, and drill participation*."

The results we got from answering FRQ1 such as involved EROs and ERs can be reused for other emergencies such as man-made and natural emergencies. Depending on the type of the emergency, basic information needs, information about necessary EROs, and ERs are varied. So, information on this can be obtained from the domain analysis part by using the above-mentioned qualitative methods. Here, the domain analysis aspect refers to knowing the involved stakeholders, and their information needs in advance in case of an emergency. If the majority of the emergency domain analysis is done before the emergency occurrence for all types of emergencies, then the involved emergency responders' work will become easy to manage the emergency. Here, the majority of the domain analysis means "analysis on who should be involved from which organizations in a certain emergency", "analysis on performing tasks depending on the emergency type", "analysis on location of the emergency", "analysis on needed resources and activities depending on the emergency type".

2. *How to solve the semantic heterogeneity issue that hinders information exchange among different information systems and eventually different emergency responders during an emergency response?*

   As the proposed framework (see Figure 3.1 and 3.2) is designed for a generic solution, to enable the systems to communicate, interact, and collaborate with each other, it is important to solve the semantic heterogeneity problem. Here, the semantic heterogeneity problem means lacking a common understanding and agreement of terminologies and their relationships that are being exchanged between two or more different emergency response organizations' data sources. The semantic heterogeneity problem can be solved by employing the semantic technologies, because they are good solution for answering this research question.

   Due to the diversity of the emergency domain and diverse data sources, a common ontology can not be developed and used to solve the semantic heterogeneity problem. Hence, the approach that we used to answer FRQ2 will be applied to answer this research question. The method that we used to develop an ontology to solve the semantic heterogeneity problem for a fire emergency in a building was *methontology*. More details on this method can be found in Sub-section 1.6.1. When it comes to applicability of the ontology that was developed for answering FRQ2 in other type of the emergencies, some parts of the ontology can be reused and then extended with additional information.

For example, if we consider the extreme weather emergency domain, some classes of our developed ontology can be used such as *Actor component (Who and What)*, *Objective component (How)*, *some parts of the Emergency component (When and What)* such as location, date, time, risk area of the emergency, and *some parts of the Building component (Where)* such as *Address, Emergency area, Location, Route*. When it comes to using our developed ontology for a "*traffic accident case*", the same components such as *Actor*, *Objective*, and *some parts of Event component* can be used for developing and extending the ontology for this particular case. In order to extend or build a new ontology to support ERs in a specific emergency, the needed additional information will be event type, cause of the event along with the existing classes. This information can be obtained only after the occurrence of an emergency.

Some information is generated just after the emergency such as "When (date and time of the emergency)". In addition, some information is generated during an emergency such as "partial information of who (involved victims)" and is not known by the ERs before the emergency. So, after the emergency, including this extra information in the developed system is not that difficult as the ERs get to know about the emergency situation and needed information. This is because the implementation is something that can be automatized or modularized.

3. *How to provide relevant information from existing various emergency response organizations' data sources into a single operational model during an emergency response?*

   In the proposed framework, the data source handling component answers this research questions. To integrate data from diverse existing data sources, a semantically-enhanced mediator-based data integration approach has been utilized. The details of the used approach represented in Sub-section 1.6.2. To fetch data from diverse existing data sources, connectors have been used. Furthermore, the fetched data is mapped with the developed ontology via an ESB which is a service-oriented architecture based middleware. An ESB has been used to establish a connection among different applications.

To test the applicability of the framework, the integration methodology and process has been applied to integrate existing university data sources to support ERs in case of an indoor fire emergency can be applied for any emergency domain. The technologies that were used to integrate data for an indoor fire case can be utilized in any emergency domain for handling diverse existing data sources.

4. *How and what information can be accessed in a reliable way and presented to the emergency responders to meet their information needs during an emergency response?*

   In the proposed framework, the information presentation component answers this research question. To make information accessible and available in a reliable way, web services have been used to present the integrated data to emergency responders. Therefore, the same solution can be applied in any emergency domain to access and provide the information. The developed GUI which was used to present the integrated data was case specific. So, it can not be used in other emergencies.

4.5 Discussion

This section begins with discussing the overall solution that has been achieved in this dissertation and then presents the discussion on comparison of our solution with other existing data integration solutions.

4.5.1 Overall Solution

Emergency response depends on the availability of relevant information in order to support search and rescue tasks and decision-making at the emergency site and at the command and control center [228]. Data from diverse existing data sources are an essential input for the ERs' decision making and situational awareness. To make relevant information available and accessible for ERs during an emergency response is challenging as the data reside in different sources with different data formats, and these sources belong to different organizations. Consequently, getting access to those organizational data sources is difficult due to organizational, political, and legal barriers. In addition, these organizations mostly use different terminology (semantics) for managing and storing their data. Utilization of such data during emergency response turns into a manual and intensive work for ERs to make it understandable to one another.

In this dissertation, we tackle the above-mentioned issues by proposing a technical solution for semantic data integration. When we started solving the technical problem which is described in Sub-section 1.2, we realized that for achieving semantic data integration for EROs' data sources, the technical problem is not the only problem that needs to be solved, but also several other non-technical problems exist such as organizational, political, and legal problems. The organizational problem is that each organization has specific responsibilities, authority, and organizational structure. This kind of problem particularly concerns human and organization behaviour which can be incompatible with interoperability.

When it comes to the political problem, the involved EROs may have lack of trust between each other for sharing information. The EROs may have developed official policies or guidelines that restrict information exchange, or lacking official guidelines on information exchange. The legal problems could be related to having ownership of the data. However, in this research, we have not dealt with solving these problems, but only the technical problem. To achieve a good technical solution for technical problem, it requires political will, supportive regulations, policies and guidelines, and giving access to the needed data. The technical solution is proposing a framework and methodologies that provide semantic data integration for an emergency response.

The proposed framework contains three components i.e., the semantic model component for solving RQ2, the data source handling component for solving RQ3, and the information provisioning component for solving RQ4. From these three components, the semantic model component is the core of the architecture which has been used to integrate data from various existing data sources and present the integrated information to the needed users. The semantic model component solves the semantic heterogeneity problem and enables the integration of data. Data which resides in various existing data sources being fetched with each individual connector and mapped with the developed information model and is stored in a virtual database (VDB). Information from the VDB is accessed and provided to the ERs in a reliable way on a GUI for supporting an emergency SAR. To test the applicability of the proposed framework, we chose a specific use-case i.e., an indoor fire emergency and developed solutions to be used during an indoor fire emergency SAR. It is because developing solutions as generic is impossible due to the diversity of the emergency domain. The solutions that are developed in this dissertation can be utilized for any kind of emergency. However, the only modification that should be done to the developed semantic model is either it should be extended for other fire emergencies or the classes might be reused for other kinds of emergencies.

During development of this research, a number of technological challenges and limitations were encountered. The most important challenge is concerning the disruption of communication infrastructure which poses a challenge for providing the real time integrated data to the ERs as it stays operational at the beginning of the emergency and again end of the emergency. With this, the data which is stored in the virtual database could be used as historical data to give an overview of the situation.

4.5.2 Comparison with Existing Solutions

This Sub-section is intended to present evaluation on a comparison of our solution with the existing solutions for solving the problems outlined in Sub-section 1.2. The evaluation criteria for the comparison are the following: providing real-time data, and structured data or unstructured data inclusion.

Currently, there are several methods and architectures are in use for integrating data from various data sources such as manual integration, common user interface, integration by applications, integration by middleware, uniform data access, and common data storage [112]. Based on these data integration approaches, specific solutions such as data warehouses, federated database systems (also called as virtual data integration) [4], and dataspaces systems [229] were realized. The review of these solutions was done by [112]. All these approaches are being used to integrate either structured or unstructured data from various structured and unstructured data sources.

In this research, we have employed virtual data integration solution for integrating data from several structured data sources. So, now we compare our solution with the data warehouse solution in terms of providing real time data criterion, and structured and unstructured data inclusion criterion. In data warehouse approach, integrating data from various data sources is possible by Extracting, Transforming, and Loading (ETL) into a data warehouse. This approach is suitable for bulk movement of large volumes of data, but not suitable for providing real-time data. Further, the data synchronization with the local databases is difficult when the number of participating databases grow. The implementation cost is also very high as a separate database needs to be developed and maintained. When we compare data warehouse approach with our chosen approach i.e., virtual data integration (VDI) about real-time data provision criterion, data warehouse approach does not provide real-time information. When it comes another criterion i.e., structured and unstructured data type, in data warehouse solution, both unstructured and structured data can be integrated.

Another solution is also valid for our case is dataspace system [229]. This system can offer a suite of interrelated services on a set of large and loosely coupled data sources where the data can be under different administrative control and not necessarily under the control of the dataspace system. The relationship between data sources need not to be necessarily known [230]. The semantics of the data can be exploited in this solution. The limitation of this approach is that it does not provide real-time data integration when it is compared with our used solution. If this solution is compared with our solution with another criterion i.e., structured and unstructured data type inclusion, dataspace system works on structured and semi-structured data.

Another important aspect to note in this dissertation is that, we investigated and integrated structured data instead of unstructured data. This is because, data in various university data sources that we have considered was already in the structured format. In reality, during an emergency, not all available data is structured or unstructured, but it is partially structured i.e., some data are more structured and some data are less structured. Unstructured data available for example from social media, text reports, textual descriptions of the conditions that were gathered at the emergency scene, it can be incorporated into the proposed framework, because there will be no problem in making the unstructured data into structured data. To incorporate unstructured data from various data sources, there are methods available to handle diverse data types from varied sources such as text mining, extracting structured information from text, linking text to relational databases, and information integration by data driven similarity. From these available methods, we prefer to consider text mining algorithms to convert unstructured data into a structured format [231]. Further, from the above-discussed factors, it can be concluded that the virtual data integration is well suited for solving the semantic heterogeneity problem by fulfilling the both criteria i.e., providing real-time data and structured and unstructured data type inclusion.

Chapter 5

Conclusions, Summary and Future Directions

This final chapter summarizes my contributions to knowledge and gives some concluding remarks. It also points out few future directions at the end of this chapter.

5.1 Conclusions

Emergency response operations demand good information access to support ERs in performing response tasks, making decisions at the emergency site as well as at the command and control center. The availability of the needed information is one of the bottlenecks for obtaining a common operational picture. In any kind of emergency response, upon first responders' arrival at the emergency site, the ERs gather information manually or semi-automatically to obtain an overview of the situation. After gathering the information, the collected information is stored in different heterogeneous data sources that are owned by different EROs in distinct locations.

When ERs from fire and rescue service request some information from police personnel, the information sharing between them is usually done either face to face or paper-based or by using hand held devices (either mobile phones or walkie-talkies). This kind of information sharing is time consuming and often cause delays in performing emergency response activities. The time first responders spend on gathering static and volatile situational information from affected people, responsible persons at the emergency site as well as from other ERs can be reduced if the needed information that are stored in diverse information sources is made available and accessible for them.

As various EROs are involved in an emergency response operation, they use their own applications which are developed individually by individual emergency response organizations. To make these independent applications accessible to different ERs in a unified way, an important challenge that needs to be addressed is the information integration problem along with the semantic heterogeneity problem of the EROs' data. To solve the semantic data integration problem, we proposed a model-driven data integration framework for emergency response. To propose the framework, we used model-driven development (MDD). MDD is an approach to system development, which increases the power of models in system development. It is model-driven because it provides a means for using models to direct the course of understanding, design, construction, deployment, operation, maintenance and modification.

The proposed framework contains three parts: Part 1 provides all data sources from different EROs, such as fire protection service, police service, health care service, and municipality. Sensor data from different sensor vendors is also used to integrate within this proposed framework. Part 2 consists of three components i.e., the semantic model component, the data source handling component, and the information presentation component. Part 3 contains the information about what purposes the framework can be used for. Part 1 and part 3 are connected by part 2. To test the applicability of the framework, an indoor fire emergency in a university building use-case scenario has been utilized as a case.

Various research methodologies have been used to answer the formulated research questions i.e., methontology for developing an ontology to solve the semantic heterogeneity problem, mediator-based data integration for handling different data sources for solving the data integration problem, human-centered design process for designing a graphical user interface (GUI), and web services for presenting the relevant integrated information on the GUI. After implementing the proposed framework, we have evaluated the developed prototype against the ERs' information requirements and usability with nine ERs i.e., six from fire and rescue service, three from police service by conducting a workshop session.

The results of the workshop session revealed that the implemented framework can solve the data access problem faced by participants' i.e., access to critical information and reduction of time for the information search. In addition, the developed prototype also solves the information overload problem by presenting the needed information in a systematic way on the developed GUI. When it comes to usability evaluation, the participants informed that the developed prototype was easy to learn how to use. The participants recommended that adding extra information such as mobile number to the victims' details and the room dimensions could have been beneficial for them to improve their decisions making process during the search and rescue operations (SAR).

To solve the semantic heterogeneity problem, the applicability of the proposed framework is tested with integrating different university data sources in an indoor fire emergency in a public building. With this, we believe that this proposed framework and used methods can help in achieving a complete solution for answering the research questions stated in Sub-section 1.3. For implementing the solution for an indoor fire case, we have used the framework, already available data connectors in MuleESB, and the developed information model. The same framework, connectors, methods, and some part of the developed information model (such as Goal, Actor component, and some parts of Emergency component) in our solution can be extended and applied in other emergencies and cases for solving the semantic heterogeneity problem. For information presentation, the developed GUI cannot be used directly in other emergencies, because it is specifically designed to support ERs during an indoor fire SAR, which may not be the same in the case of other emergencies e.g. landslides or floods. The processes that we used to present the information can be utilized.

5.2 Summary

This dissertation addresses the semantic data integration problem which is critical for emergency responders' information sharing during the SAR. Research questions raised in Chapter 1 are answered one by one upon reaching the research objective in the subsequent chapters.

- **Answer 1** to *" What are the critical information categories needed by the emergency responders during an emergency response?"*.

  In order to find the critical information needs of the emergency responders (ERs) during any kind of emergency response, we have answered this question using a single case. This is because, a general answer does not exist for the posed question due to diversity of the emergency domain, but the same approach can be replicated for a new single extended case. In this research, we considered an indoor fire emergency in a public building as a use-case scenario. Qualitative methods such as surveys, interviews, and drill participation have been utilized based on our use-case scenario for finding the information needs of ERs during the SAR.

- **Answer 2** to *"How to solve the semantic heterogeneity issue that hinders information exchange among different information systems and eventually different emergency responders during an emergency response?"*.

  To address the semantic heterogeneity problem, we used an ontology approach that arguably enables to reuse and share application domain knowledge using a common vocabulary across heterogeneous applications. In brief, it provides a promising approach to deal with semantic heterogeneity problems. In this research, we developed an ontology to conceptualize the building fire emergency response domain concepts and their semantic relationships as presented in Sub-section 3.2.3. This model facilitates structuring and integrating the knowledge from diverse university information systems which can be used in an indoor fire emergency response SAR inside a building. With this ontological development, we have pointed to a methodology described in Sub-section 1.6.1 to extend an existing ontology or to define a new ontology.

- **Answer 3** to *"How to provide relevant information from existing various emergency response organizations' data sources into a single operational model during an emergency response?"*.

  We have answered this research question by using a semantically-enhanced mediator-based data integration approach and a SOA-based integration solution for solving the semantic data integration problem. Although separate emergency response organizations' information systems can work well individually, their combination does not form a seamless solution because of the encountered data conflicts or semantic incompatibilities.

- **Answer 4** to *"How and what information can be accessed in a reliable way and presented to the emergency responders to meet their information needs during an emergency response?"*.

  We have answered this research question by employing web services to make the integrated data accessible in a reliable way and present on the developed user-friendly GUI. A human-centered design process methodology has been employed to develop a GUI for presenting relevant and needed information. In this research, the developed GUI is dependent on the application area i.e., can be used only for an indoor fire emergency. This means that the developed GUI is very special for the case that we have considered. On the one hand, the GUI can not be reused in other emergencies. On the other hand, the processes that have been used to present the information can be utilized in other kind of emergencies.

This research provides a holistic view of improving the accessibility and availability of relevant and needed information during an emergency response SAR. The results of this research are focused mainly to emergency response in the indoor fire emergencies which are usually relatively small and have short duration. The problem of the information integration for an emergency is universal and general in nature. Although the implemented solutions are limited to an indoor fire emergency response SAR, the proposed framework and used methods can be equally applicable in other domains, crisis scenarios, bigger emergency organizations, and in more complex data sources. In this work, to solve the semantic heterogeneity issue for data integration, we have presented that semantic technologies can be exploited in various contexts.

5.3 Contributions

In order to support different emergency responders during the SAR, this dissertation investigates the possibility of improving availability and accessibility of needed information from various existing data sources by solving data integration issues. The main contributions to knowledge of the research in this dissertation are summarized as follows.

- A model-driven data integration framework has been proposed and implemented to solve the semantic data integration problem to improve timely access and availability of information from various existing data sources of emergency responders during the SAR. The proposed framework enables the involved emergency responders to reduce time on information search. This proposed framework is flexible enough to incorporate new available structured data sources or applications. The framework is presented in Sub-section 3.1.2. Details of the framework can be found in papers C and D.

- In this research, an information model has been developed for fire emergency response in buildings, which is another contribution to the emergency management domain. This model is developed manually by using UML to explore the semantics of a fire emergency response in a building metadata to enable knowledge sharing and data exchange among involved emergency responders. This developed model is flexible enough to be extended according to the needs of the emergency responders. If the extension is done, then it is easier to integrate the structured data from new data sources. More details can be found in Sub-section 3.2.3 and in papers A and B.

- A semantically-enhanced mediator-based data integration approach has been utilized for handling various data sources. With this approach, all data from the existing structured data sources is mapped with the developed information model and stored in a virtual database. This contribution is presented in Sub-section 3.2.4 and in paper C.
- Data from various existing data sources have been made available and accessible. Relevant information is presented on a GUI for fulfilling different ERs' information needs during an indoor fire emergency SAR. Sub-section 3.2.5 and paper D presents more details of this contribution.

5.4 Future Work

This dissertation addresses the semantic heterogeneity problem for providing better information accessibility and availability to support different emergency responders in an emergency response domain. A data integration framework has been proposed. For implementing the proposed framework, a use-case scenario has been used. Since the research work covers different aspects in the field of integration, many aspects are left out to be addressed further in the continuation of this work. Several important future work directions are summarized as follows:

- In this dissertation, only the response phase of the emergency management is considered for investigating and solving the problem of information accessibility and availability from various applications. This problem is common in all other phases of the emergency management. So, as a future work, the applicability of the proposed framework to other phases has to be done as well to investigate and solve the information access problem.
- In this work, we have integrated only the structured data and provided to the users, but not considered and incorporated the unstructured data such as data from social media into our developed system due to limitations of the project period. So, as a future work, algorithms to transform unstructured data into structured data have to be developed and then integrated with the developed information model to provide relevant information to involved ERs.
- In this research, to integrate different existing data sources, we have used manual and semi-automatic methods for mapping the data with the developed information model. In addition, the integration is done on a small amount of data. So, as a future work, more sophisticated algorithms for automatic data

mapping, and for large amounts of data could be developed. This can include the adoption of more complex mapping and reasoning processes adopted from the artificial intelligence domain.

- Information and communication security were not taken into account so far for data exchange and communication. It is assumed that all communications are handled using secure channels. When data exchange and communications among different existing data sources occur, there are a lot of security issues. As a future work, research on security requirements for information accessibility and availability and security mechanism for authenticating the existing data sources' for secure communication have to be carried out.

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PART II

Paper A

Title:	Identifying First Responders Information Needs: Supporting Search and Rescue Operations for Fire Emergency Response
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Identifying First Responders Information Needs: Supporting Search and Rescue Operations for Fire Emergency Response

Vimala Nunavath, Andreas Prinz and Tina Comes

A

Abstract — **At the onset of an indoor fire emergency, the availability of the information becomes critical due to the chaotic situation at the emergency site. Moreover, if information is lacking, not shared, or responders are too overloaded to acknowledge it, lives can be lost and property can be harmed. Therefore, the goal of this paper is to identify information items that are needed for first-responders during the search and rescue operations. The authors use an educational building fire emergency as a case and show how first-responders can be supported by getting access to information that are stored in different information systems. The research methodology used was a combination of literature review, fire drills participation, and semi-structured interviews with first-responders from different emergency organizations. The results presented are identified information items and an information model.**

Keywords—Educational Buildings, Fire Emergency Response, Information Items, Information Model, Inter-Organizational Information Sharing, Search and Rescue Operations, Situational Awareness.

I. INTRODUCTION

Fire is one of the most frequently occurring emergencies that causes loss of lives and infrastructure destruction [1, 3]. In Norway, the fire statistics for the year 2014 shows that fire emergencies caused 54 deaths [4] and almost 4 billion NOK economic damage [5]. In case of fire emergencies, rescuing people from areas filled with smoke and fire might get decreased due to unavailability of needed information. Therefore, it is important for first-responders to improve their search and rescue operations (SAR) by reducing the time spent on information search and more on rescuing people.

The purpose of the SAR is to "prevent loss of life and injury through search, locate and rescue persons in distress by alerting, responding, and aiding activities using public and private resources" [6]. As a case study, we consider fire emergency in the university building. An important factor that affects the effectiveness of the search and rescue operations is the availability of information related to the topography of the building and its occupants. The baseline information which is needed for first-responders is stored in different university systems and may not be accessible by the first-responders at the emergency location due to security, privacy and legal issues. Hence, first-responders usually collect information from questioning the security personnel at the campus or the victims and by investigating the location visually [10].

Victims may be under shock and gathering information from them is very time consuming and the collected information may be incomplete. Consequently, first-responders have to spend a lot of time for collecting information. Moreover, the collected incomplete information prevents responders from developing situational awareness and may result in harm to people or property.

Situational Awareness (SA) can be described as the state of understanding that a responder has of an emergency situation, that means the dynamic understanding of "what is happening", especially with respect to the needs of command and control operations [7, 9]. Sarter and Woods defined SA as "all knowledge that is accessible and can be integrated into a coherent picture, when required, to assess and cope with a situation" [9, 43].

The research question that we address in this paper is: "Which information items are needed by the first-responders for an effective fire emergency response?." We address this research question through a combination of literature review, fire drill participation, and semi-structured interviews conducted with first-responders from different crisis response organizations and civil protection authorities. The objective of addressing this question is that first-responders' search and rescue operations can be improved by providing access to the immediately needed or relevant information at the emergency site before or during the search and rescue operation. On the basis of the collected, a UML information model is developed and validated with first-responders' feedback.

The rest of the paper is organized as follows. First, we describe an indoor fire emergency scenario which was used to know the information list that is needed by the different emergency responders as well as to collect from the literature review and then the research methodology which was used to identify the information needs of first-responders is explained. Later, literature review on recent studies on needed or relevant information items during fire emergency management is presented and then the results are presented. Finally, the discussion and conclusion part summarizes the lessons learned from this research and discusses directions for future research.

II. Emergency Scenario

Emergencies can vary greatly. For each kind of emergency, responders require different information and procedures to handle them. In this paper, we concentrate on one specific case to illustrate how to identify information needs of first-responders to manage search and rescue operations efficiently.

"Imagine there is a big fire in the university building. The fire starts from the ground floor of the building A at the University of Agder Grimstad campus. But, unfortunately the fire alarm sensor and sprinkler system did not work and did not alert the security officials. As a result, the ground floor of the building is filled with smoke and the fire started spreading over from one room to the other. After a few minutes, students on the first floor alert the security personal. Immediately, the sprinkler system gets activated manually and, within a minute, security guards activate the fire alarm. Thereafter, responsible persons of the building floors begin an orderly evacuation.

As everyone knows that, this time, it is not a drill, tensions are high and some students begin pushing to get to the entrance. However, due to fast spread of the fire, fire is beginning to spread into the other parts of the building. Due to the fire accident, no one is allowed to take the elevators to evacuate. There are 50 vulnerable persons from the people who are at the university (vulnerable are old people, children, pregnant, allergic to smoke and heat, disabled person). Those people cannot reach the exit quickly and are spread over the whole building. Visitors are not aware of the evacuation procedures, exit routes and due to poor visibility and as they are also being stuck inside the building due to structural collapse. Many others are suffering from severe burns and smoke inhalation. Damage to the building is extensive. The roof collapsed in the classrooms near to the room where the fire first occurred.

There is also heavy smoke coming out of the building and electricity damage occurred. So, evacuating occupants from multiple floors of a high-rise building involves a lot of time to travel great vertical distances on stairs. After a lot of people self-evacuated, 50 victims are still trapped in each floor in the university building. As the university building has several floors, at least 10 victims got stuck inside each room. However, first-responders are unaware of total number of victims and also the number of persons inside each floor of the building and their exact location to get an overview of the situation and to evacuate them".

In the above mentioned case, the first-responders are the fire protection service, police, municipality and health care. From these first-responders, responders from fire protection service are the one who arrive first at the emergency site. The basic tasks of the fire responders are to go to the emergency site with their trucks to evaluate the emergency situation by collecting the information from the security personnel and the affected victims.

If the on-scene commander decides the emergency is big he or she informs to the fire command center and request for the additional personnel to help them in emergency response. Meanwhile, the responders who are at the emergency site start performing the search and rescue operation such as fighting the fire and evacuating the victims from the building. The detailed description of emergency management procedure which includes the processes and roles of the emergency responders are presented in our previous research [11].

The fire and rescue service's chief acts as an on-scene commander until police personnel arrive at the emergency site. After the police service personnel arrival, police chief acts as an on-scene commander at the emergency site. The on-scene commander duties are to lead the situation and provide his or her decisions to other emergency responders. The responsibilities of the other police responders' are to follow the on-scene commander orders.

However, the medical personnel duties are to aid the injured victims and transport them to the available hospitals. The responsibilities of municipality personnel are to provide information to the media and help to calm down and support emotionally affected victims. All the above mentioned tasks and the roles of emergency responders are clearly defined in their emergency plans and procedures.

In order to perform the above mentioned basic tasks, first-responders need access to relevant information. With the help of this specific case, in the following section we present the information items needed by first-responders which were found through literature review, by participating in fire drills, and finally with semi-structured interviews.

III. Research Methodology

3.1. Data Collection

In this study, the information items were identified in a three-stage process, including a literature review, semi-structured interviews with responders, and fire drill participation.

3.1.1. Literature Review

We used the exact phrase "information needs" OR "information requirements" OR "information demands" AND "first-responders" OR "Fire brigades" AND "Fire protection" OR "Firefighting" OR "fire emergency response" as keywords for an exhaustive search in the ISCRAM, IEEE Explore, Elsevier, Jstor, Scopus and Springer-Link digital libraries to find publications from 1960 to 2016. The keywords that we have used in this study are for giving us a representative overview of the existing literature on information needs/requirements/demands of the first-responders during the fire emergency response.

The results included information needs for different types of emergencies. After eliminating the redundant results, 190 articles remained. To further narrow down the search, we carefully checked if the paper contained information on any of the following four aspects: (1) indoor fire emergency/protection/fighting, (2) search and rescue operation, (3) information needs/requirement/demand of first-responders/fire brigades and (4) ALL (indoor fire emergency, search and rescue operation, and information needs of first-responders). The results are presented in Table A.1.

3.1.2. Interviews

We interviewed three police officials, 15 fire-fighters and two municipality officials. The involved interviewees were from bottom to top level officials. Before the interview, three documents were given to understand the fire departments' search and rescue team division in Norway [13], about firefighters operations in smoke filled or hazardous areas [14], and about police preparedness system [12]. All interviews were audio recorded for later analysis and notes were taken. The audio-recordings were carefully transcribed and analyzed manually after the interview to ensure that all the details revealed during the interviews were taken into consideration for the identification of the information items.

Each interview took approximately 2 hours and many open-ended questions were asked to determine first-responders' data collection methods, used applications, and their information needs as well as difficulties (might be technical and physical) they face in collecting information before/ during the search and rescue operations.

According to [15], the author mention that information which is being exchanged among various emergency responders can affect the overall organizational and network performance during emergency response. Therefore, keeping this point in mind, the authors of this paper wanted to know which information is required and which information is desired to perform better in the search and rescue operation. So, from the semi-structured interviews with the first-responders, the identified information items were derived into two categories "Required information" and "Desired information" for situational awareness. This information categorization was done based on the first-responders' point of view. Here, the "required information" means that this information should be known to the first-responders during the search and rescue operation, whereas, "desired information" means that this information is nice to have.

3.1.3. Observations

The research team also got the chance to observe three fire drills. Basically, fire drill was for one whole day to train their emergency response professionals and to learn from the flaws. From the drills, the research team observed their information sharing methods and information needs of first-responders.

3.1.4. Information Model Development Process

An information model is defined as "a notation by which the structural properties of information from a certain domain can be described in a precise but implementation independent manner" [18]. In the literature, different methods are used to model the concepts and relations formally, e.g., description logics [20], ontology [19], object-oriented modeling [21,22]. As suggested by the following authors [16,23,24], Unified Modeling Language (UML) can be used to build the models. Here, UML is based on object-oriented design concepts and is independent of any specific programming language.

The central notion of the UML is a class diagram in which structural aspects of the information is modeled. So, in this paper, we use Model Driven Approach (MDA), where the UML is a most natural language for the information modeling [17]. The information model is a part of the conceptual design process. The information model focuses on what information should be stored in the information base. Moreover, the information model is used to design relational tables. A sequence of iterative steps is

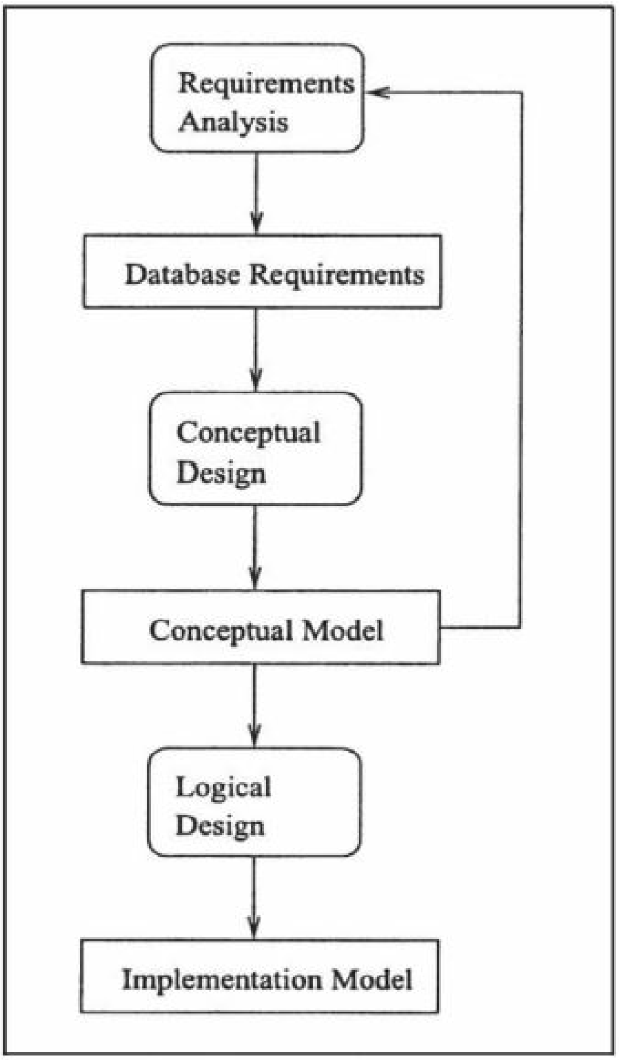

Figure A.1: Conceptual Information Modeling Process ([25])

followed to construct an information model.

Figure A.1 outlines a possible design process, adapted from [25]. The information modeling process consists of three main steps:

- **Requirements Analysis:** In order to build the model, the information model gets its input from the planning and requirement analysis step. First, information should be collected about the requirements of the information base by reviewing existing documentation and interviewing end-users.
- **Conceptual Design:** The use of a conceptual information modeling notation to describe the information identified in requirements analysis.
- **Logical Design:** This step is about the development of an implementation

information structure from the conceptual model such as the creation of a collection of table definitions for use in a relational information base system.

IV. Related Work

Current Search and Rescue (SAR) guidelines for fire emergencies focus on general procedures. However, these SAR guidelines do not characterize the information items needed by first-responders to obtain the overview of the situation [28] [27].

Many frameworks that capture information needs were developed for disaster management, especially for situational awareness during the response phase [11, 26, 34, 35, 37, 39, 40, 46, 48, 54, 55]. Some of these studies focused on improving information sharing and coordination among different first-responders [29–31, 38, 42, 44, 47, 50, 56]. Besides standardizing information items a priori, there are also exploratory approaches that identify information needs at run-time [33, 41]. However, those solutions are mostly suitable for strategic problems.

Few studies provided information items that are needed by first-responders for fire emergency management [2, 3, 19, 32, 36, 40, 51, 57–63]. However, there were no lists or overviews provided of the particular needs of first-responders during search and rescue in an indoor fire.

While there is some generic information needs which are relevant to all kinds of emergencies such as the number of victims and their needs, we here elicit information items exclusively for indoor fire emergencies especially for the university building. During a building fire emergency, first-responders are most likely do not have enough time to collect and analyze all information items. Therefore, prioritization of information items is needed for different stages of building fire emergency response operations [3].

In addition, only few studies in the literature focused on locating both first-responders as well as trapped victims at the building fire emergency scene [39, 53]. Some other studies listed in their work that the information needs of first-responders are occupants' identity information [3, 31, 56, 57, 59, 62–64]. Few other researchers pointed out that the information items related to hazardous goods is necessary during a search and rescue operation [3, 31, 57, 60, 62].

Some researchers mentioned that information related to the building infrastructure is the most needed information item to have for fire emergency response [2, 3, 31, 32, 36, 56–58, 60–64].

Few researchers indicated that fire related information is also a needed information item by first-responders [2, 3, 31, 36, 56, 59–63].

Only few studies have specified that the victims' family information is also an important information item needed by first-responders' of the police service [36, 57].

Occupants'location information	No	No	No	No	No	No	No	Yes	No	No	No	No	No	Yes	Yes
Occupants' medical information	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No
Occupants' family information	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No
Hazardous goods' information	No	No	Yes	Yes	No	No	No	Yes	No	No	Yes	Yes	No	Yes	Yes
Fire related information	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Occupants' identity information	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	No	No	No
Building related information (including Resources' information)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Research Study	[59]	[58]	[57]	[31]	[46]	[56]	[63]	[3]	[19]	[2]	[60]	[62]	[61]	[52]	[51]

Table A.1: Necessary Information Categories and Items Provided in the Literature

A

In addition, trapped victims' medical information is also needed by first-responders while performing search and rescue and is suggested in [62] and trapped victims' location and presence information item was listed in [3].

The identified basic information items from the literature review that are needed by first-responders during a search and rescue operation are listed in Table A.1. The most commonly mentioned information item is building related information, which includes important information about the building layout plans, hazardous material location, resources location, floors, and rooms etc., Furthermore, the other most commonly mentioned information item was fire related information such as color, location and condition of the fire.

V. RESULTS

Based on the results of the literature review, semi-structured interviews and fire drills, information items were identified that are needed for fire search and rescue operation and an information model was developed.

5.1. Identified Information Items

To perform the search and rescue operation (SAR), emergency responders should have an overview of the situation in order to perform the SAR operation. The aim of the SAR is to protect and evacuate the victims, extinguish the fire, prevent the fire from spreading and timely coordination of the available resources on time.

As part of the search and rescue operation, first-responders initially retrieve the emergency plans and procedures that have to be followed at the emergency site. After reaching the emergency site, first-responders gather building map and information related to the university building such as number of floors, number of emergency exists, number of labs, safest route to enter to obtain the overview of the building. This information assists the first-responders to take decisions such as sending their crew from the safest entrances.

After entering the building, first-responders need information about the persons who are inside the university building, and their presence and location. The persons could be students, employees, and visitors. This information helps the first-responders to obtain awareness of the situation. In addition, first-responders also need information related to the fire such as location, size, condition and duration of the fire. The condition of the smoke is a necessary information item required by search and rescue teams. In addition, hazardous goods inside the building related information such as type, amount, and impacts, is also needed to take decisions such

Table A.2: Identified Information Categories and Items

Needed Information Categories	**Detailed Information Items**	**Required /Desired**
University Building Information	- Type of building	R
	- Name of the building block	R
	- Number of exits	R
	- Number of elevators	D
	- Type of labs	D
	- Number of rooms	R
	- Room numbers	D
	- Type of material used	D
	- Accessibility	R
	-Risk areas inside the building	D
	- Building map	R
	- Number of floors	R
	- Year of construction	D
Hazardous Goods Inside the Building	- Amount, Location, Type, and Impacts	D
Information about Occupants	- Count on number of occupants inside the building such as students, employees and visitors	R
	- Occupants' location in specific time periods	D
Occupants' Personal Identification Information	- Full name and Social security number	D
Occupants'Medical Information	- Allergenic, Disabilities, and Pregnancy	D
	- and Asthma	D
Fire Related Information	- Cause of the fire	D
	- Location	R
	- Size	D
	- Duration	R
	- Condition of smoke	R
	- Condition of fire	R
Resource Information Inside the Building	- Location of available fire hoses	D
	- Coverage length	D
	- Floor	D
Occupants' Family Information	- Full name	D
	- Relation	D
	- Mobile number	D
	- Social security number	D
	- Address	D

as secure the area and also rescue the people as soon as possible. Resource information such as fire extinguisher, location of available fire hoses, coverage length, which floor they are in, is also required by first-responders to help them in extinguishing the fire and rescuing people.

If the first-responders were provided with medical information of the students, employees and visitors such as disabled and allergenic to smoke, heat, it would help them to prioritize in the rescuing process. Occupants' identification information such as name and social security number is needed to search and rescue teams as it helps them to recognize the persons after rescuing. Information about victims' family is important for the first-responders to inform in case of any fatalities and injuries. Information about first-responders (who are inside the building to perform search and rescue operations) is vital information during the SAR.

Table A.2 shows the different types of information categories and items needed by first-responders. However, the information categories which are identified and documented in the table represent the semantic aspects of the information. This information is most often available, but in reality the identified information is distributed heterogeneously i.e., stored at different university information systems and can be located inside and outside the building. Therefore, to obtain the needed or relevant information in fraction of seconds, the information which is stored in different systems must be integrated and presented to the first-responders after a fire emergency occurrence.

5.2. Developed Information Model with UML

5.2.1. UML Notation

Figure A.8 shows the developed class diagram of an information model in the Unified Modeling Language (UML). Here, UML describes the structure of the information model by showing the model's classes, their attributes, and the relationships among the classes.

A class is "a description of the attributes, operations and relationships of a set of objects" [18]. For an example, a class is shown in Figure A.2 is: *Fire_Emergency*. Basically, a class is depicted as a rectangle, within which the name of the class is stated.

The Relationship represents an association between two or more classes. A "Generalization" is depicted by a closed headed arrow and is called "a kind of" or an "is a" relationship shown in Figure A.3. Example relationships from the developed

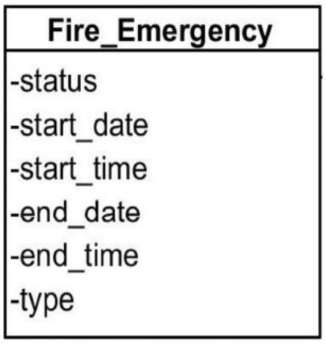

Figure A.2: Class Diagram

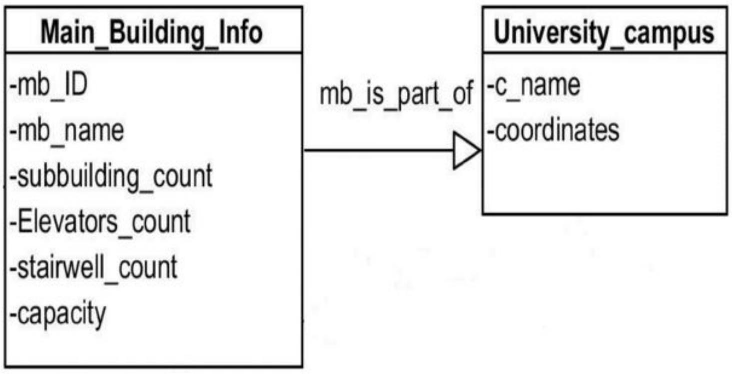

Figure A.3: Generalization Relationship

information model in Figure A.8 are: from the *Main_Building_Info* class to *University_Campus* class. Here, the *University_Campus* class is said to be a super class of the *Main_Building_Info* class, and the *Main_Building_Info* subclass of the *University_Campus*. All the attributes, relationships and operations of a super class are inherited by its subclasses. Relationships (other than the inheritance/generalization relationship) between classes are known as "associations" in UML.

The associations used in our model are: bi-directional, uni-directional, aggregation and composition. For example, in Figure A.4, the class *Fire_Emergency* has uni-directional association with the class Location. Basically, this means that the *Fire_Emergency* and the *Location* classes are related to each other.

In Figure A.5, the *Floor_Info* class has composite association relationship with the *Sub_Building_Info* class. This relationship represents that the class *Floor_Info* cannot stand alone. That means that the class *Floor_Info* is depended on the class *Sub_Building_Info*. In other words, the *Floor_Info* class cannot be existed if the *Sub_Building_Info* class is not existed.

In Figure A.6, the class *Medical_Info* has aggregation association relationship

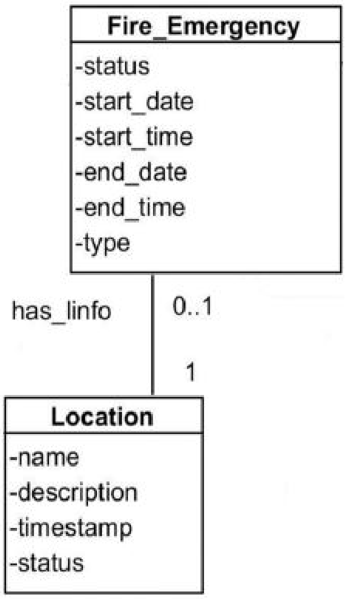

Figure A.4: Uni-directional Association

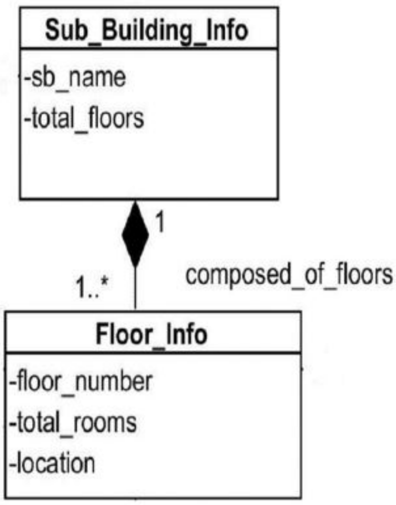

Figure A.5: Composition Association

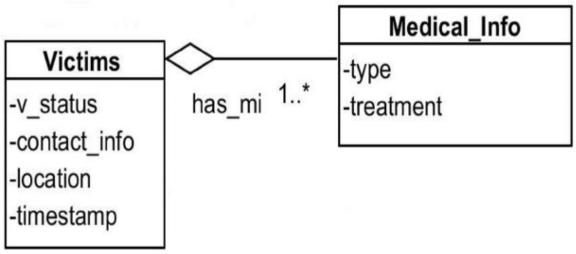

Figure A.6: Aggregation Association

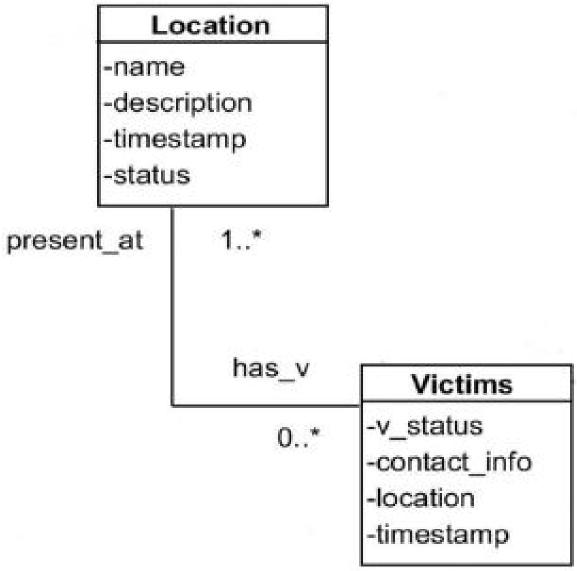

Figure A.7: Bi-directional Association

with the *Victims* class. In this case, the relationship between the *Medical_Info* and the *Victims* classes is represented as that the child class instance i.e., the *Medical_Info* class can exist without its parent class i.e., the *Victims* class.

The class *Victims* has bi–directional association with the *Location* class (see Figure A.7. This relationship between the *Victims* and the *Location* classes represent that the association is navigable from both sides i.e., victims present at a specific location and location has victims.

5.2.2. Developed UML Model for Identified Information Elements

The developed UML model consists of total 21 classes and detailed explanation of each class and their attributes are described below. The class *Fire_emergency* describes the information related to the fire emergency. It consists of the following six attributes: *type, status, start_date, start_time, end_date, and end_time*. These attributes are described as follows.

- *Status:* This is about status of the fire (such as high, low, burning, spreading).
- *Start_date:* The date when the emergency start to occur.
- *Start_time:* The time when the emergency started.
- *End_date:* The date when the emergency is considered over.
- *End_time:* The time when the emergency ended.
- *Type:* This is about type of fire (such as building fire or, tunnel fire or fire in the train and etc.,).

In Figure A.8, the *Fire_emergency* class is associated with the other classes *Fire_info, Mission, Smoke_info, Location, and Victims* and so on. Here, the *Fire_info* class consists of four attributes which are described below.

- *Fire_condition:* This is about condition of the fire such as acute, moderate, and low.
- *Fire_color:* The color of the fire such as: red, orange.
- *Size:*The size of the fire.
- *Cause:* Cause for the fire occurrence.

The *Mission* class is included with two attributes which are described below.

- *Type:* Type of the goal.
- *Required_resource:* The required resource to achieve the goal.

The *Smoke_info* class consists of two attributes which are explained as follows.

- *Smoke_color:* The color of the smoke such as dark, grey, white.
- *Smoke_severity:* The severity of the smoke such as: dense, thin.

The *Victims* class consists of four attributes which are described below.

- *V_status:* The status of the victim such as normal or handicapped.
- *Contact_info:* The victim's contact information.
- *Location:* The location of the victims inside the building.

- *Timestamp*: The timestamp of the victims' location inside the building.

The *Location* class is resided with four attributes which are presented below.

- *Name:* The name of the location.
- *Description:* The description of the location such as south, north, west and east.
- *Timestamp:* The time stamp for the fire emergency and victims' location.
- *L_status:* The location's status such as accessible or blocked.

The *Medical_info* class has two attributes which are presented below.

- *Type:* The type of medical issue.
- *Treatment:*The information related to treating the medical issue.

From our interviews, we got to know from the first-responders that the information items in this class are desired for them to get an overview of the victims' medical condition during search and rescue operation.

The *Fire_location* class includes three attributes, can be seen below.

- *Interval:* The intervening period of time.
- *Timestamp:*The time to reach the location.
- *Status:* The fire status such as high, low, burning, spreading.

The *Person_info* class has attributes *first_name, last_name, address, email and phone_number*. This is a super class to the classes *Victims, Visitor, Student and Employee*. These attributes are presented as follows:

- *First_name:* The first name of the person.
- *Last_name:* The last name of the person.
- *Address:* The address of the person.
- *Email:* The email of the person.
- *Phone_number:*The phone number of a person.

The *Visitor* class has only one attribute which can be seen below: This class represents any visitor who visits university for a short period or for a long period. It means that the first-responders are also represented as visitors in the information model.

- *v_username:* User name of the visitor (both guest and first-responder).

The *Student* class consists of four attributes. All these attributes are explained as below.

- *S_ID:* The student number.
- *Course:* The courses the student got registered to.
- *S_username:* The username of the student.
- *Term:* The term he or she is in.
- *Languages:* Languages the student knows.

The *Employee* class is incorporated with six attributes which can be seen below.

- *Employee_ID:* The employee ID.
- *Employee_username:* Username of the employee.
- *Department:* Department the employee belongs to.
- *Teaching_courses:* Courses the employee teaches.
- *Joined Year:* The employee joined the university.
- *Languages:* Languages the employee knows.

Here, the employee can be considered as either victim or emergency first-responder group. In the university evacuation procedure, it is stated that, each floor of the university buildings has a responsible person (employee) to evacuate the entire floor. So, if the employees are part of the first-responders' group then They are categorized in the respondent group.

The *University_Campus* class has two attributes and this is a super class to *the Main_Building_Info* class. All the attributes are described below.

- *C_name:* The name of the campus.
- *Coordinates:* The coordinates to locate the university campus on the map.

The *Main_Building_Info* class includes six attributes which are described as follows.

- *Mb_ID:* The building identification number.

- *Mb_name:* Name of the main building.
- *Subbuilding_count:* The count of the different buildings inside the main building.
- *Elevator_count:* The information related to the total number of elevators inside the building.
- *Stairwell_count:* The information related to the total number of staircases inside the building.
- *Capacity:* This is about the capacity of the building

The class *Address* is incorporated with seven attributes. This class represents the address of the university campus. All these attributes are described as follows.

- *Street_name:* This is about the name of the street where the fire emergency occurred and the university campus belongs to.
- *Street_number:* This is about the street number of the location where the fire emergency occurred and the university campus belongs to.
- *Postal_code:* Postal code of the location (where the fire emergency occurred and the university campus belongs to).
- *City:* The name of the city (where the fire emergency occurred and the university campus belongs to).
- *District:* The name of the district (where the fire emergency occurred and the university campus belongs to).
- *Region:* The region name (where the fire emergency occurred and the university campus belongs to).
- *County:* The county name (where the fire emergency occurred and the university campus belongs to).

The *Sub_Building_Info* class has two attributes which are presented below.

- *Sb_name:* The name of the sub building.
- *Total_floors:* The total number of floors in the sub building.

The *Floor_Info* class consists of three attributes. These attributes are elucidated below.

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- *Floor_number:* The information related to floor number.
- *Total_rooms:* The total number of rooms inside each floor.
- *Location:* Location of the floor such as east, west, north, south.

The *Room_Info* class has two attributes which are represented as follows.

- *Type:* This is about the type of the room such as big, small and medium.
- *Room_number:* The information related to room number.

The *Inbuilt_Resources_Location* class has three attributes. The detailed description of the attributes is given below.

- *B_ID:* This is about building ID.
- *Coordinates:*The coordinates to locate the resources location.
- *Location:* The location of the resources e.g., beside room 20.

The *Equipment* class has four attributes which are explained below.

- *Name:* The name of the equipment.
- *Type:* The type of the equipment such as smoke detector, fire alarm, sprinkler system, fire extinguisher, fire hose.

The *Dimension* class has three attributes which are described below.

- *Height:* The information related to height of the main building, sub-building, floor, and room.
- *Width:* The information related to width of the main building, sub-building, floor, and room.
- *Length:* The information related to length of the main building, sub-building, floor and room.

VI. Discussion and Conclusions

Emergency response operations demand well information access to support search and rescue tasks and decision-making at the emergency site and at the command and control center as the availability of the needed information is one of the bottlenecks [45]. However, in any kind of emergency response, upon arrival at an emergency

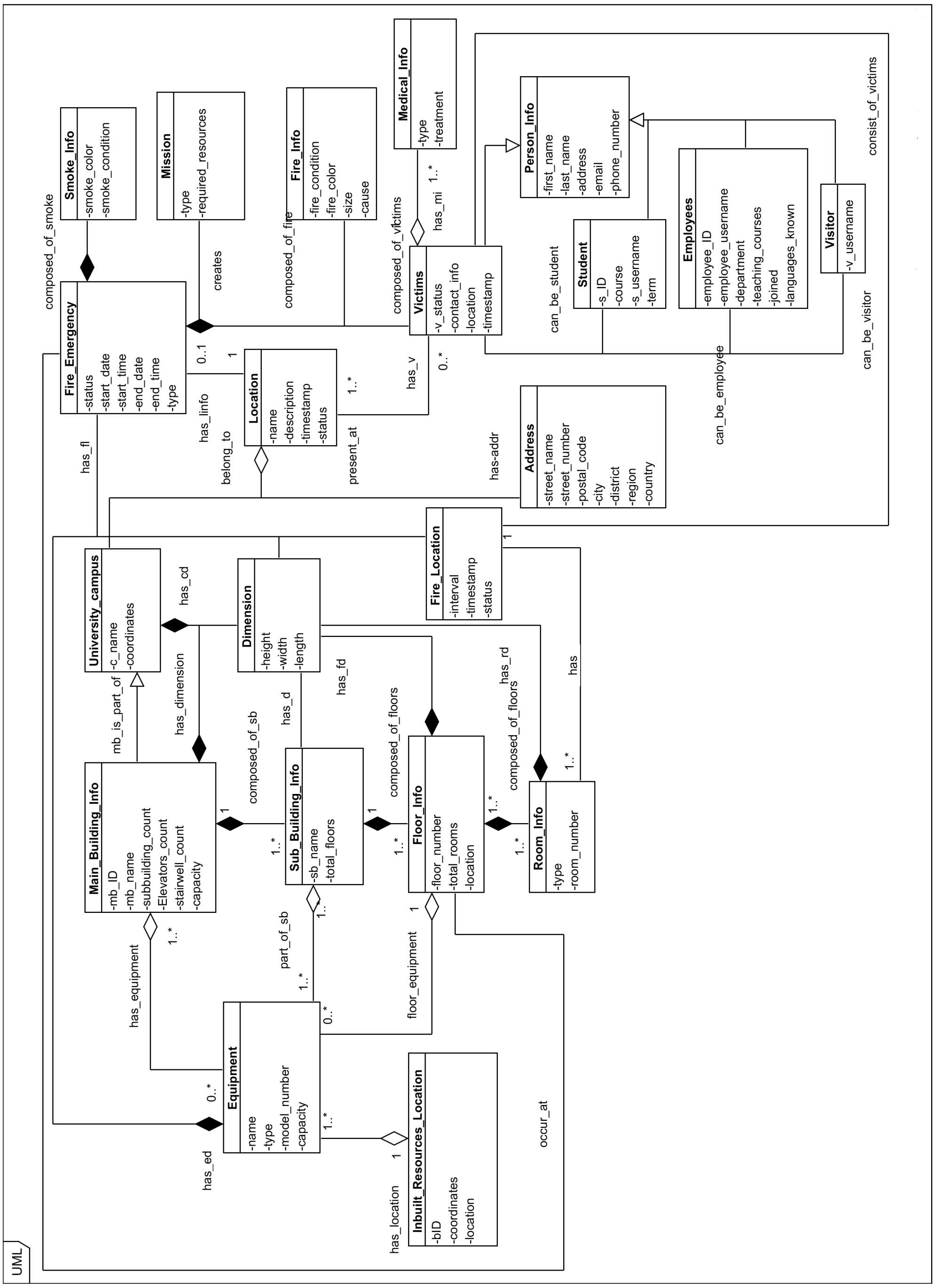

Figure A.8: Unified Modeling Language (UML) Information Model location, first-responders usually use lot of time gathering information to obtain an overview of the situation. The time first-responders spend on gathering static and volatile situational information from affected people as well as from responsible persons at the emergency site can be reduced if they are given with accessibility or availability of the needed information.

This study presents the basic information needs of first-responders that were identified in case of a fire emergency in the educational building. These information needs got identified through a literature review and through semi-structured interviews with emergency organizational first-responders and also by participating in several fire-drills. The findings show that first-responders not only need information related to the educational building but also information related to students and employees. However, the results that are presented in this study not only permitted to fire in the university building, but also can be used to the other kinds of fire emergencies as the identified information categories are similar in all kinds of fire emergencies.

After collecting the information needs, an information model was being developed by using UML. The developed information model was validated by emergency responders' feedback. The main objective of the information model was that information models are considered as a proven technology for many years in numerous software projects for representing the information structures [18]. However, they have not been particularly used with building fire emergency information despite the increasing number and complexity of different information resources. By developing the information model, this paper seeks to increase awareness of the role that information models can play a vital aspect in describing and understanding the structure of building fire emergency information. Moreover, benefit of information model is that it presents the information in a pictorial form and considered as a valuable tool to communicate with the end-users (i.e., first-responders).

The developed information model includes the detailed information items related to a university building, and related to occupants and their medical information. Most of the information incorporated in the information model cannot be readily available and accessed by first-responders to perform search and rescue operation due to technical and physical difficulties. Still, the developed information model reflects the needs and requirements of first-responders during a building fire emergency. Some of the needed information is stored in different university systems' information bases.

Obtaining a clear understanding of the semantics of information which resides in different systems is not always easy. Getting a clear and agreed view of the information in emergency management domain is quiet challenging, as responders

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from different emergency organizations will see the whole emergency situation in different ways, use terminology differently and emphasizes different features. In such circumstances, information models can be helpful in developing, making explicit and communicating clear and detailed descriptions of information that is available or that is about to be produced. Also, to make the information readily available to first-responder on demand is possible, but requires that the information from those different systems is integrated.

Therefore, our future work is to find a way to bringing all the available information systems together based on the developed information model, in order to provide the access to the needed or relevant information to the first-responders during a fire emergency to ease the currently growing problems such as semantic inconsistencies, management and sharing of emergency information (with other responders). After the implementation, the system will be validated by testing it with an indoor fire emergency drill with real emergency responders. Another possible future work is to incorporating GIS technologies like Open Street Maps and Google Maps in the future developing system in order to be used in larger emergencies such as earthquakes and floods to get access to the information for example, damaged area.

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Paper B

B

Title:	Representing Fire Emergency Response Knowledge Through a Domain Modelling Approach
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Representing Fire Emergency Response Knowledge Through a Domain Modelling Approach

Vimala Nunavath, Andreas Prinz, Tina Comes, and Jaziar Radianti

Abstract — **When any kind of emergency occurs, Emergency Responders (ERs) from different emergency organizations (such as police, fire, ambulance, and municipality) have to act concurrently to solve the difficulties which are posed at the emergency site. Moreover, during the immediate response, getting the awareness of the situation is very crucial for ERs to lessen the emergency impacts such as loss of life and damage to the property. However, this can only be done when ERs get access to the information in a timely manner and share the acquired information with each other during an emergency response. Despite ERs share knowledge with each other they have to use same concepts to obtain the semantic understanding in order to perform actions for achieving goals. In addition, the success of the emergency response lies on the ERs' coordination and their interoperability (information systems interoperability). Therefore, in this paper we provide a formal structure to the concepts that describes the building fire emergency management domain in order to provide a common semantic understanding for ERs. In our study, domain modelling approach has been used to represent the concepts formally. The presented results combine the knowledge from semi-structured interviews, document analysis, and through literature review. The developed domain model includes four aspects: i) characteristics of the event, ii) actors involved, iii) goals to achieve, and iv) Building characteristics. Besides, the developed domain model serves as a foundational component to create an information system to unify, facilitate and expedite access to emergency related information for facilitating data exchange format and enable knowledge sharing among different emergency actors.**

Keywords—Domain model, Emergency response, Building fire emergencies, First responders, Search and Rescue operation.

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I. INTRODUCTION

Emergency response is often managed by different emergency responders (ERs) from different emergency organizations such as fire protection service, police service, hospital and ambulance service. These ERs always perform the emergency response operations in teams. The primary goal of these emergency response teams is the protection of people and property. This can only be achieved when the emergency teams get the right information to the right person at the right time to coordinate well and have a common operational picture [25].

During the response, ERs can coordinate well only when they have common understanding of the concepts used in the management of the emergency. If the ERs do not have common semantic understanding of the situation, then the whole emergency situation is misinterpreted [50]. Moreover, emergency situation is dynamic in nature and has to be handled with the support of timely information, which is in fact, is often delayed. In addition, the involved ERs follow their own organization's policies, applications, procedures and documents. The emergency management procedures and tasks might differ from one organization to other. Likewise, the documents that help the ERs to understand their own underlying terminology, concepts and relationships might be uniform from one organization to other. Yet, the involved different ERs use their own applications and data exchange formats. In such a case, ERs get the syntactic understanding, but not semantic understanding. As a result, ERs face difficulty in obtaining a common operational picture [55]. Therefore, a conceptualization of emergency response concepts using domain modeling approach is necessary to solve the semantic conflicts (such as representing the same underlying terminology, concepts and relationships in different ways) that are bound to occur among different emergency organizations in building fire emergency management domain.

Fire emergency management in the public buildings such as universities is an interesting case for the application of the proposed approach. In USA, for example, from 2000 - 2015, 89 fires have occurred on a college campus which killed 126 people. Taking further Norway as an example, the statistics show that out of 5,084 million population [54], 2,83 million people are going to different universities across the nation [53]. Some of the universities are located in small cities such as University of Agder in Grimstad. If we consider this as case, from this 2,83 million population, almost 5000 people are registered as students [21]. As Grimstad is a small town with 22100 population [32], the emergency organizations are also small with 5 to 10 persons capacity. In case of a fire emergency in the campus, this available capacity is not enough and is also not fully prepared for response. In this case, the local emergency organizations ought to take help from the other responders who work in other counties. Misunderstanding due to different terminologies may arise when inter-organization collaboration in emergencies occurs, and the proposed model in this paper can contribute to mitigate comprehension problems due to different terminologies between organizations.

In brief, the objective of this paper is to model the domain concepts (building fire emergency management domain) for ERs so that the same concepts are used by all involved emergency organizations for emergency response. The developed domain model would provide a basis for understanding the emergency response process. Different methods can be used to model the concepts and relations formally, e.g., description logics [20], ontology [8], object-oriented modelling [3,22]. As suggested by [19,31,51], UML can be used to build the domain models. In this paper, we use Unified Modelling Language (UML) to give an overview of the emergency response process by showing its classes and the relations among them. UML is based on object-oriented design concepts and is independent of any specific programming language.

This paper starts with a literature review. In Section 5.4, the methodology for developing the domain model is presented. We then present the developed model in detail in Section 5.4. Section **??** concludes the study with future developments.

II. Meta-modelling background and Methodology

This section will introduce the overall meta-model and ontology principles and provide an overview of existing crisis/emergency/disaster management meta-models and ontologies.

2.1. Meta-modelling and ontology

Research on meta-models and ontologies development has tremendously increased over the past decades. According to [48], a meta-model serves as a representational layer of domain expertise. Whereas, Stephen [43] describes a model consists of sets of elements that describe some physical , abstract or hypothetical reality. That means that a model is a simplified representation of a certain reality [33]. A model is captured by a particular meta-model. A meta-model is simply a model of a model. It defines the structure, semantics, and constraints for a family of models, which shares common syntax and semantics. As claimed by [17], "*A meta-model is a model of a model which captures a particular domain's essential properties and a list of relevant relationships between these concepts. These include the concepts it supports, its textual and/or graphical syntax and its semantics*".

Ontology is considered as a specification mechanism to formal representation of the knowledge based on the concepts for a domain of interest. A conceptualization is represented as an abstract notion which contains domain and a set of relevant relations on the domain [36]. Ontology defines "*the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary*" [18]. There are other types of ontologies that are identified to fulfill different roles in the process of building information systems. They are [1, 27]:

- *Domain ontologies:* They model the content of the information sources.
- *Meta data ontologies:* These ontologies encapsulate the concepts for describing the content of a specific domain. These are equivalent to meta-model of a modelling language.
- *Generic or common sense ontologies:* The purpose of these ontologies is to capture general knowledge about the domain. These can be valid across several domains.
- *Representational ontologies:* These ontologies are not valid to any particular domain. Such ontologies provide representational entities without stating what should be represented.
- *Method or Task ontologies:* These are the ontologies which provide term specific for particular tasks. These ontologies provide a reasoning point of view on the domain knowledge.
- *Information ontologies:* They describe the different kinds of information sources, their structure, format properties.

2.2. Crisis/Emergency/Disaster Meta-models and Ontologies

In the literature, a lot of meta-models and ontologies have been developed in order to define the concepts and their relationships for improving the information interoperability across emergency responders' functions within the emergency response domain. However, the developed information models (Frameworks.) are restricted either to one organization [39] or to a specific case [6] [14, 16, 41, 52, 60, 61] or to a specific goal [25, 47] or to a specific purpose [7, 42, 59].

In [30], the W3C Emergency Information model represents the concepts and relationships that define an overall context for sharing of coordination information in an emergency. The model uses the scenario "Who (organizations or people)" does "What (activity)", "Where" as a basis to derive high-level concepts and relationships. This is developed based on data schema from existing emergency information systems. They did not look into "When and How". In [41], they have reused the W3C Emergency Information model by adding "When" for developing an information system.

Zlatanova [62] used formal modelling in her work to model the tasks to support geo-information in emergency response in order to give deep understanding about the spatial data structures and corresponding terminology to the emergency experts. In the work [23, 25], Dilo and Zlatanova developed a data model to capture and manage both operational and situational information along with spatial data structures in emergency response, but not mentioned or included in the model about the required resources for the emergency management.

Onorati [47] has developed an ontology named SEMA4A ontology to for managing knowledge about accessibility and evacuation guidelines during emergency situations. The main classes of the ontology include "Evacuation, Location, Personnel, Procedure and Transportation". Chen [16] has developed a data model for fire emergency response. This data model is applied only to fire emergencies. In [2], a geo-data model was developed to specify the components to determine the application schemas of geo-data themes and to harmonize geo-data to enable semantic interoperability. In this model, the authors focus on spatial data structures, but on the emergency actors and their tasks.

In [4], a ontology was developed to model the emergency management domain. In this model, the authors included incident classification, agents, roles and profiles, geographical objects, map symbols, time, space, resources, infrastructure, spatial point objects, communication objects, activities (task and movement), but not the severity or emergency impacts and escalation. Barros along with other researchers [8] developed an EDXL-RESCUER ontology for semantic integration. The developed model uses EDXL (Emergency Data Exchange Language) to model the coordinating and exchanging of information with legacy systems. The concepts included in the model were alert, info, resource, incident, response type, area, category, message type, status, and scope. In this model the authors mainly focused on alerting the people. This model however, does not cover the time and spatial information.

Bitencourt [14] developed an ontology for emergency response protocols, in particular, to fires in buildings. The developed ontology supports the knowledge sharing, evaluation and review of the protocols used, contributing to the tactical and strategic planning of organizations. This model however is restricted only to fire emergency and not applied to other emergencies. In this work [15] a ontology was developed which is called DIRES. It was developed to describe emergency situations and the key factors that are associated with response activities to the incident. It also defines terms related to scenario, people and organization and others.

Babitski [5] developed a ontology called SoKNOS, which includes resource planning, damages and geo-sensor information. In [9], a meta model called ISyCri was developed to conceptualize the crisis coordination. The developed model includes categories of entities affected by crises, the treatment system, and the crisis description. Othman and Hassan [49] developed a meta model for each phase of the disaster management domain to define the concepts and to serve as a representational layer of the disaster management expertise. The classes that exist in the meta-model were: Event, Organization, Procedure, Requirement, Policy, Actor, ElementsAtRisk, Team, Domain Knowledge, Resource, ActorRole and MessageCommunication. However, this model did not cover the “Where” aspect of the emergency.

In [39, 44], an ontology was developed for emergency shared situational awareness. The main components of the model were: Event, Mission, Resource, Context and Actor. In this model only “What” and “Who” were included, but not “When, Where and How” of the W3Consortium [30]. In their seminal work, Jihan, Satria and Aviv [38] developed a Context Ontology for Humanitarian Assistance in Crisis Response. This context ontology was included with two parts: global ontology and local ontology. The classes in the global ontology were: crisis identification, place, crisis need. The classes in the local ontology were: Event, actor, time, impact and place. Fan and Zlatanova [26] proposed a model to explore the semantic interoperability of the terms and spatial information to be used by different emergency response organizations. The proposed model was consisted of dynamic data ontology for assisting responders in decision making.

In our work, we reuse the existing information models from the previous work and at the same time extend the existing models with our new findings.

III. Research methods

3.1. Meta-model Engineering

Basically, a series of approaches/methodologies have been reported and suggested for building meta-models in the literature [11, 18, 27, 28, 35, 37, 40, 45, 56–58]. According to [18], a domain model can be build either from scratch or by reusing the existing knowledge (models). In this paper, we build our own domain model by considering the existing knowledge and models.

Uschold and Kings's method [57] for building meta-model contains four activities: (1) identifying the purpose of the ontology, (2) building it, (3) evaluating it, and (4) finally documenting it. Authors [37] propose a methodology for development of knowledge-based systems using first order logic. In the work [40], the methodology used for building the ontology consists of three phases. The first phase consists of the manual codification of articles and pieces of knowledge. The second and third phases consist of acquiring new common sense knowledge using natural language or machine learning tools.

The methodology used by the authors [34] for building ontology is METHONTOLOGY. As defined by [29] Methontology is a well-structured methodology to build ontologies from scratch. This method is developed within the ontology group at Technical University of Madrid. This methodology highly recommends the use of existing models. It consists of 6 tasks [29] and being used in our work. The tasks are:

- *Build a requirements specification document:* Getting the knowledge about the scope of the ontology, intended uses, level of formality, and intended end users.
- *Acquire knowledge:* Knowing the sources of knowledge from which the knowledge can he elucidated using in conjunction techniques such as: brainstorming, interviews, formal and informal analysis of texts, and knowledge acquisition tools.
- *Conceptualize the meta-model:* In this phase, structuring the domain knowledge in a conceptual model that describes the problem and its solution in terms of the domain vocabulary identified in the ontology specification activity. Conceptual model consists of domain concepts, their meanings, attributes, and instances.
- *Implement the meta-model:* In this phase, the ontology is codified into a formal language.
- *Evaluate during each phase:* Evaluation means to carry out a technical judgment of the ontologies, their software environment and documentation with respect to a frame of reference (in our case the requirements specification document) during each phase and between phases of their life cycle.
- *Documentation after each phase:* Documenting after each phase of the ontology development.

This methodology includes several techniques, methods and guidelines, particularly for the domain model building. To solve the semantic inconsistencies, we have used document analysis, semi-structured interviews and targeted literature survey. In the following section, we implement the METHONTOLOGY methodology in order to build a relevant domain model for Building Fire Emergency Response (BFER).

3.2. Data collection Approach

To build domain model, first, an indoor fire emergency scenario was designed. This scenario was used to collect the data related to fire emergency management domain concepts and the relation between them through semi-structured interviews. Semi-structured interviews were conducted with several emergency responders who were from different emergency organizations. Before the interviews, documents related to different emergency response organizations were given to understand the domain, emergency plans and emergency procedures to mitigate the emergency. During the interviews, the research team got to know about the concepts related to fire emergency management procedure, required information, used terminology and applications, involved actors, and characteristics of the emergency.

Similar to [10, 12, 13], we have manually extracted concepts from all existing meta-models and ontologies. From existing meta-models and ontologies, a careful examination was done to identify the potential concepts that are required in our BFER domain model.

IV. Fire Emergency Response Meta Model Building

In this study, the data exchange agreements such as on concepts, their properties, terminology and relations in the fire emergency management domain among different emergency organizational responders can be structured and formalized as "*domain ontologies*". Therefore, the contribution in this paper lies in developing a domain model of building fire emergency management domain to facilitate the process agreement on data exchange by representing the concepts, terminology and relations between them. This domain model will provide a common basis for understanding the general behavior of information sharing among ERs.

4.1. Build a requirements specification document

In order to build the BFER domain model, we provide in this section the key factors of the model such as required terminology, intended uses and users.

In any fire emergency, there is a diversity of emergency responders from different organizations coordinate together to manage the emergency efficiently [46]. These emergency responders are distributed geographically at the emergency site for better handling of emergency. However, these emergency responders have different roles to perform, different tasks to handle, and different modes to communicate, which would lead to provide insufficient view of the complete emergency situation at the emergency site.

Mismatch on perceived emergency pictures among organizations and fragmented knowledge can be bridged by building a shared knowledge-management system, based on the representation and the characterization of a BFER. As discussed previously, in this context, the domain model should be able to tackle the problem of revealing and sharing the implicit and explicit BFER knowledge. A dedicated domain model can be considered as an unavoidable first step to manage the design of information systems contributed to this field. As discussed in the background section above, there is no fully satisfactory model available in the current literature.

4.2. Acquiring Knowledge

Based on our interviews with first responders from different emergency response organizations and literature review, we have identified two main categories that have to be considered in our domain model:

- Involved stakeholders
- Needed information and flows for achieving efficient response.

The Stakeholders: As mentioned in the previous sections, fire emergency is managed by different emergency responders from different emergency organizations. These resources will be divided into responders who work at the emergency on-site, and at the command and control center. The responders who work on-site receive information and support from the command center responders. Unfortunately, in emergency situation, information collection at the emergency site is gathered manually. The gathered information is needed for different purposes and is stored in each respective emergency organizational database, in different format. When the information is stored in own organizational databases, it is not available to other emergency organizations as each organizational responders use their own information system. As a result, the responders face a lot of difficulties in getting the overview of the situation, while they have to perform several tasks simultaneously. Therefore, the domain model is considered as the prerequisite for building a shared knowledge management system.

Needed Information and Flows: When fire emergency occurs at any type of building, the first information the first responders look for is total number of occupants inside the building. And then, they will further collect fire related information such as fire location, severity, start time and date and building related information such as access to the building, location of the building, route to the building and other necessary information to save the victims. Usually all this information is shared with other responders either face to face or through hand-held devices. The information is flown in two ways: top-down and bottom-up to get the global view of the situation, however, is poorly structured and managed.

4.3. Conceptualize the domain model

The developed domain model consists of four components (event, objective, actor and building) and is shown in Figure B.1. The detailed description of components is given below.

- *Event Component:* It contains components and characteristics of the event.
- *Objective Component:* It is about the missions to achieve, which have to be managed by the emergency responders.
- *Actor Component:* This is about involved people, material, tasks, required resources.
- *Building Component:* This includes components and characteristics of the building.

The detailed description of each component is given in Figure B.1 below.

Event Component: The event component includes all the elements related to the emergency elements that permit to describe the building fire emergency characteristics and the links between them, which can be seen in Figure B.2.

- *Fire Emergency:* Any emergency related to fire.
- *Emergency severity:* The degree of severity or scale of the fire.
- *Emergency cause:* The cause of the emergency.
- *Emergency start time:* The time when the emergency started.

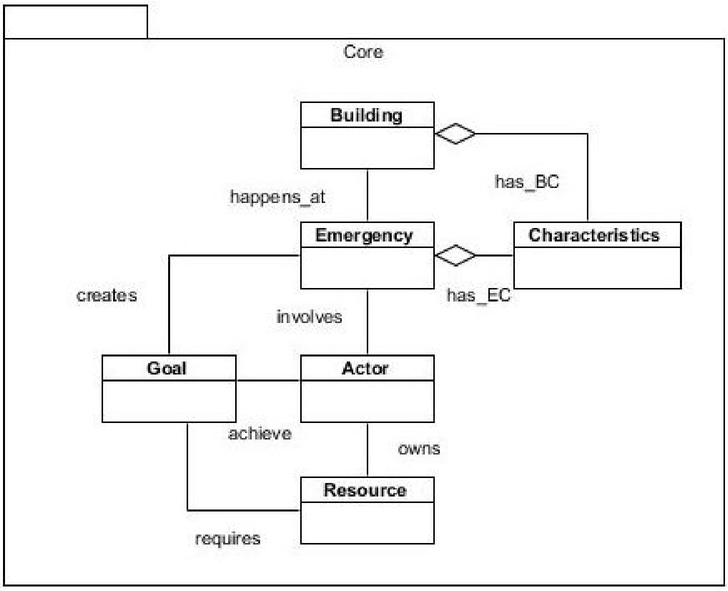

Figure B.1: Different Components in the Domain Model

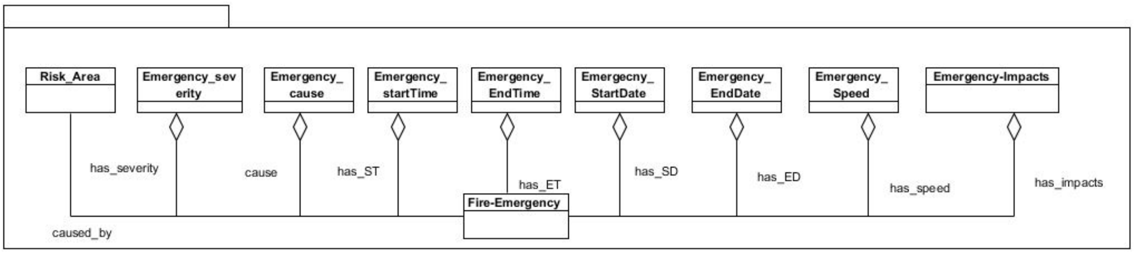

Figure B.2: Event Component

- *Emergency end time:* The time when the emergency ended.
- *Risk Area:* The information related to areas inside or outside the building that are considered risky or vulnerable when fire emergency occurs.
- *Emergency speed:* The escalation of the emergency speed (ultra-fast, fast, slow)
- *Emergency start date:* The date when the emergency start to occur.
- *Emergency end date:* The date when the emergency is considered over.
- *Emergency impacts:* The information related to emergency impacts such as damages due to fire emergency.

Actor Component: This component incorporates all the elements that specify the responders' properties (role, task, team, resources, status, etc.), which can be seen in Figure B.3.

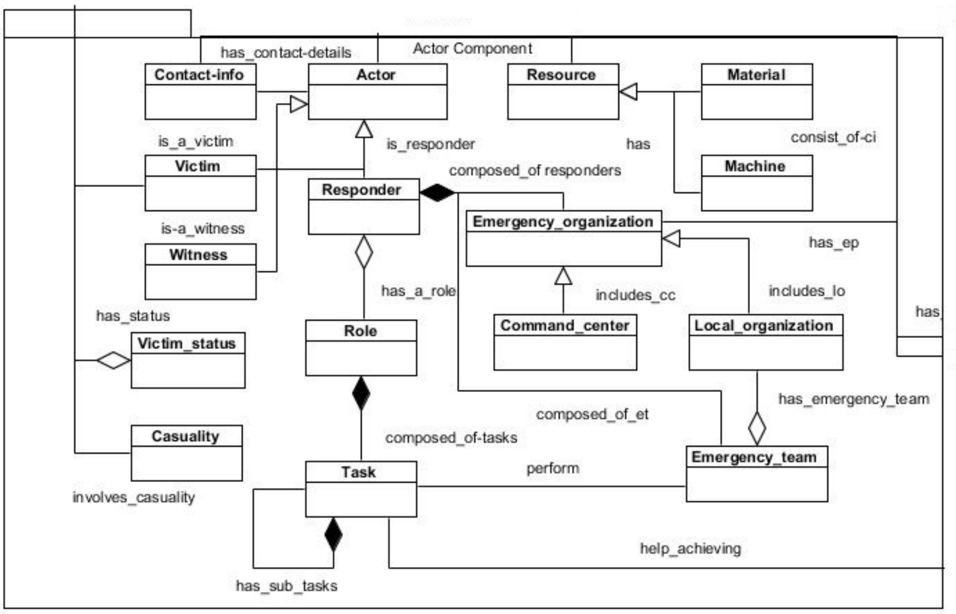

Figure B.3: Actor Component

- *Actor:* Any actor involved in the fire emergency (e.g., firefighters, policemen, municipality staff, ambulance personnel, causality, and witness).

- *Role:* The role performed by the actor in the emergency setting (on-scene commander, smoke divers, smoke leaders, crew manager).

- *Task:* Task performed by the actor (search, evacuate, transportation, treating victims, investigation, firefighting).

- *Emergency organization:* Any organization that should be involved in managing emergency situations (fire protection services, police services, hospital services, and municipality services).

- *Command center:* Command center belong to any emergency organization (fire command and control center, police command and control center, hospital command and control center).

- *Local organization:* Any local organization (local fire department, local police department, local municipality, and local ambulance services).

- *Emergency team:* Team belongs to any emergency organization (fire team, police team, ambulance team and municipality team).

- *Resource:* Any additional, non-information resource needed for achieving the life-saving objectives i.e., machine (trucks, equipment, and etc.), and material (documents related to emergency plans and procedures).

- *Contact info:* Contact information of the involved actors.

- *Victim status:* Status of the victim (injured, dead, unconscious).

Objective Component: This component contains the information related to the goals to fulfill based on the procedure and alternative plans by emergency responders even if the responders face any obstructions from the weather conditions, which can be seen in Figure B.4.

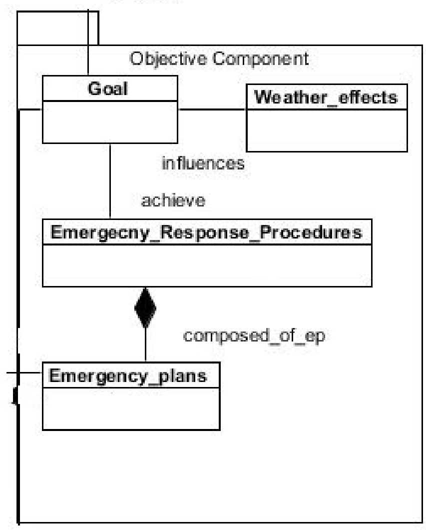

Figure B.4: Objectives Component

- *Goal:* Objectives that are formulated and prioritized after the emergency occurs and need to be achieved by the responders during the emergency handling (sheltering, protection, preventing fire, treat injured, mitigation, safety).

- *Emergency response procedure:* Emergency procedures followed by the actors to achieve goals.

- *Emergency plans:* Any plans followed by actors to achieve their goals.

- *Weather effects:* Any environmental conditions which influences the actors' capability for achieving their goals.

Building Component: The building component depicts the information related to the characteristics of the building and link between them, which can be seen in Figure B.1.

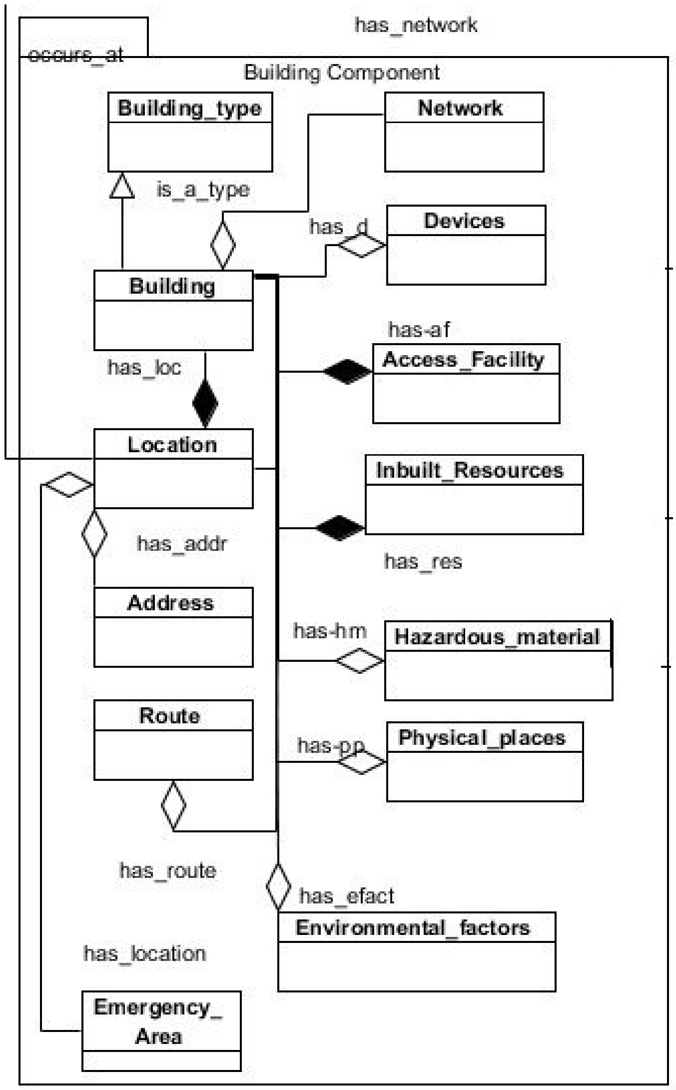

Figure B.5: Building Component

- *Building:* Any building where the fire emergency occurs.
- *Building type:* The type of the building that got involved in the emergency.
- *Network:* Wireless network inside the building.
- *Access facility:* Any access facility is the element that has type of access to the building (such as doors, windows).
- *Devices:* Any devices (e.g., sensor devices) that are inside the building.

- *Inbuilt Resources:* Any resources that are inside the building (e.g., fire hydrants, fire hoses, fire extinguishers).
- *Hazardous material:* Any hazardous material (e.g., chemicals, gasoline, etc.) that are inside the building.
- *Physical places:* Any place where the elevators are located. Factors: any factors that influences the fire inside the building (such as wind, moisture).
- *Emergency Area:* Any fire emergency area inside the building.
- *Location:* Location of the building where fire emergency occurred.
- *Address:* The street address of the building where the emergency occurred.
- *Route:* Possible route to reach the building where the emergency occurred.

On Figure B.6, a big picture of the developed domain model is shown.

VI. Conclusions And Future work

In this paper, a Building Fire Emergency Response (BFER) domain model has been proposed and developed to facilitate to structure and to integrate the knowledge that can be used in fire emergency response search and rescue operations inside the building. The model is drawn from extensive literature review in combination with the interview with emergency organizations. The domain model is conceptualized and composed into four components: Event component, Actor component, Objective component and Building component. Each component contains several different elements and all components capture the complete building fire emergency response. The design of the model was done through domain modeling approach. The main contribution of the developed domain model is that it is more comprehensive and aims specifically to design the information system.

Future work: The current BFER domain model is an attempt to describe and integrate the concept related to building fire emergency response. Moreover, this gives a static view of the BFER. By implementing it, we can obtain a “picture” of the BFER as observed in a given moment. As a future work we want to consider this model to build an information system which can facilitate the data exchange between the different emergency response actors, and hence improved fire emergency response operations in case of building fire. Another possible work will be introducing actors’ behavior component to the developed domain model to define the operational processes that the BFER actors do to achieve the goals in a given context.

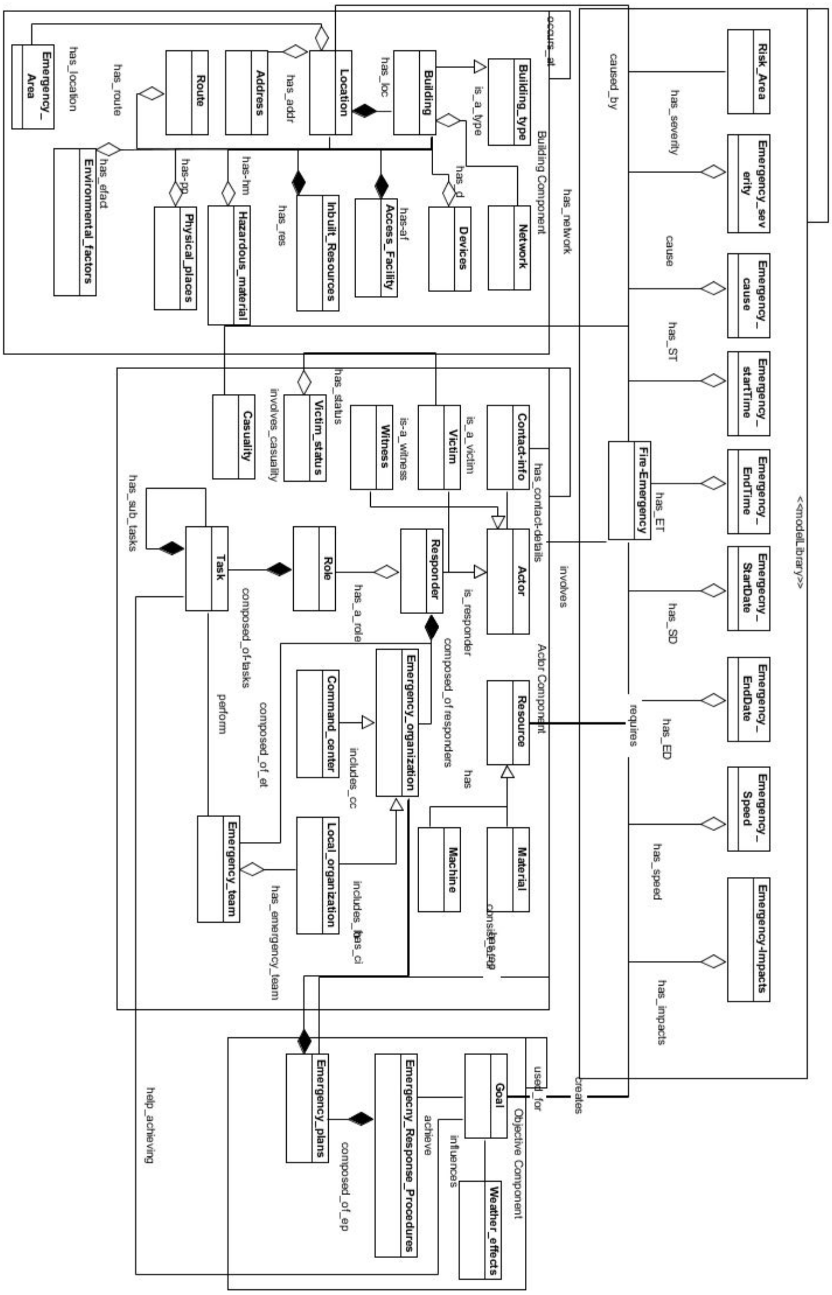

Figure B.6: A Building Fire Emergency Response Domain Model

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Paper C

Title:	Data Sources Handling for Emergency Management: Supporting Information Availability and Accessibility for Emergency Responders
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Data Sources Handling for Emergency Management: Supporting Information Availability and Accessibility for Emergency Responders

Vimala Nunavath and Andreas Prinz

***Abstract* — Information is an essential component for better emergency response. Although a lot of information being available at various places during any kind of emergency, many emergency responders (ERs) use only a limited amount of the available information. The reason for this is that the available information heterogeneously distributed, in different formats, and ERs are unable to get access to the relevant information. Moreover, without having access to the needed information, many emergency responders are not able to obtain a sufficient understanding of the emergency situation. Consequently, a lot of time is being used to search for the needed information and poor decisions may be made. Therefore, in this paper, our research focuses on bringing the available heterogeneously dispersed information together to improve the information accessibility for ERs. In this study, we present an approach for integration of heterogeneous databases in the Semantic Web context using a mediator-based approach based on an information model. We propose an architecture using the Enterprise Services Bus (ESB) and web service technologies for facilitating knowledge sharing and data exchange between different ERs. Based on the proposed architecture, we developed a system prototype and presented it with an indoor fire emergency response scenario**.

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Keywords—Indoor Fire Emergency, Mediator-driven Data Integration, Information Accessibility, Situational Awareness, Information Exchange, Mule ESB, Enterprise-Service-Bus (ESB), Data Mapping, Service-Oriented Architecture (SOA), Human-Centered Design (HCD), Model-driven Architecture (MDA).

I. Introduction

Recently, many countries have been impacted by various natural and man-made disasters which caused immense damage [1]. If we consider fire emergency, it has become one of the major challenges in today's world that causes loss of lives and devastating impacts on infrastructures and economies. In 2014, all over the world, almost 28 million fire emergencies occurred with a total of 21000 fatalities and losses of 110 billion US$ worldwide [2]. According to the Center of Fire Statistics of CTIF report [2], the second largest fire emergency occurrence type is in structures i.e., in buildings. If we consider Norway as a case, the fire statistics for the year 2015 shows that, in total, 2717 building fire emergencies were occurred and caused 35 fatalities [3]. Almost four billion NOK economic damage were paid for the year 2014 [4].

Generally, to mitigate the emergency impacts and damages, a complex network of emergency responders (ERs) from different emergency response organizations (EROs) such as fire and rescue service, police service, health care service, and municipality personnel work together in teams for managing emergency efficiently. During emergency response, these involved ERs collaborate and coordinate by share right information to the right person at the right time to obtain a common operational picture, to make decisions, and to perform tasks such as protecting the life of the people, reducing the property damage, extinguishing the fire, rerouting the traffic, aiding victims, transporting the victims to nearest hospitals, supporting emotionally affected victims at the operational level [5, 6]. The example information that is exchanged among different ERs could be victim information, information about location and condition of the victim, resource information, building information, information about hazardous goods inside the building and information about victims' medical condition and so on. However, one of the key challenges faced by involved ERs is often lacking adequate information [7].

According to the Utøya incident report [8] and Statens Havarikommisjon for Transport report [9], one of the key challenges for the involved ERs during the Utøya disaster and fire in the Gudvangatunnel was not having access to the adequate information. Consequently, 77 fatalities occurred in Utøya disaster and 23 were seriously injured, while 5 were severely injured due to smoke in the Gudvangatunnel emergency. So, from both these reports it is evident that ERs did not access appropriate information in a timely manner. As a result, the information flows were broken down and it was difficult to make timely decisions during emergency response [1, 9].

Another challenge that ERs encounter is that even though the needed emergency related data is available, it is difficult for ERs to access it as the data is heterogeneous and distributed at various places [10]. However, to solve this problem, a data integration framework was proposed by authors of this paper and can be sound in [11]. In addition, another challenge is that misunderstanding between ERs is caused due to semantic differences of distributed data [12, 13]. Moreover, the involved ERs do not use common terminology for representing same thing. This semantic inconsistency data make ERs' decision making process slow, thereby, results in inefficient emergency management. However, to solve the semantic inconsistency problem, an information model was developed by authors of this paper and can be found in [14]. Apart from them, in this paper, we focus on the process of connecting existing data sources with the developed information model. So, the research question is formulated as: "*How to connect the existing data sources with the developed information model?*".

The purpose of addressing this research question is to provide a holistic way for improving access to the needed/relevant information for enabling the data exchange and knowledge sharing among different emergency responders who are at both on-site and off-site i.e., at Control and Command Center. The rest of the paper is organized as follows. Section 2 presents background for the emergency management operations and information access challenges, current ICT tools that are in use in Norway. Section 3 presents the proposed framework for understanding the data source handling process, and section 4 presents the results of data source handling development and implementation. Literature review and the results are discussed in section 5. Finally, conclusion part summarizes the lessons learned from this research and discusses directions for future research in Section 6.

II. Data Integration for Emergency management

In this section background to emergency response operations and existing ICT tools that are used by ERs in Norway is presented. After that, we discuss the challenges that ERs face during emergency response. In this paper, information needs of involved ERs who are at the emergency site are handled.

2.1. Emergency Management Operations in Norway

As mentioned in earlier paragraphs, when emergency occurs, lot of information is generated at diverse sources. Despite the rapid development of Information and Communication Technology (ICT), the data is manually collected by the ERs at the emergency site [6, 15].

To deal with emergency, at first, one Crew Manager (CM) and two Smoke Divers (SDs) from the fire and rescue service go to the emergency site immediately after receiving the emergency fire alarm or call from either the Command and Control Center (110) or from the emergency location. After reaching the site, they evaluate the situation by collecting the information manually from those who are at the emergency scene (either from victims or from witnesses or from the owner of the place). The collected information could be about number of people, fire location, fire cause, access routes, building map, hazardous goods and so on. This manually collected information is then passed to the fire chief with a hand-held device such as either mobile or walkie-talkie to make him obtain the overview of the situation and to make decisions. The CM acts as an On-Scene Commander (OSC) until the Fire Chief (FC) arrives at the emergency site. The FC arrives at the emergency location only if he thinks that the emergency is not minimal and will create major impact.

When the FC arrives at the emergency site he/she takes over the OSC responsibilities from the CM and acts as an OSC until ERs from police services and ambulance services arrive to the scene. However, in the Agder region of Norway, all EROs are so far using their own customized information systems [16]. So, collected information is manually documented first on a paper and then in a Microsoft word document by fire personnel. This electronic report is called a situational report which is stored in their information systems. This report is accessible only internally and not available for other emergency organizations. When police staff arrives at the emergency site, leader of the police takes over the OSC responsibilities from the FC and acts as an OSC. The OSC makes all the decisions at the emergency site and guides other EROs such as fire and protection services, ambulance services, and municipality staff. A conceptual model of data exchange and knowledge sharing among different ERs is shown clearly in Figure C.1.

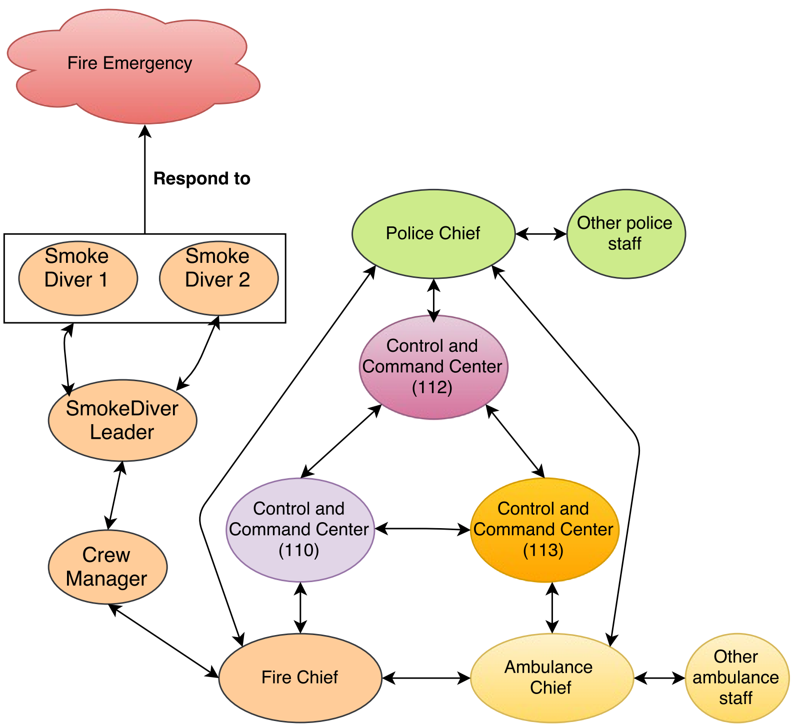

Figure C.1: A Conceptual Model of the Emergency Organizational Partners' Information Communications

The tasks of each organization are documented in Table C.1. In addition, based on

Table C.1: Involved Emergency Organizations and their Tasks during the Fire Emergency Response

Emergency Organization	Tasks at emergency site
Fire Protection Service	- Extinguishing the fires - Saving lives, averting danger and limiting damage. - Evacuating victims from the buildings
Police Service	- Saving lives, averting danger and limiting damage. - Maintain peace, order and security on site - Assist with salvage of cargo so far, the service and circumstances warrant. - Issue death notification of accidents, Disasters and criminal acts. - Register fatalities, injured and missing. - Investigation. - Distributing information with media and others.
Health-care Service	- Provide first-aid. - Transporting victims to health centers.
Municipality Personnel	- Noting down the details of incoming victims - Informing details about saved victims to police.

the fire and rescue protection report [17] and police services book [18] the conceptual model (Figure C.1) for various ERs information communication is formulated. In this conceptual model, the data exchange and knowledge sharing among ERs of each individual organization is being sketched. Information communication between ERs of each emergency organization may have similar characteristics and requirements and the shown information flows, however, are bidirectional. When the OSC commander receives information such as fire and victims' information from the FC and victim transportation information from ambulance service chief, he or she notes downs this information manually and shares that information with other operational staff and Control and Command Center (CC) personnel (112). When the CC staff receive this information, he or she manually stores the received information in their information systems in the form of a Microsoft word document. This document will be available and accessible only internally.

A similar information storage process is done by the health care (113) and municipality staff as well. Despite each emergency organization being equipped with advanced information technologies to support their emergency response activities, the stored information is not accessed by other EROs. Due to this limitation, ERs often have out-of-date information. In such case, they cannot make right decisions and cannot manage the emergency efficiently. In addition, lack of sufficient on-site information for the ERs might be due to not upgrading the off-site information systems as well.

In Norway, different ERs from police, health and fire services use different terminology for representing the same words (semantic heterogeneity), thereby creating uncertainties in collaboration and communication [19]. In addition, due to syntactic, schematic heterogeneity, the involved ERs face challenges at emergency site. Moreover, large amounts of information from various ERs make it difficult to orient themselves during emergency response. Therefore, information must be provided quickly, actively and periodically, to ensure that everyone takes accurate and relevant information, thereby enhancing the emergency management operations effectively. This can be achieved only by enabling the semantic, syntactic and schematic interoperability between different systems.

2.2. ICT solutions used by Emergency Responders in Norway

In Norway, the following ICT systems are mainly have been used for emergency management. Those ICT systems are: 1) A crisis incident management (CIM) tool used by the police and municipality staff, 2) LOCUS used by the fire and rescue service, and the health service, 3) BRIS used by the fire and rescue service, and 4) VISION BOSS used by the fire and rescue service.

- **CIM:** It is a software program for crisis management support, produced by One Voice AS, a company delivering crisis management solutions for a variety of organizations. It supports aspects of crisis management such as quality assurance, risk and vulnerability analyses, emergency planning, training, and evaluation. The purpose of this tool is to notify police personnel when major incidents occur. It supports notification and alerting of personnel through distribution lists for sending messages by email, SMS, and phone. The system provides the receiver with several response alternatives which are logged, so that the sender of a message can keep track on the status of each alerted individual [20, 21]. It is currently used by many organizations that the police collaborate closely with, among others, the Directorate for Civil Protection and

Emergency Planning (DSB), The Norwegian Civil Defense, and all Norwegian municipalities and county governors.

- **LOCUS:** It is a company delivering mission-critical solutions and products to the fire and rescue service as well as to the health service, among others (e.g. transport and logistics, security service companies). The solutions are designed to reduce time constraints through being a tool for the emergency agencies to make the right decisions in relation to resource allocation. The LOCUS' solutions are directed to-wards use by the 110 and 113 emergency call centrals (TransFire for the fire and rescue service and TransMed for the health service) and mobile devices installed in vehicles for the tactical personnel (TransMobile 7). The detailed information about the solutions can be found in [21].

- **BRIS:** It is a reporting system with an overview of the missions that the fire and rescue handle. All assignments that got recorded in 110 control project management tool are automatically transferred to the BRIS. This facilitates the reporting of employees of fire and rescue services. The data collected via the BRIS, should provide a better basis for carrying out preventative work, and to develop fire and rescue service at local, regional and national levels. This tool is mainly used during emergency recovery [22].

- **VISION BOSS:** It is a project management tool which is used by the 110 opera-tors for creating incident reports. These reports are made available both during and after an emergency event. This tool also includes crew-lists with contact details and their competence information. It also contains information about resources such as vehicles and equipment content [23].

The drawbacks of these above-mentioned ICT tools are that they do not give automatic real-time information from the emergency site to provide awareness of the situation. They do not support the ERs who are facing operational problems in accessing information from various sources. So, the vision of a common emergency response system with common terminology available for all emergency stakeholders in Norway is still not available [16]. Therefore, in this work we proposed a data integration framework and implemented a prototype to realize efficient timely information access.

III. A PROPOSED DATA INTEGRATION FRAMEWORK

Before proposing and developing any kind of information system, as per the Human-Centered Design (HCD) approach [24], it is necessary to understand the domain in which the system is being used. So, we considered the emergency management domain and particularly, the response phase.

3.1. Emergency scenario

We used an indoor fire emergency (i.e., in educational building) as a use-case for domain analysis which was as follows.

“Imagine there is a big fire in the university building. This fire emergency happens in building A at the University of Agder Grimstad campus. There are 100 persons stuck inside the university. From these people, 10 persons are vulnerable (vulnerable are old people, children, pregnant, allergic to smoke and heat, physically-challenged person). These vulnerable people cannot reach the exit quickly and are spread over the whole building. Visitors are also there and stuck inside the building. They are not aware of the evacuation procedures and exit routes to escape. After lot of people self-evacuated, 50 victims are still trapped in each floor in the university building. As the university building has several floors, at least 10 victims got stuck inside each room. However, first responders are unaware of total number of victims, the number of persons inside each floor of the building and their exact location to get an overview of the situation and to evacuate them”. The detailed emergency scenario description can be found in our previous research [25].

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To deal with this kind of emergency situation, ERs should have access to different university’s information systems in order to know how many people are still in-side the building and also their location. However, in reality, the data resides in several systems and ERs do not have access to these systems. In addition, the ERs cannot get a unified view of the several systems’ data. Therefore, there is a need a way for integrating and handling data from different sources with different formats via a unified system is essential. Furthermore, with the help of this scenario, information needs of various ERs were identified. After identifying the information needs, a data integration framework was proposed. To develop an information system, the authors of this paper could not get access to different EROs’ databases and applications due to security and privacy barriers. Therefore, for data integration, different applications and databases of University of Agder (UiA) have been used to provide a holistic way to access the relevant information in a timely manner.

3.2. Information Requirements and Model

Information is the content of the communication that takes place within the frame-work of emergency response. The following information is essential to obtain situational awareness and for decision making. The information requirements are about "Who, Where, When, What, and How". Here, Who means the information related to the involved people and organizations. Where means, the information related to the location of the emergency. When is, the information related to the date and time of the emergency. What means, the information related to the type of the event, needed resources (material) and what kind of activities should be involved. How means the information related to the cause of the event and performing tasks. The detailed description of the acquired information needs and the developed information model can be found in our previous research [14, 25].

3.3. Data Integration Framework

Based on the proposed reference architecture for emergency management operations a data integration framework was proposed which can be seen in [11]. The proposed framework consists of three parts i.e., the first part is data layer, the second part is semantic layer and the final part is information presentation layer.

- The data layer consists of applications or data sources from different EROs such as fire and protection services, police services, ambulance services and municipality.
- The semantic layer represents the key concepts in the emergency management domain and their semantic relationship. By using this semantic model, a centralized database (CDB) will be developed. This CDB is an instance of the developed semantic model. The input data for the CDB is provided by the data source handling layer which collects data from the different EROs' databases.
- The output data from the CDB is provided to ERs through the information provisioning layer for different purposes such as getting overview of the situation, for decision making, setting up the shelters, and arranging ambulances for victim transportation. The acquisition of the needed data supports ERs in managing the emergency efficiently and effectively.

IV. System Implementation

In this section, we present the results of data source handling development and implementation part of the proposed framework.

4.1. Data sources

As mentioned in the previous section, we consider fire in a university building use case as a proof of concept for handling existing data sources.

Table C.2: Used Data Sources for Data Integration ([26])

Used Applications	Description
FS system	It contains information related to students who have registered to the courses and program at the university.
SAP portal	It contains information related to the full time and part time employees.
Syllabus system	It contains information related to the time plan of the scheduled courses.
UiA system	It contains information related to university building information, resources information and hazardous material information.
Sensor database	It contains information related to the smoke, fire, and temperature inside the room.
Cisco Prime Infrastructure application	It contains information related to the connected users over Wi-Fi.

The reason for selecting the university building as a use case is that, university consists of several floors, blocks (buildings) and several people. If any emergency occurs inside the building, it is difficult for the emergency responders to locate the victim's location as they are wide spread in the entire area. To fulfill the above-mentioned information needs of the ERs, we considered a semantically-enhanced mediator-based data integration approach for handling data sources in an Enterprise Service Bus (ESB). The detailed description of the mediator based data integration approach can be found in [27]. The six different applications that used are: FS system, SAP portal, Syllabus system, UiA system, Sensor database and Cisco Prime Infrastructure Application. The description of each system is given in Table C.2.

4.2. System Description

During implementation, we used connectors to provide access to the above-mentioned data sources such as FS, SAP, Syllabus, UiA and Cisco Prime Infrastructure application (Cisco PIA). This can be seen in Figure C.2. For the schematic mapping from the local databases, we have used mule ESB. Mule ESB is an open source lightweight integration framework that combines messaging, web services, data trans-formation, and intelligent routing to reliably connect and coordinate the interaction of significant numbers of diverse applications across extended enterprises with transactional integrity.

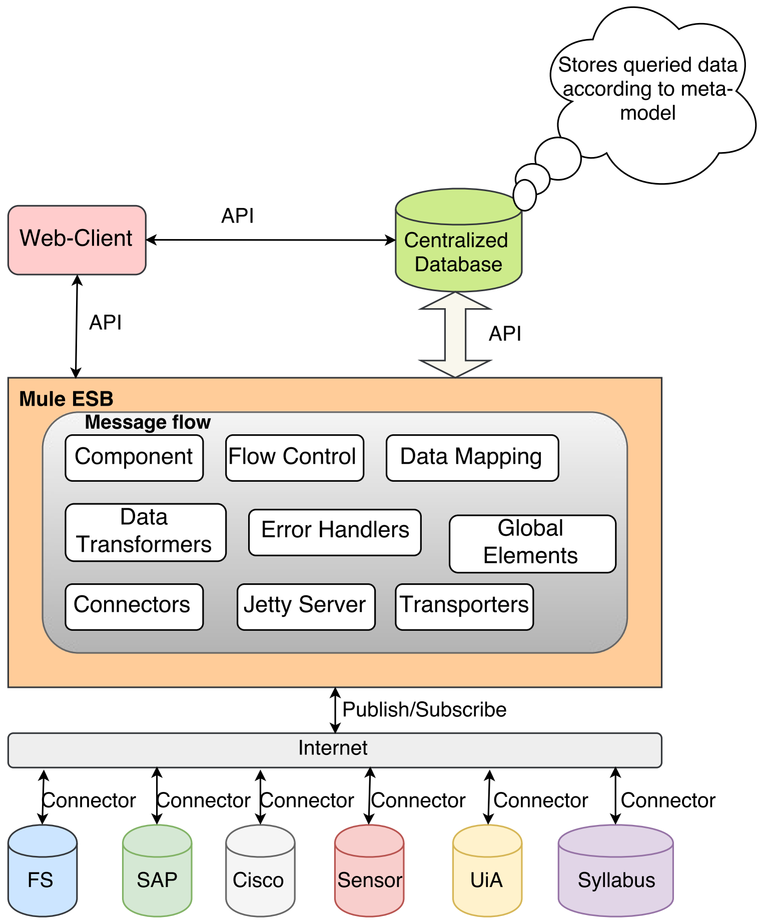

Figure C.2: A Data Integration Prototype for the Fire Emergency Response

In our system development, a message flow was implemented to specify how a service request is to be parsed in the system. Mule uses message flows to plug together a series of message processors. The typical message flow has a message source (usually connectors), which accepts messages from an external source (e.g., databases or applications or third party APIs) either via standard protocol i.e., HTTP and triggers the execution of the flow. It also typically includes a series of message processors which transforms (i.e., convert message payload data to a format that another application can understand), filters, and enriches messages. The message flow for the implementation included an HTTP endpoint component as message source, which made the flow available as an HTTP service. In addition, there are two types of endpoint-based connectors i.e., inbound endpoints and outbound endpoints in mule ESB. Here, inbound endpoints serve as a message source for a flow and outbound end-points send information to the external systems (i.e., web services or files or databases). The final prototype implementation in mule ESB can be seen in Figure C.3.

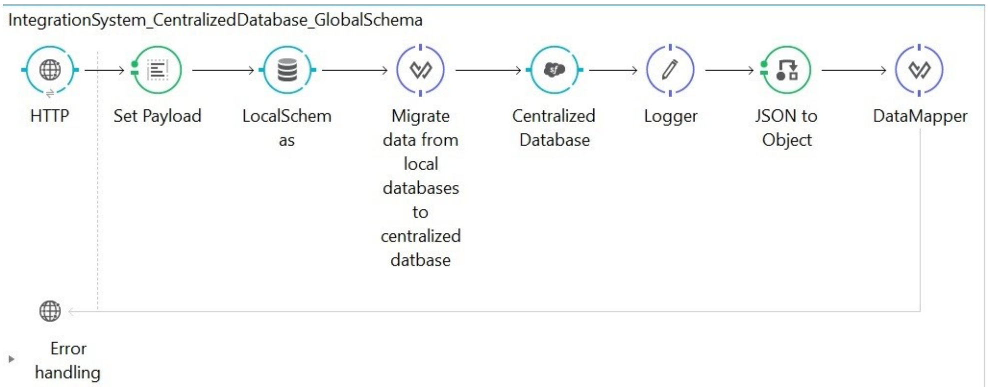

Figure C.3: The Final Implementation in Mule ESB

In Mule ESB, HTTP endpoint connector was used in collaboration with the Simple Object Access Protocol (SOAP) component, where the service was configured with an appropriate jetty transport representing the different operations that could be invoked on the service bus. The SOAP component would make the service available for cross-computer communication. Transformers and jetty transport were being used to perform data conversion (i.e., from JSON to Object) and to expose Mule Services over HTTP using a Jetty HTTP server. Data mapper takes data in a specific format and outputs the same data in the format of our choice. Therefore, we have used this component to solve the semantic heterogeneity problem. Data Sense uses message metadata to facilitate application design. With this functionality, Anypoint Studio proactively acquires information such as data type and structure, to prescribe how to accurately map or use this data in your application.

4.3. Data mapping

To integrate the data from different databases, we first developed a meta-model which can be found in our previous research [14]. The reason for developing the meta-model was, when the data are stored in individual databases, then these databases are simple and good enough to handle queries against them. But, when it comes to integrate these individual databases into different systems or vice versa, there will be problems with mapping different database structures due to mismatch in

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naming domain concepts. For an example, user name in one data can be named as "user_name", but in another database, it can be named as "u_name" or "u_id". It is obvious that these concepts have the same semantic i.e., information about the user_name. But syntactically, they are different. This difference is not easy for a human-being to recognize the similarity when they are from different organizations. Moreover, it is also not an easy task for a machine to integrate. Therefore, resolving semantic heterogeneity not only helps machines understand the domain concepts, but also give users a unified way to access distributed data.

After developing the meta-model, few rules were made. These rules were then used to make query plan for retrieving data from stored data sources. To retrieve data, we used local schemas and global schema. Local schemas are the schemas that were used to extract data from local databases i.e., FS, SAP, Cisco, Syllabus and so on. Global schema is the schema that was used to extract data from centralized data warehouse. The extracted data from local databases are mapped with developed meta-model (ontology) that we used and stored in the centralized database i.e., cloud infrastructure.

An example metadata mapping from local databases to centralized database is as follows. Victim_ID in meta-model (CDB) = **User_name** in FS, **U_name** in SAP and **U_ID** in Cisco; **Victim_status** in meta-model = **status** in FS, **P_status** in SAP; **Device_type** in meta-model = **d_id** in Cisco; **Network_id** in meta-model = **Access-point_ID** in Cisco; **Network_name** in meta-model = **AP_location** in Cisco.

To demonstrate the use of the prototype system, an example case is considered i.e., if ERs request the following information on the GUI: "the persons and their location inside the building during fire emergency which occurred between 9 to 10 am". To present this information, first a global schema was created and then local schemas. Here, queries against the database were made by using Structured Query Language (SQL). The rules (query plan) that used to extract data from local databases and store them in CDB and present on GUI are as follows.

- A Student is identified with username in the FS and in the Cisco database (**user_name** in FS= **u_id** in Cisco).
- An Employee is identified with username in the SAP and in the Cisco database (**u_id** in Cisco = **u_name** in SAP).
- The Student location should be matched with the location of any registered course (if heshe is registered to any course) (if **u_id** in Cisco= **user_name** in FS; then **course_id** of connected user in FS = **c_id** in Syllabus; **r_location** in Cisco = **room_location** in Syllabus).

- The Employee location should be matched with the location of any teaching course (if he/she teaches any course) (**u_id** in Cisco= **u_name** in SAP; **course_name** in SAP = **coursename** in Syllabus; **r_location** in Cisco = **room_location** in Syllabus).
- If an employee is not teaching any course, then the location of the employee should be matched with the employee's office (**r_location** in Cisco = **room _location** in SAP).

If a victim is connected to the Cisco network with several devices, and these devices are shown at two different locations at the same time, then we choose the victim's location based on the following criteria. However, in this criterion, first we check what kind of devices and how many are connected to Cisco network with one username. (we assume that the user is always connected to Wi-Fi with two devices i.e., mobile and laptop and carries mobile phone with him/her). If user is connected to Wi-Fi with two devices to Cisco network, then we check the location of the connected mobile and laptop as follows.

For employee:

- First, we check the location of the connected devices (in Cisco db). If both the connected devices' location (in Cisco db) is matching with location of employee's office room (in SAP db) then we assume that the user is at office room and show that information on the GUI.
- If the connected laptop's and mobile phone's location is not matched with employee's office room location, then check whether this employee has any class to teach at that time (in Syllabus db). If employee has class to teach and both devices' location is matched with teaching room location, then we consider teaching room's location information and show it on the GUI.
- If the connected laptop's location matched with office room's location and mo-bile phone location matched with teaching room location, then check whether this employee has any class to teach at that time (in Syllabus db). If employee has class and mobile phone location is matched with teaching room location, then we consider location of the mobile phone and show it on GUI.
- If both connected laptop's and mobile phone's location is not matched with employee location, then we check whether laptop's and mobile phone's location is moving from one place to other. If yes, then we consider the location of both devices' information and show it on the GUI.

- If the connected laptop's location is matched with employees' office room and mobile phone's location is in other location, then we check whether mobile phone's location is moving from one place to other. If yes, then we consider the mobile phone's location information and show it on the GUI.

For student:

- If student is connected the Cisco network with laptop and mobile, then check the location of the laptop and mobile. Now, check whether this student has any classes to attend. If yes, then check whether the student's mobile phone and laptop's location is matching with course class room's location. If yes, then show the course class room's location on GUI.
- If student is connected to the Cisco network with laptop and mobile, then check the location of the laptop and mobile. Now check whether this student has any classes to attend. If not, then show the current location of student on GUI.
- If student is connected to the Cisco network with laptop and mobile, then check the location of the laptop and mobile. Now check whether this student has any classes to attend. If yes, then check whether the student's laptop's location is matching with course class room's location. If no, then check whether the mobile is matching with course class room's location. If yes, then show location of mobile on GUI.
- If student is connected to the Cisco network with laptop and mobile, then check the location of the laptop and mobile. Now check whether this student has any classes to attend. If yes, then check whether the student's laptop's location is matching with course class room's location. If no, then check whether the mobile is moving from one place to other. If yes, then show location of mobile on GUI.

In Figure C.3, the used components in the message flow perform the following actions.

- *HTTP:* It is a connector which can send and receive HTTP and HTTPS requests given a selected host, port, address. With this connector, we can choose the methods such as GET, POST, DELETE. In addition, this connector can be configured to listen for incoming HTTP requests that can be expected to reach a given HTTP address.

- *Set Payload:* This is a transformer which is used to set the payload. The payload can be a string or a mule expression. Here, mule expression is a language which can be used to access and evaluate the data in the payload to filter, route, or otherwise act upon the different parts of the Mule message object.
- *Local Schemas:* It is a database connector which connects to all databases separately and queries data as local schemas into a flow.
- *Migrate Data from Local Databases to Centralized Database:* It transforms mes-sage i.e., transforms data structure and format to produce the output Salesforce connector expects.
- *Centralized Database:* It is a Salesforce connector used as outbound connector which connects with Salesforce cloud, and performs an operation to push data into Salesforce according to the developed meta-model.
- *Logger:* It is a component reference which is used to log messages such as error messages, status notifications, or exceptions.
- *JSON to Object:* It is a transformer which converts a JSON encoded object graph to a java object.
- *Data Mapper:* It is a tool to query and transform data inside Mule. Data transformation can be done graphically mapping the fields by dragging and dropping them inside the mule.
- *Error Handling:* In mule, if faults occur, they are referred to as exceptions. When an activity in the Mule instance fails, Mule throws an exception. To manage these exceptions, Mule allows to configure exception strategies [28].

V. Discussion and Related Work

Emergency response operations depend on the availability of relevant information in order to support search and rescue tasks and decision-making at the emergency site and at the Command and Control Center [29]. Data from diverse sources are an essential input for the ERs' decision making and situational awareness. However, to make relevant information available and accessible for ERs during emergency response is challenging as the data reside in different sources and these sources belong to different organizations. Consequently, getting access to those organizational data sources is difficult due to technological, political and organizational barriers.

In addition, these organizations mostly use different terminology (semantics) for managing/storing their data. Utilization of such data during emergency response turns into a manual and intensive work for ERs in order to make it understandable to one another.

During the last years, researchers have proposed and developed various information systems by using different integration approaches to solve syntactic, schematic and semantic heterogeneity problems. Casado et.al, [30], proposed and developed a data interoperability software solution for cross-border collaboration. The main goal of their work was to translate emergency related terms and symbols from one language to other language with the help of a common and modular ontology called EMERGency in case of a border fire. In addition, also to translate emergency related symbols from one country to other country. For data interoperability, service-oriented architecture has been used for solving mediation issues. In addition, in this project, semantic mapping for different predefined information artifacts, information representations and languages between countries in Europe was focused. However, if their work is compared with our work, semantic mapping of the incident information was left out.

Balogh et.al, [31] proposed to use an agent-based infrastructure for supporting interoperability as part of the SECRICOM project. The data sources that were used for integration were not EROs' data sources. Moreover, the authors have used agent-based integration approach and did not look into the semantic differences of the data sources.

Fahland et.al, [32] developed a prototype system called HUODINI for the flexible integration and visualization of heterogeneous data sources for disaster management. HUODINI collects information from several freely available data sources on the web, such as news feeds, personal blogs, tagged images, and seismo-graphic information. However, in their work, textual and multimedia data was integrated. Moreover, the developed and used ontology provides only event and object related information. The other information such as where, when, how and who are left out.

Romanowski et.al [33] implemented a web-based decision support tool for emergency managers by using data fusion, data mining and data integration techniques. The purpose of this developed system was to build scenarios based on the integrated data (historical data). However, in their work, the authors did not look into the semantic differences of the data sources.

Ashish et.al, [34] developed an information system that provides integrated access to a wide variety of information sources. With this developed system, both previous data and real-time information are integrated. However, the purpose of the developed system was to provide information related to the location such as maps of the location and facility, floor plans of buildings in the area, hazardous material location information, and other potentially useful information such as work schedules and shift timing information. Moreover, real-time sensor data such as surveillance cameras in a building at the incident site also made available to the fire brigades. However, in their work, the authors look into the geospatial aspects, but neglects the deep semantics of the emergency.

Li et.al [10] proposed and implemented a decision support system by integrating diverse EROs data sources to enable the collaborative information sharing among community-based NGOs, public, and private organizations within a community. However, we consider the used point-to point integration approach as not scalable, that means, when the number of applications increases, the complexity of the whole system increase. In addition, any change in one application will make the whole system change. Moreover, new connection between the that application and others need to be reestablished. This can result in high maintenance costs and a lack of flexibility when it becomes necessary to make changes [35].

Mecella et.al [36] proposed and developed a 2 layer peer to peer service-oriented software infrastructure to support decision making during emergency situations. It provides a decentralized, event-driven information integration environment. In this project, task analysis technique called Hierarchical Task Analysis was used to identify the task requirements for various emergency scenarios. However, the developed solution partially solves semantic mapping of the geo-data, but neglects deep semantics of the emergency.

Alamdar et.al [37] integrated geospatial data of different sensor databases and used for a flood use-case and Lezcano et.al [38] proposed an archetype approach for integrating different sensor data sources for solving semantic heterogeneity. However, both these solutions, tried to solve semantic heterogeneity of different type of sensor data.

In [39–43],the authors integrated different spatial data sources for providing spatial data to the emergency responders, Kou et.al [44] proposed a heterogeneous data integration framework for providing video and audio data. However, to our knowledge, this framework has not yet been developed and tested with a use-case.

Raman et.al [45] proposed and developed a web-based disaster management system called CEMAS for providing resource related information to the emergency responders. The information provision was done by integrating different data sources. The main objective of their system is to provide emergency alert about surrounding area via SMS or email to the emergency responders in case of natural disasters.

Christman et.at [46] proposed a methodology to integrate tactical level information integration from two systems i.e., Civil Information Management (CIM), and Data Processing System (DPS). For data interoperability, a data exchange format called National Information Exchange Model (NIEM) was used. However, the used NIEM data model solves semantic heterogeneity partially when compared to our solution.

Subik et.al [47] provides multi-disciplinary rescue teams with an integrated and intelligent communication and information system for efficient data sharing and emergency process management before, during and after major incidents. Their developed system allows mapping internal onto an external data structures and vice versa for achieving technical and syntactical interoperability. However, their work completely neglects the semantic one.

SINTEF [48] proposed and built a middleware which allows data, system and network interoperability for multi-agency emergency collaboration and decision-making. In their project, multimedia information has been integrated by using SOA paradigm and web services technology. For requirement analysis, participatory design methodology and ethnographic studies were being used. In addition, they use EDXL standard for information exchange. This project provides data from the social media to the involved ERs for situational awareness social-media data integration. However, in their work, semantic mapping was done on unstructured data i.e., social media data. Whereas in our solution, semantic heterogeneity of structured data of existing systems is solved.

Apisakmontri [49] proposed and developed an ontology to integrate different humanitarian aid information and disaster management systems However, in their work, semantic mapping was done on unstructured data i.e., social media data. Whereas in our solution, semantic heterogeneity of structured data of existing systems is solved.

Erskine et.al [50] used a hybrid approach for aggregating data from social networks for natural disasters. Here, hybrid approach means utilizing automated data mining tools and crowd-sourcing to optimize the information. However, in this study, solving semantic heterogeneity aspect was not considered.

Careem et.al, [51] developed a software application called SAHANA for managing resources and information in disaster response, but does not address the semantic integration of content.

Although various information systems have been developed by introducing novel ideas to provide information to the emergency responders in order to improve emergency management, there are still gaps: 1) deep analysis of the semantics of the technological/man-made emergency domain and 2) disseminating the needed/relevant information to the involved ERs at the right time to the right person at the right time. So, we presented a methodology and developed a prototype. The novelty of our methodology lies in providing functionality for more data usage in terms of on-the-fly integration of different data sources and analysis.

Here, on-the fly data integration means, for example, after the emergency occurrence, the involved ERs realize that extra information is available at the emergency site for example, information related to victim and resources inside the building. The involved ERs could think that they can use this extra available information in their search and rescue operations. Although this information is available at the emergency site, involved ERs do not have access to that kind of information. In such a scenario, ERs could consider our implementation part, particularly the domain analysis aspect. Here, the domain analysis aspect is nothing but knowing the involved stake-holders, their information needs and so on in advance in case of an emergency.

If 90% of the emergency domain analysis is done before the emergency occurrence for all types of emergencies, then it is easy for the involved stakeholders to manage the emergency. Here 90% of the analysis is nothing but partially who (analysis on who should involve from organizations), partially *how (performing tasks depending on the emergency type)*, *where (location of the emergency)*, partially *what (needed resources and activities depending on the emergency type)*. However, some information is generated just after the emergency i.e., when (date and time of the emergency). In addition, some information is generated during the emergency i.e., partial information of who (involved victims) and is not known by the ERs before the emergency. So, after the emergency, including this extra information in the developed system is not that difficult as the ERs get to know about the emergency situation and the needed information. This is because the implementation is something that can be automatized or modularized.

If we compare our solution with the commercial tools e.g. CIM [20], Esri's ArcMap [53], Map info [54], WebEOC [55], Crisis Commander [56] and so on, they typically have all-in-one approach i.e., in these developed tools, the information is taken in from other sources and claim that the data belongs to them at the end. Consequently, again poor access to the needed information. Furthermore, since these systems are commercial, it is not clear to us whether the semantic consistency issue has been taken in to consideration in the development of these systems. If we consider our work as whole, we find out that Xchangecore [52] is related to our work. It is an open source system developed by XchangeCore Community. Xchangecore is widely used in USA for supporting data orchestration for emergency management. This system is based on international data exchange standards such as Common Alerting Protocol (CAP), Emergency Data Exchange Language – Distribution Element (EDXL-DE), and Emergency Data Exchange Language – Resource Management (EDXL-RM). One of the components of this solution is similar to our solution i.e., information interoperability for providing real-time information. In this system, data sharing agreements are made in advance for accessing the information and for sharing. To use Xchangecore, a complex installation process is involved. Moreover, to integrate any other application to the Xchangecore, a connector has to be implemented, which can not be done by non-programmer. Furthermore, guidance is required to understand the whole systems and components. However, in our solution, different data get linked easily with the information model to present an holistic overview. In addition, all our interviews with ERs revealed that the domain analysis part can be done in advance i.e., for all kind of emergencies where ERs can be prepared.

VI. Conclusions

In this paper, the authors studied a process for bringing inter-agency data together as a potential source for providing real-time information for emergency management. Based on an indoor fire emergency case study, the issues, information and functional requirements regarding access, dissemination and usage of data from existing data sources for managing emergency were identified. To address the investigated challenges and requirements, a data integration framework was proposed and a prototype was developed. This data integration framework consists of three layers. (1) the data layer, (2) the semantic layer and (3) the presentation layer. The implementation was done based on an approach called semantically-enhanced mediator-based data integration. Based on the presented approach, a prototype is developed by integrating existing data sources with the developed information model in real-time to support ERs for situational awareness and for decision-making.

In conclusion, having information from various places through mediator-based data integration approach would give more efficient access to the information during emergency management. The presented approach would also provide improvement in inter-agencies' knowledge sharing and data exchange through providing more automation in the interaction among organizations involved in emergency management. As future work, we plan to evaluate the prototype and the methodology with a questionnaire based survey and prototype demonstration workshop session with various ERs to get their feedback and recommendations for further improvements.

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Paper D

Title:	LifeRescue: A Web Based Application for Emergency Responders during Fire Emergency Response
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LifeRescue: A Web Based Application for Emergency Responders during Fire Emergency Response

Vimala Nunavath and Andreas Prinz

Abstract — **In order to respond to any kind of building fire emergencies, first-responders have to use lot of time to get access to the emergency data such as location of the victims who are still inside the building, location of the hazardous material, location of the resources and location of the exits in order to perform search and rescue. However, search is possibly one of the most dangerous activities on the fire ground. Sometimes the visibility is zero and the environment is really hot. Because of the limited operating time in the building, the key to successful search is how quickly firefighters can get the access to the emergency related information in order to save victims and the property. In this paper we present a developed web portal called LifeRescue, which enables the emergency responders (both on-scene and remote) to get access to the emergency information during search and rescue operation. This application facilitates awareness of the information such as number of victims still inside the building and their location to the emergency responders who are both remotely and on-scene. Our system also provides the information related to the location of the fire and also its development through sensor data.**

Keywords—Fire Emergency response; Information availability; Emergency web-portal; University Building; Information sharing.

I. INTRODUCTION

When emergency strikes, emergency responders (ERs) from different emergency response organizations (such as fire-protection service, police service, health service and municipality (officials) get involved in order to perform many activities (such as search and rescue operation, debris removal, victim transportation and identification) to manage emergency efficiently. All these activities are successful only if the emergency responders (who are working at remotely and on-scene) get access to the needed information from available information in a timely manner. The consistent challenge faced by the emergency responders during emergency response is lack of proper communication and lack of access to the needed information [1].

Effective emergency response requires a moment-to-moment situational analysis and real-time information access to assess needs and also to check the available resources that can change suddenly and unexpectedly [2]. Moreover, during the emergency response, emergency responders need to coordinate and share information with each other to ensure that they have a common understanding of the situation to align their actions. During emergency response, coordination, however, is a challenging task as it involves uncertainties, and highly volatile information [3].

Another main challenge faced by emergency responders in uncertainty environment, is to get the awareness of the situation as quickly as possible based on the available information i.e., a thorough review of the actual situation. The teams' situation awareness critically depends on the information that is acquired and shared within the team. Ideally, the information acquired by team members must be easy to understand, fast to process and includes clear clues that trigger action. Moreover, the information is also efficiently shared within the team so that collectively the team can make decisions based on better situation awareness [4].

Often, in emergencies, ERs are confronted with time pressure, complexity and uncertainty [5]. The complexity of an emergency increases with the number of emergency organizations are involved [6]. In fact, in fire situation, once the firefighters arrive on the scene, they use a lot of time to assess the emergency situation before starting to rescue. They need, for example, to know information related to where the fire started, how many people are trapped inside and their location, and how to get inside the building and so on. However, this information is available at various places and in different formats.

Moreover, if the fire occurs in a large building, the firefighters have to wait for a briefing from a responsible person in the building to show them where the fire is and how to reach that location. They also have to check each and every room in the building for potential trapped person or victims. This is a time consuming process that can lead to fatalities in some cases [7]. Therefore, in this paper we want to address the following research question: “”How and what information is provided and presented to the emergency responders in order to meet their information needs during a fire emergency search and rescue operation in order to perform better?. We address this question by implementing a web-portal called LifeRescue which can enable emergency responders who are at both remotely and on-scene to get access to the emergency related information in time pressure, complexity and uncertainty environment. This paper takes an end-user centric approach rather than a platform centric approach in the design of an emergency web-portal for emergency responders. Moreover, the information which is visualized on the LifeRescue GUI is actually integrated data from various data sources. The data got integrated by using mediator-based data integration approach.

The remainder of this paper is organized as follows. We motivate our approach by providing essential background on emergency response operations in Grimstad and then describe about the involved organizations; their data/information needs in Section 2. The third section summarizes our research methodology used to develop the web-portal, including the description of emergency management context in Norway. The proposed architecture and developed web-portal is introduced in the fourth section. The literature review on existing applications is listed in Section 5. Finally, the sixth section discusses the main findings of this research, as well as recommendations for further studies.

II. Emergency Response Operations in Grimstad

In this section, we explain the emergency response operations and the involved stakeholders during a fire emergency search and rescue operation. The considered use-case in this study is fire in the university building.

A. Emergency Response Procedure

When a fire emergency occurs in the university building, Arendal Emergency Coordination Center (AECC) (emergency call number: 110) is responsible for taking all emergency calls. Upon receiving the fire alarm or a call to AECC about the fire, AECC immediately alerts Grimstad fire station personnel by sending signals to their walkie-talkie to know their availability. Fire fighters who receive the signal have a chance to inform AECC by accepting or rejecting the received signal.

After accepting the received signal, fire fighters get dressed and go to the fire engine truck. When they are inside the truck, they decides their coordination model such as who will be smoke leader , smoke diver and crew manger based on the fire fighters availability and also radio channels to communicate. The number of fight fighter responding to a fire emergency is based upon type, size and severity of the emergency accident.

When the fire fighters reach the emergency area, smoke divers start wearing the oxygen masks for fighting with the fire, whereas crew manager and on-scene commander meanwhile collect all basic needed information from the university building security personnel and also from the victims who came out of the building in order to get initial overview of the situation to start firefighting activities.

Upon collecting the basic information, on-scene commander decides how many smoke diving teams have to enter into the fire emergency area to start executing the tasks such as search and rescue, extinguishing the fire, smoke control, finding out the hazardous material, reporting. After entering the fire emergency zone, smoke divers

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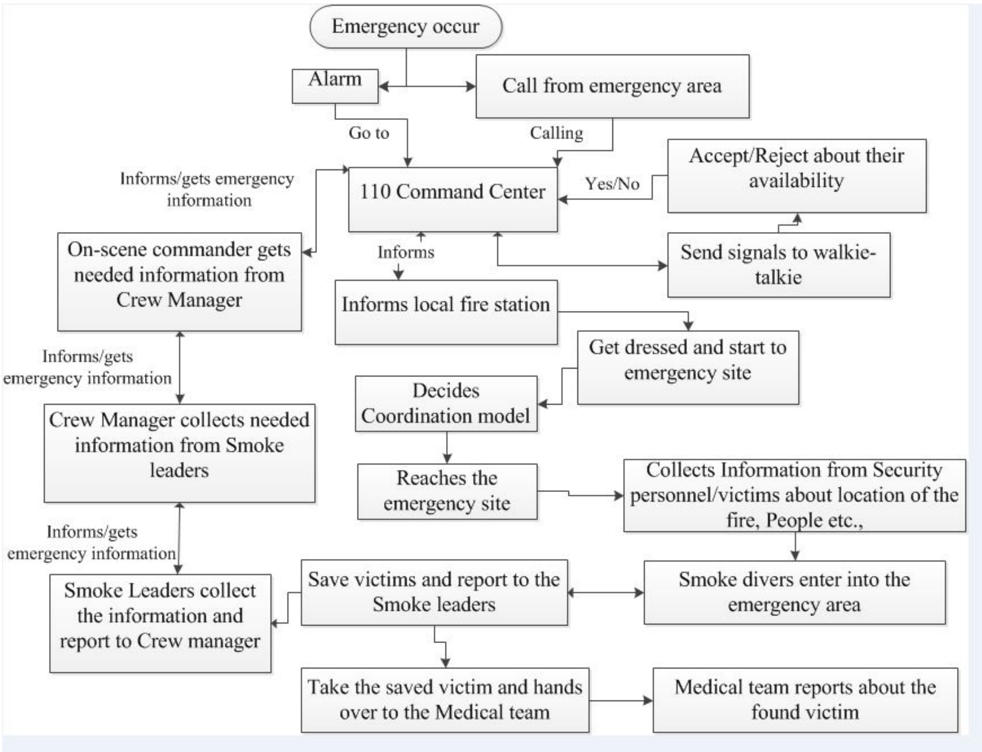

Figure D.1: Step-by-step Process of an Indoor Fire Emergency Response Operation

search for the victims to evacuate and report the corresponding smoke leader about fire, smoke and victim situation. After finding the victim, take the found victim to the medical team for first aid and medical team also reports to the on-scene commander about victim status.

After receiving information from smoke diving teams, the information is shared from smoke leaders to crew manger, from crew manager to on-scene commander, and from on-scene commander to AECC to obtain the shared situational awareness as well as to help all emergency response leaders to make decisions on emergency response activities.

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The detailed step by step process of fire emergency response procedure is shown in Figure D.1. In Figure D.1 above, two sided arrow represents two-way communication to share information and one sided arrow represents one-way communication to share information.

B. Involved emergency stakeholders

When the emergency responders from fire protection service are deployed to the emergency site, on-scene commander from the fire protection service is responsible for organizing, directing and coordinating work at the emergency area until the police service officials reach the emergency site. When the police responders arrive at the scene the leader of the police personnel take over the fire protection service on-site commander responsibilities. In a rescue operation, on-site commander from police services will not direct the efforts of the fire protection or health services [8], but helps them in achieving goals. The main responsibilities of each emergency organization are listed in Table D.1.

In order to perform their duties, all responders from the emergency organizations need information in a timely manner in order to help in dealing the specific problem they are focusing on. However, what information is of concern and interest is changing rapidly and constantly due to dynamic environment of the emergency. Therefore in the next section, we present our research method to find out the fire protection service information needs in case of a fire in the university building.

III. Research Methodology

In this section, we provide the research methodology that we used to propose architecture and develop the web-portal for emergency responders.

A. Data collection

In this study, we interviewed 3 officials from police department, 14 officials from fire-department and 2 officials from municipality to know the emergency management procedure in case of an indoor fire emergency and also to know their information needs during immediate response. Moreover, the research team also observed three fire drills to derive the information items needed by first-responders, and to identify information bottlenecks.

Prior to the interview, the research team were given with three documents i.e., one is about fire departments' search and rescue teams division in Norway [9], another one is about firefighters operations in smoke filled or hazardous areas [10] and the last one is about police emergency preparedness system, which includes guidelines for police contingency planning and incident management [10]. All the interviews were audio recorded for later analysis and notes were taken. The audio-recordings were carefully transcribed and analyzed manually after the interviews to ensure that all the details revealed during the interviews were taken into consideration for the identification of the information items and for knowing the ERs' emergency management procedure.

Each interview took approximately 2 hours and many open-ended questions were asked to determine first-responders' data collection methods, and their information needs as well as difficulties (might be technical and physical) they face in collecting

Table D.1: Involved Emergency Response Organizations during a Building Fire Emergency Response

Type of organization	**Name of the organization**	**Responsibilities during emergency response**
Government Organizations	Fire Protection Service	- Rescuing lives - Extinguishing fires and handling the rescue operations. - Imposing safety measures in dangerous areas.
	Police Service	-Rescuing lives together with other emergency services. - Leading and co-ordinating in the emergency response. - Maintaining safety in the area of deployment and cordoning off areas. - Preventing criminal activity. - Investigation.
	Ambulance Service	- First aid. - Transporting victims to the nearest hospitals. - Informing medical emergency centers and hospitals about the required resources.
	Municipal organization	- Provide necessary support to the emergency service personnel. - Provide information to the media.
Media	Media channels	Provide information to the public

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information before/during search and rescue operations. The research teams also got chance to participate in the observation protocol of the fire drills thrice. Basically, the conducted fire drills were for whole one day to train their emergency response professionals and to learn from the flaws. From the drills, the research team observed their information sharing methods and information needs of first-responders.

IV. LifeRescue: A web Based Application

A. Data Analysis

After the interviews, we retrieved all data from audio recordings. To analyze the data, first, the history of the voice recordings were carefully examined and documented in excel-sheets to ensure that the communication done during the semi-structured interviews was taken into consideration.

Table D.2: Information Needs of First-responders during a Building Fire Emergency Response

Categories of Information needs	Description
University Building information	Information related to university building.
Hazardous goods inside the building	Information related to hazardous material inside the university.
Information about occupants	Information related to the victims' location and their status.
Occupants' personal identification information	Information related to victims identification.
Occupants' medical information	Information related to victims' medical status.
Fire related information	Information related to the location of fire and its development.
Resource information inside the building	Information related to resources inside the university.
Occupants' family information	Information related to victims' family.

The verbal content of the communicated messages were analyzed through the thematic analysis which is a basic method for qualitative analysis method. Thematic analysis is a method for identifying, analyzing and reporting patterns (themes or categories) of the data [11]. The analyzed data were separated into 2 columns in an excel sheet. The data which listed in column 1 of the excel sheet was about needed information and Second column was the description of the information category. The extracted and identified information categories are listed in Table D.2.

B. Data Sources

In this study, as mentioned in the previous section, we consider fire in a university building use case as a proof of concept for integrating different data sources. The reason for selecting the university building as use case is that, university consists of several buildings and several people. If any emergency occurs inside the building, it is difficult for the emergency responders to locate the victim location as they are wide spread in the entire area.

Table D.3: Data Sources Used for the Data Integration

Used Applications	Description
FS system	It contains information related to students who have registered to the courses and program at the university.
SAP portal	It contains information related to the full time and part time employees.
Syllabus system	It contains information related to the time-plan of the scheduled courses.
UiA system	It contains information related to university building information, resources information and hazardous material information.
Sensor database	It contains information related to the smoke, fire, and temperature inside the room.
Cisco Prime Infras-tructure application	It contains information related to the connected users over Wi-Fi.

In order to fulfill the above mentioned information needs of the emergency responders we considered the data integration approach to integrate six different real time applications which are being used in the university. The six different applications are: FS system, SAP portal, Syllabus system, UiA system, Sensor database and Cisco Prime Infrastructure Application. The description of each system is elucidated in Table D.3.

C. System Architecture

In order to provide needed information to the emergency responders we have proposed a client-server architecture, which is shown in Figure D.2. In this architecture, it is believed that the emergency responders from different emergency organizations can get access to the information through a web client called LifeRescue, which is shown in Figure D.5. The proposed client-server architecture consists of four

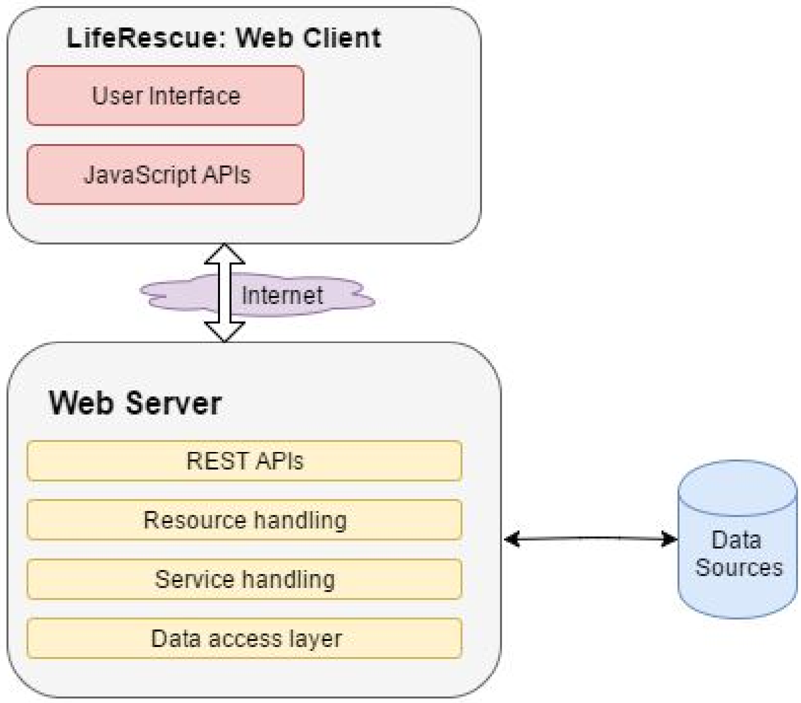

Figure D.2: The Prototype Architecture

layers in the server side. When emergency responders request for the information, the layer REST APIs provides all available APIs by the web server and accessed through web-based application. Each resource definition is given in the resource handling layer in corresponding to the APIs. The connection between the resource handling layer and the data access layer is handled by service handling layer. The basic service like data persistence is provided by this layer. In addition, the data processing is also done in this layer. Moreover, this layer handles transferring data transfer object (DTO) to domain data object (DDO) and vice versa

Common methods to access the data sources such as, SELECT, UPDATE are supported in the data access layer. The client side consists of user interface and

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javascript APIs layers. By using AJAX technology, REST APIs are called through JavaScript. Request and response information can be shown in JSON or XML format.

D. Implementation

The interaction between client, server and server's layers is presented in Figure D.4. Restlet [12] [13] is a high-level Application Programming Interface (API) based on the HTTP servlet technique. It provides an abstraction of Representational State Transfer (REST) applications, resources, and data representations. Applications developed using Restlet can run on any Servlet engine [14]. Tomcat 9.0 [15] was used to provide HTTP web server and servlet container, and JDK 1.8 (Java Development Kit) for supporting Java application.

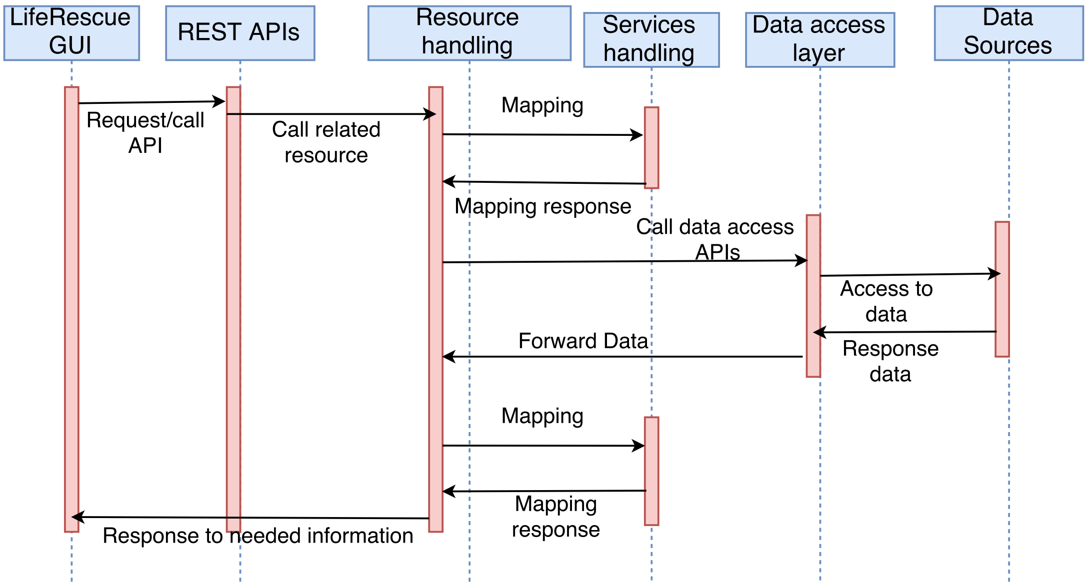

Figure D.3: The Client-server Interaction

JMS (Java Message Service) was implemented to support publish/subscribe feature. In addition, WADL (Web Application Definition Language) extension provided in the Restlet framework was also implemented in the system in order to provide definitions of available services. AJAX technology was used to retrieve data from the server side asynchronously and present it on the client side. It is a popular web development technique for client-side REST applications [14].

E. LifeRescue:Web Based Application GUI

It is a user-friendly human machine interface which enables efficient ways to access the reliable data and provides to the emergency responders. The data from above mentioned different university systems are integrated and made available to the emergency responders who are on-site and at command center through web service with secured user credentials. Making information available through web applications increases the availability of information due to platform independence and easy access.

Figure D.4: Location of the Victims on a Specific Floor Map

We use REST-based web services to enable accessibility to victim data such as number of victims still inside the building and their location in case of an emergency. We also use AJAX (Asynchronous JavaScript and XML) technology to handle the messages from the server (which contains integrated data) and display on the web browser.

Victim information such as the total number of victims (both normal and disabled persons) still inside the university is provided to the first-responders through web browser in a pie chart format. In addition, total number of victims in each floor of a specific building is also presented. The location of the victims' data is displayed on the map of each floor of each building. The victim localization information is extracted from Cisco Prime Infrastructure application and combined with the Syllabus system to measure the correctness of the victim location.

Victim information from Cisco Prime Infrastructure application is combined with the FS and SAP system to let the first-responder know about whether the victim is either student or employee with details: full name, age, gender and medical status. Here 'medical status' refers to, whether the victim is normal or handicapped person.

Figure D.4 represents a map of a specific floor of a specific building. On this map, the location of the victim is clearly seen. The shown victim location on the floor map is based on the student or employee or visitor's Wi-Fi connection inside the building. On the map, the blue colored icon represents the victim who is handicapped. In the developed web application, fire related information is also presented. The fire data are extracted from the sensor database and shown as heat map which illustrates the state of the fire in each room on the floor map of the building. The heat map is updated every second to take into account the latest development of the fire. The colors on the floor map (in Figure D.4) go from green to red depending on the intensity of the fire.

Emergency responders can also get access to static information of "university building information" such as type of building, material used for constructing the building, number of floors. Information related to location of the hazardous goods inside the building and location of resources such as fire hoses and fire extinguisher which are needed for the fire extinguishing and its details such as coverage length of the fire hose, capacity of the fire extinguisher, model of the fire hose and fire extinguisher also presented. The detailed LifeRescue web based application can be seen in Figure D.5.

F. Use-case Scenario

Consider a fire emergency in the university building case where the fire begins to spread inside the building. Even though most of the persons occupied in the building can escape, some people get trapped and are unable to evacuate by themselves. In this case, first-responders who arrived at the emergency site cannot get aware of the information: how many people are still inside the building and their location, how the fire gets spread from one location to other. In Grimstad, at present, there is no system available to help the fire protection personal to get access to real time data in case of emergency at university building. They have to completely rely on their experience, knowledge and the collected information from victims and building responsible personnel. In such case, our web application is very useful to obtain the information awareness as well as situational awareness.

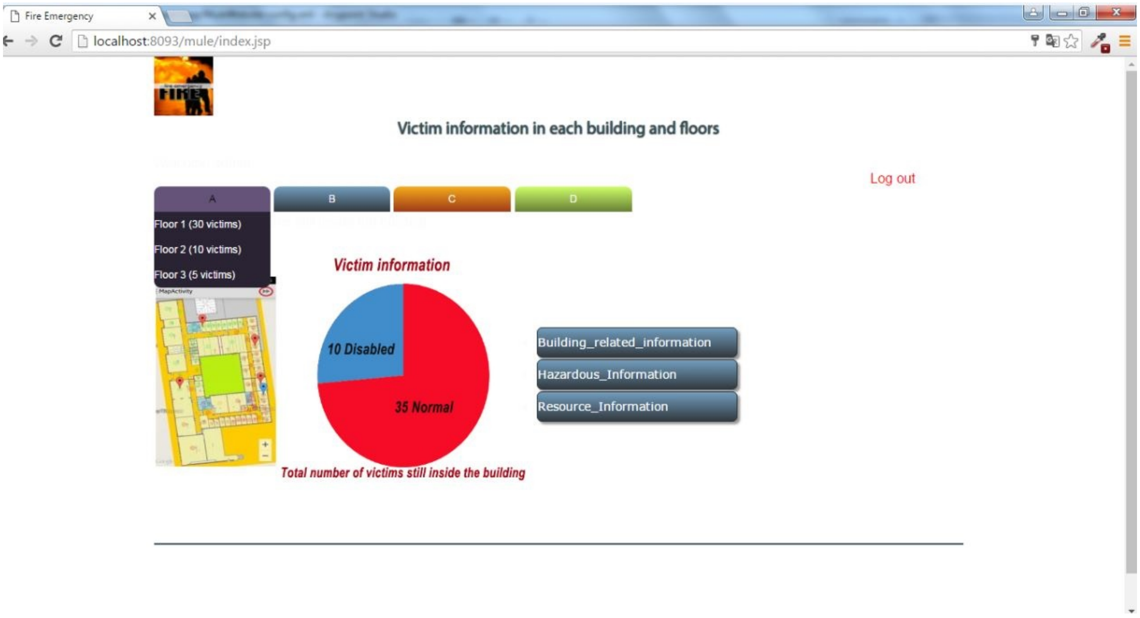

Figure D.5: LifeRescue Web Application GUI

The ERs who are at emergency scene and at command center can login to the LifeRescue web application. When they log in, they could see on the user interface how many are still inside the whole building. From this total number of victims, they could know how many are normal and how many are disabled persons in a pie chart. Emergency responders can also see the location of the victims and the fire status in each room. This can be observed on the floor map (see Figure D.4 and D.5). The fire development (spread) is also shown in the web application. When the fire protection service teams have access to the fire and victim related information through visualization, they could decide quickly who should be given priority and can also decide which one is the best and fastest way to reach and save the victims.

V. Related Work

In the scope of our work, we examined the existing emergency management platforms, context aware applications, supporting technologies and the degree of use of web based applications which can be used during search and rescue operation in case of fire in the university building. There are many systems have been developed in the literature for evacuation [16–21], indoor localization of victim and first-responder [7, 22, 23], fire prediction [7, 24–26], for peer communication [27–29] and for navigation [30], for route analysis [31], indoor maps [32], evacuation time [33] and for fire risk assessment [34]. All these applications could provide either fire related information or victim information, but not both. However, SmartRescue application [7] could provide information related to fire as well as victim, but not other features like resource information, hazardous information, building related information, victims' details, and medical details when compared to our application.

VI. Discussion and Conclusions

Making emergency related information (such as number of victims still inside the building and their location) available and accessible to the emergency responders is important, since the time used for search and rescue operations can be shortened. Consequently, the cost of losing life and property can be reduced. In this work, first the involved stakeholders were listed, then the information needs were presented and architecture was proposed and developed in order to give access to the needed information to the first-responders to perform search and rescue operation in less time during a fire emergency response. During the prototype implementation process, the proposed web application was evaluated with the fire protection service responders and the given feedback was incorporated into the developed prototype.

The information provision was done by integrating different existing university systems. The indoor localization was based on Wi-Fi connection which helps the firefighters in finding trapped victims without checking each and every room in the university building and its floors. Our application helps in facilitating and speeding up the work of firefighters in order the save more lives and property.

The future directions of this work would be to first introduce a data derivation model to handle missing data to support fire fighters to evacuate victims safely from a burning building and another one would be to handle the data quality dimensions such as accuracy and timeliness of the victim's location on the GUI.

Acknowledgements.

We would like to owe our gratitude to the Arendal and Grimstad fire service officials who supported and cooperated with us by allocating their valuable time to participate in the semi-structured interviews and also for evaluating the proposed web application. We would also like to thank Kristiansand police services and Grimstad municipality officials for letting us know about their responsibilities, duties, bottlenecks, and information needs during the management of the emergency.

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Paper E

Title: LifeRescue Software Prototype for Supporting Emergency Responders during Fire Emergency Response: A Usability and User Requirements Evaluation.

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LifeRescue Software Prototype for Supporting Emergency Responders during Fire Emergency Response: A Usability and User Requirements Evaluation

Vimala Nunavath and Andreas Prinz

Abstract — **For an efficient emergency response, emergency responders (ERs) should exchange information with one another to obtain an adequate understanding and common operational picture of the emergency situation. Despite the current developments on information systems, many ERs are unable to get access to the relevant information as the data is heterogeneous and distributed at different places and due to security and privacy barriers. As a result, ERs are unable to coordinate well and to make good decisions. Therefore, to overcome these difficulties, a web-based application called LifeRescue was developed for supporting easy information access during emergency search and rescue operation. The goal of the paper is to test the developed LifeRescue system against the user requirements. We conducted a workshop with nine participants i.e., six ERs from fire protection service and three ERs from police service. First, the workshop session started with prototype demonstration and trial, then a System Usability Scale (SUS) questionnaire was given, and finally a semi-structured interview was conducted to collect data on the user requirements validation. The results presented in this paper combine both qualitative and quantitative data from a semi-structured interview and a survey conducted after the prototype demonstration and trail. The interview results indicate that our developed system fulfills the user requirements of 6 ERs from fire-protection and 3 ERs from police services. Furthermore, the survey results indicate that the participants would like to use our developed system frequently as they felt that it was easy for them to get access to information with a simplified view.**

Keywords — Emergency Management, Search and Rescue Operation, User Requirements Evaluation, Usability Evaluation, User-Centered Design, Emergency Response Information System, SUS-questionnaire, Qualitative and Quantitative data analysis, Information Awareness, Information Accessibility, Nvivo tool, Human Computer Interaction.

I. INTRODUCTION

Information is considered as a key requirement for managing any kind of emergencies [1]. When an emergency happens, a complex network of emergency responders (ERs) from various emergency response organizations (EROs) such as police service, fire protection service, hospital service and municipality officials are involved in emergency response operations to alleviate both property and human losses. Furthermore, among these involved ERs, few ERs work on-site and others off-site (Control and Command Center). In addition, the involved ERs are often fragmented into different teams to carry out different tasks (such as evacuation, finding victims, fire-fighting, preventing property and so on) at different geo-locations [2]. Due to geo-graphical dispersion, these fragmented teams must get access to relevant information such as location of the victim, location of the fire, location of the resources, location of the exits and so on to share within or among (intra-inter) teams to obtain or help to get the overview of the situation, to cooperate effectively and for decision-making [3].

When an emergency occurs, a lot of data is generated from various places. The volume and velocity of generated data tend to be extremely high, making it hard for ERs to process it [2, 4]. Without having enough and the right type of information, it is difficult to gain situational awareness [5–7]. Particularly, in dynamic and time critical situations, it becomes difficult for the first response teams to adequately decide which information might be relevant for other teams to support overall coordination. Despite the rapid development of ICT for emergency management information on-site is still typically collected manually [8, 9].

In addition, each organization stores data in different formats in their own databases, making retrieval and sharing is difficult. Consequently, the responders, both on-site and remotely face a lot of difficulties in getting an overview of the situation. The time pressure and the urge to respond worsen the problem and information may be ignored, even though it is available [10]. Therefore, to overcome these difficulties, the authors of this paper proposed a data integration framework for emergency management. So, the research question that we want to answer is *"Does the developed information system which can be used in any emergency response meet the user requirements of various ERs?"*.

As this research question is generic and difficult to answer, we have formulated the above question to a specific case i.e., an indoor fire emergency search and rescue operation. The goal of this paper is to address the following research question: *"Does the developed information system (LifeRescue) which can be used during indoor fire emergency search and rescue operation meet the user requirements of different*

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ERs?".

To address the formulated research question, the authors of this paper developed a prototype named LifeRescue and conducted a workshop session by following a three-step process: (1) prototype demonstration and trail session, (2) semi-structured interview, and (3) individual questionnaire. The results presented in this paper were analyzed after the workshop session. The significance of this work lies on providing a holistic way to access information for supporting different ERs during indoor fire emergency search and rescue operation with a developed software prototype consisting of a GUI.

The remaining sections of this paper are organized as follows: we first begin with presenting the proposed data integration framework. Then, in section three, we describe the research methodology that was used for evaluating the user requirements. In section 4, we describe the developed LifeRescue prototype. We then present our findings in the results part. Thereafter, the findings of the prototype evaluation are discussed. Finally, contribution and conclusion of this research are discussed with directions for future research.

II. Data Integration Framework for Emergency Management

To overcome the above-mentioned challenges, we proposed a framework for supporting different ERs. This proposed framework supports a holistic way of improving

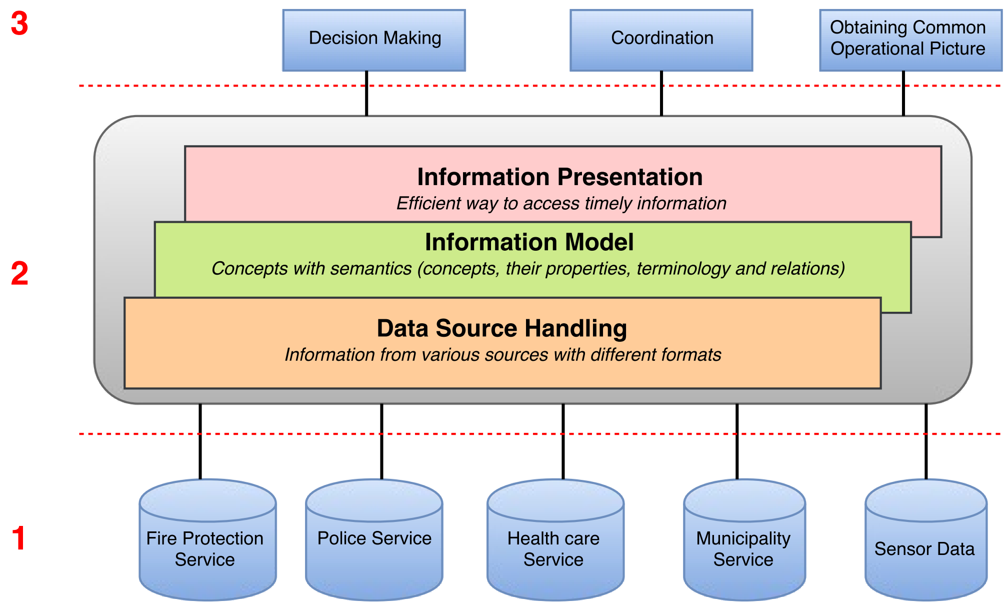

Figure E.1: A Data Integration Framework for the Emergency Response

information availability and accessibility for sharing information among various

ERs during emergency response by using data integration approach which can be seen in Figure E.1. In Figure E.1, the data integration framework consists of three layers. One is data source handling layer, second semantic model layer and third information provisioning layer. The complete details of the proposed framework can be found in our previous research [11].

To develop an information system based on the proposed framework, the authors of this study could not get permission to access different EROs' databases and applications. So, we used an indoor fire in educational building emergency scenario as a use-case and different university applications for data integration. This is because, to develop an effective Information System (IS), a detailed analysis of end-users' information needs is required in order to make the system consistent [12]. In addition, the usability of such application is crucial for the continuous, efficient and satisfactory use of the system. In the system development, the approach of Human-Centered Design (HCD) involves end-users in each stage of the development cycle [13–15]. So, indoor fire emergency use-case scenario was used to capture the user requirements of different ERs. The details of user requirements elicitation can be found in our previous research [16].

III. Research Methodology

As mentioned in [17], evaluation of the system is necessary to analyze the user requirements and usability requirements. Therefore, in this section, we present the methods and material that were used to analyze the user requirements and usability requirements.

3.1. Emergency Scenario and used user requirements

The indoor fire emergency scenario which was used during workshop session was as follows. "Fire accident happened inside the third floor of A' block of the university building. The building consisted of many students (who might be normal, physically challenged, and sick), library, laboratories and storage rooms. Most of the students noticed smoke, flames, and screams inside the building. Some of the victims also report fire intensification. Due to the fire, the emergency site became chaotic and many students inside the building were wounded and traumatized. The number of people inside the building was unknown. But, the people who were running out of the building were giving information about the seen victims. To respond to the emergency, ERs did not know how many people are still inside the building and also their location" [2].

Table E.1: The Used User Requirements of different Emergency Responders

User Requirement ID	User Requirement Description	Stakeholders	
		Fire fighters	Police
1	The user can connect to the system from at any place and at any time	✓	✓
2	The user can get data from diverse sources in a structured form.	✓	✓
3	The user can know the victims' count and their location who are inside the building.	✓	✓
4	The user can know the resources' location and its details	✓	×
5	The user can get the building related information.	✓	✓
6	The user can get the hazardous materials' location and its details.	✓	✓
7	The user can get real time information access to the other emergency response organizations' databases.	✓	✓
8	The user can get family information of the victims.	×	✓
9	The user able to know information related to victims' details.	✓	✓
10	User can get trustworthy information.	✓	✓
11	Users can not face information overload on the screen.	✓	✓
12	Users can understand the language that is visualized on the GUI including acronyms, signs and symbols.	✓	✓
13	User can see the rescuers location inside the building.	✓	×

This emergency scenario was also used for user requirements elicitation, for convenience, these requirements are shown in Table E.1.

3.2. Developed LifeRescue Prototype

Based on the proposed data integration framework, we developed a prototype as a proof-of-concept. According to the suggestion given in [18] and described in our previous paper [19], we followed an HCD process for developing the LifeRescue system and it's GUI. During entire software development process, different ERs from both police and fire protection services have been involved at several stages (for an example, indoor fire in a university building scenario creation, knowing user requirements for performing the search and rescue operations, mock-up GUI design and so on) to increase the usefulness and acceptance of the system, and to provide feedback and their requirements for the GUI features with us [20].

The GUI of the LifeRescue can be seen in Figure E.2 and E.3. Figure E.2 represents the log-in page for the developed application. Figure E.3 presents relevant information to different ERs. However, to provide relevant data to different ERs for prior emergency scenario, the authors have used university systems' applications for data integration. The prototype architecture, description of each data source, its metadata and implementation can be found in our previous research [19].

The developed LifeRescue provides both static and dynamic information to the ERs. Here, dynamic information means the information which gets changed over time during fire emergency and static information means the information which remains unchanged all the time during fire emergency. Both types of information are provided to the ERs with the following features which are listed below.

- **Pie-chart:** In this chart, ERs can understand the total number of victims who are still inside the university building in a pie chart format. When the victims are res-cued and out of the university building, then the count on the pie chart will be changed automatically (see Figure E.3). So, it is a dynamic information. This information can make the ERs get awareness of the situation and help them in making decisions.

- **Floor map:** In GUI, the floor map represents each floor. The location of the victims' is displayed on the map of each floor of each building block. The icons on the map (red and blue) represents location of the victim and their details (such as full name, age, gender and medical status) on a specific floor and the color of the icon helps the ERs to distinguish whether the victim is a normal or a physically challenged person. In this floor map, ERs can also see the fire related information with heat map (i.e., state of the fire in each room).

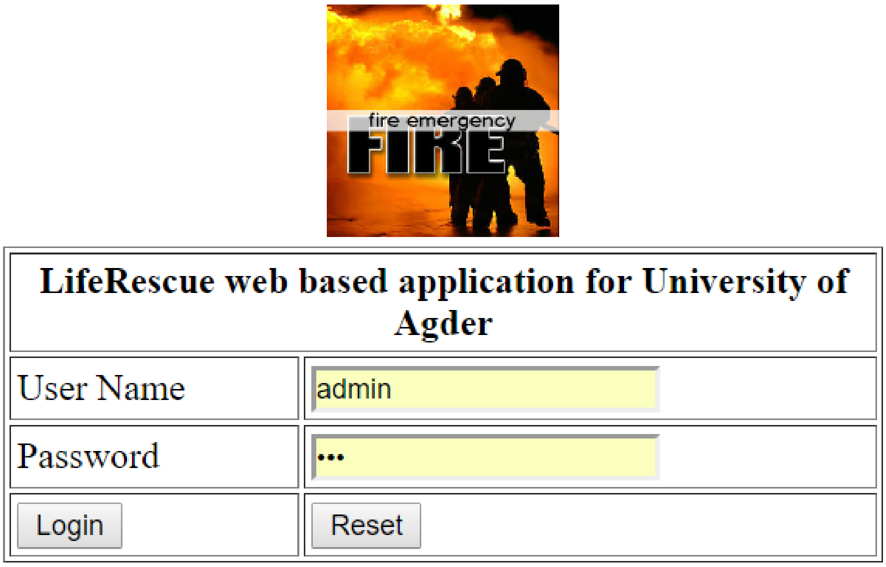

Figure E.2: The Log-in Page of LifeRescue Prototype Graphical User Interface

The heat map is updated every second to consider the latest development of the fire. The colors on the floor map (in Figure E.3) go from green to red depending on the intensity of the fire. In the same floor map, ERs can also have a chance to see information related to the movement of the victims (i.e., moving from one location to other). So, this information is dynamic information. With this information, ERs get awareness of the victim lo-cation and can decide what should be done to rescue the victims.

- **Tabs:** Tabs represent each block (such as A, B, C, D) which is located inside the university building. In each tab, the total number of floors can be seen. For an example, Block A has three floors (e.g., Floor 1, Floor 2, Floor 3) (see Figure E.3). In each floor, information related to the total number of victims can also be seen in the GUI. So, it is a dynamic information.

- **Building related information:** This information is related to university building such as type of building, material used for constructing the building, number of floors and exits. This information can make ERs decide e.g., how fast the building-gets burned, which entrance is safe to enter and so on **(see Figure E.3)**. So, it is a static information.

- **Hazardous Information:** Information related to location of the hazardous goods inside the building. This information gives overview of the hazardous materials for the ERs (see Figure E.3). So, it is a static information.

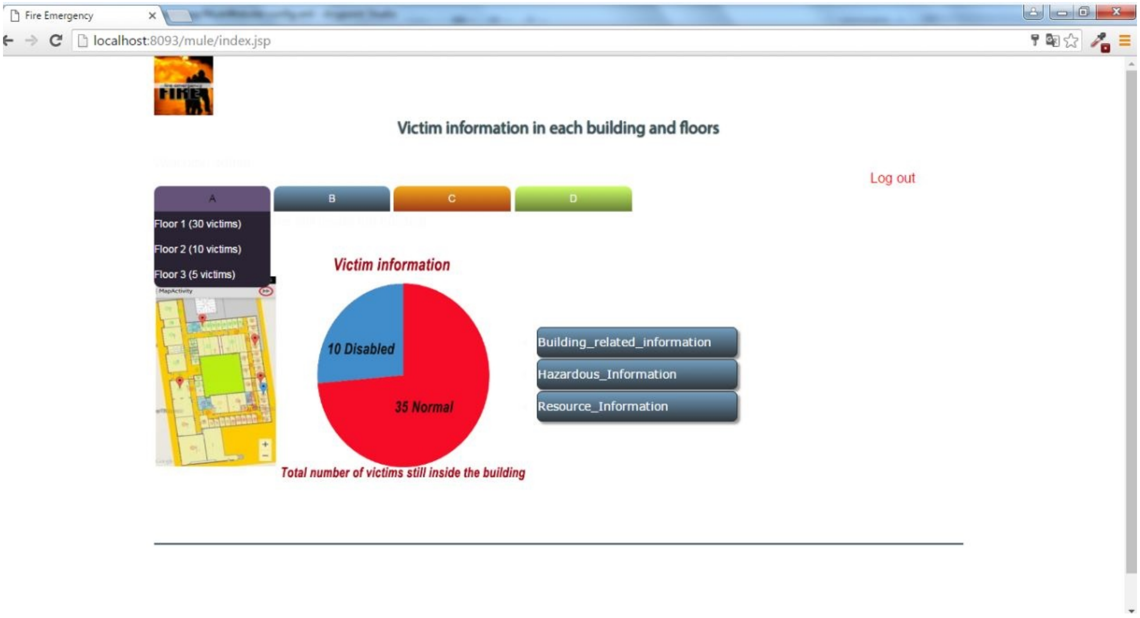

Figure E.3: The Main Page of LifeRescue Prototype Graphical User Interface [19]

- **Resource information:** The location of the resources such as fire hoses and fire extinguisher which are needed for the fire extinguishing and its details such as coverage length of the fire hose, capacity of the fire extinguisher, model of the fire hose and fire extinguisher also provided to the ERs (see Figure E.3). So, it is static information.

3.3. Procedure and participants

We first narrated the aforementioned scenario and demonstrated the prototype to different ERs. Then, we asked the participants to try the prototype. After that an individual SUS questionnaire was given to scale their opinion on the system usability and finally a post-test group interview was conducted with ERs to know whether the system fulfilled their information requirements.

The evaluation of the system was made with 6 ERs from fire-protection and 3 ERs from police service departments in their respective organizations. The facilities had a meeting room with external screen and keyboard. In the meeting room, all the ERs gathered and the authors of this paper narrated an indoor fire in the university building scenario. After narrating the scenario, the developed prototype was demonstrated on the external large screen after connecting with a laptop where the prototype was running on. All features of the LifeRescue GUI were explained thoroughly to the ERs for 30 minutes. Then, participants tried the LifeRescue.

Among the participated 6 ERs of fire protection service, one works as fire chief

(FC) who acts as an on-scene commander, 1 person as crew manager (CM), one as smoke diver leader (SDL), and three persons as smoke divers (SD). Whereas, 3 ERs from police service, 2 work as police chief (PC) at emergency site, and 1 as control room supervisor (CRS). The experience of the involved participants in responding to the emergency situations ranges from 4 to 20 years' experience. The entire workshop session carried out for 2 hours (120 minutes). During the session, participants were encouraged to ask questions and comment on the LifeRescue prototype.

3.4. Data collection

The data collection was done by using audio recording of the post-test group interview and with SUS questionnaire.

- **Semi-Structured Interviews:** After the prototype demonstration and trail, a semi-structured interview session was held with all participants to obtain in depth feedback in relation to the user requirement fulfillment and to get any suggestions for the system improvement. The whole interview session was audio recorded for the content analysis.

- **System Usability Scale questionnaire:** After the semi-structured interview, a System Usability Scale (SUS) questionnaire [21] which consists of 10 questions was given to each participant to evaluate the usability and performance of the system. The SUS questionnaire, is composed of 10 statements that are scored on a 5-point scale of strength of agreement.

The SUS was developed by Brooke [30] as a "quick and dirty" survey scale that would allow the usability practitioner to quickly and easily assess the usability of a given product or service [22]. Although there are a number of other excellent alternatives surveys available such as After Scenario Questionnaire (ASQ) [23], Computer System Usability (CSUQ) [23], Post-study System Usability (PSSUQ) [24], Software Usability Measurement Inventory (SUMI) [25], System Usability Scale (SUS) [21], Usefulness, Satisfaction and Ease of Use (USE) [26] [27], and Web Site Analysis and Measurement Inventory (WAMMI) [28], the SUS has become a good choice for general usability practitioners.

The reason for this is the initial paper of Brooke [21] where the SUS questionnaire was first published has been cited over 3500 times, and studies have confirmed the reliability of the SUS with Cronbach's alfa 0.91 [30] with the conclusion that SUS can positively supplement a usability test and evaluation program.

In the study [30], all the above mentioned surveys were compared and the results summarized that the SUS survey was the most reliable one. Therefore, in this paper,

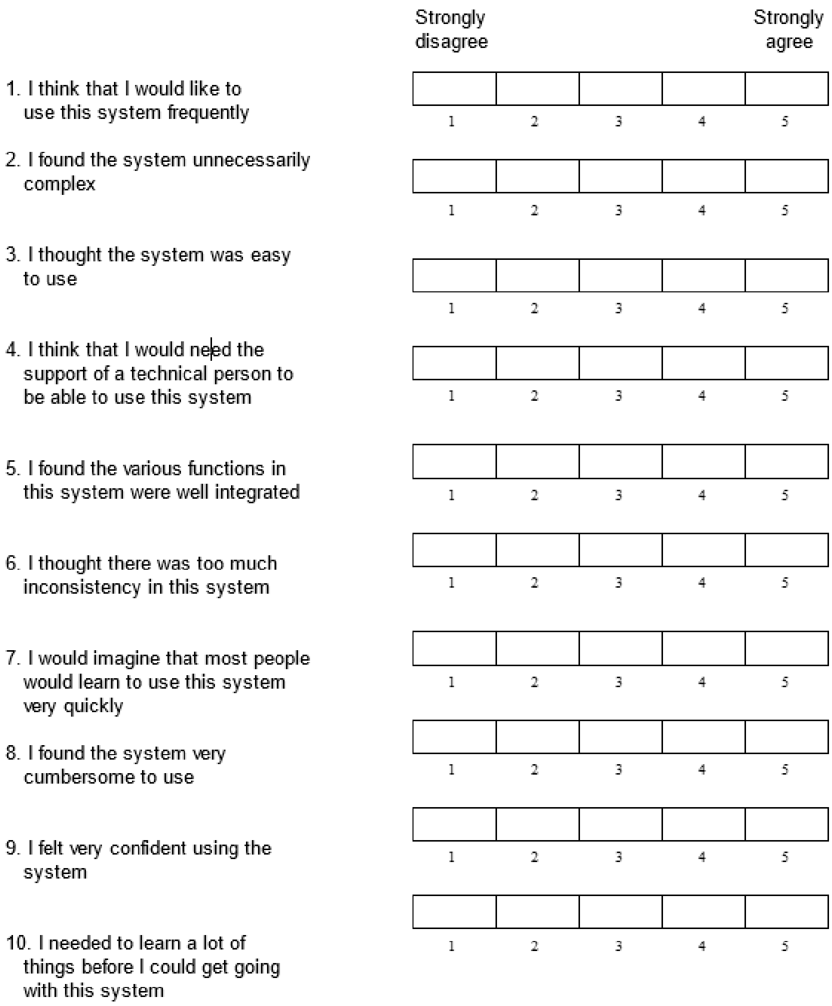

Figure E.4: The System Usability Scale [21]

SUS survey has been used to evaluate the user satisfaction and usability of the system. In SUS, final scores range from 0 to 100, where higher scores indicate higher user satisfaction and better usability.

According to the researchers in [29, 30], the researchers used an adjective scale by dividing the SUS scores as follows: score of 0–25: worst, score of 25–39: poor, score of 39–52: OK, score of 52–85: excellent, and score of 85–100: best imaginable. So, in this paper, we have adapted the same adjective scale in our study. The used SUS questionnaire format and questions can be seen in Figure E.4.

3.5. Data Analysis

After the workshop session, all the data from SUS questionnaires and audio recordings of the group interview were transcribed into excel sheet. After transcribing, the scores of the each SUS questionnaire were calculated. The score calculation was based on the details of scoring the SUS which was explained in the article [21]. The recordings data were imported into QSR NVIVO 10 tool [31] for transcription and a qualitative content analysis.

IV. Results

In this section, the results of the system evaluation are presented with the help of qualitative and quantitative analysis.

4.1. Qualitative analysis

During workshop session, participants got access to the LifeRescue. After getting access to the GUI, they went through the GUI features thoroughly. Then some questions were asked to the participants. Their answers were audio recorded and later encoded into Nvivo tool. The coded content organized into 4 groups: User Requirement Evaluation, GUI Placement, GUI Features Recommendations, and Existing Systems vs LifeRescue GUI.

4.1.1. User Requirement Evaluation

During the interview, all the participants from fire and rescue service mentioned that “after reaching the emergency site, we have no idea how many people are still inside the building and their location. This information we generally collect manually from either security personal or from floor responsible person”. With this statement, it is apparent that there is no ICT system used in Norway to support ERs’ information needs during an indoor fire emergency at university.

We then asked the participants about their first impression after seeing our developed system. All participants stated and agreed that “the system is very well integrated and gives relevant information to us”. We then asked the participants whether the developed system fulfills the user requirements that they stated at the beginning of the system creation. Answer to this question was given by FC and PC1 that “it is easy to login to the GUI and the screen was useful to get overview of the inside situation i.e., victims and their location”.

Another four participants (1 SDL, 1 CM, 1 SD and PC2) positively commented on the pie chart feature of the GUI, “it helps to get the overview of the number of victims still inside the building”. Based on the responses to the questions, we have categorized the participants’ responses into YES or NO (i.e., if user requirements are met then answered as “YES” and if user requirements are not met then answered as “NO”). The results of the user requirements evaluation are presented in Table E.2.

4.1.2. GUI features

All participants found that features that got incorporated in the GUI were very well integrated and useful for supporting their information needs to perform emergency response activities. They also mentioned that navigation was very easy and the in-formation that was displayed on the GUI was with good visibility. However, they have provided some recommendations to improve the current GUI features by adding some extra information i.e., adding phone number to the victim details. With this information, either police or fire personnel can send mass messages to the trapped victims. Furthermore, the participants also mentioned that adding information related to room and corridor dimension (such as width, breadth and length size) will be helpful for the fire fighters.

Participants have also stated that displaying all information in a single browser with a single click was an outstanding idea, because, participants have lot of thing to perform at the same time at the emergency site. So, if they are given with multiple browser windows, that would be overloading for them to remember the information that they get from the LifeRescue GUI.

Participants have also commented that getting fire related information on the LifeRescue GUI was an excellent feature. However, they recommended that *“coloring whole room would be better instead of showing this information in a dot form on the LifeRescue GUI”*. All the firefighters agreed and specified that *“instead of showing which room has hazardous materials in a list form, better to show them on the LifeRescue GUI with a symbol form”*.

4.1.3. GUI Placement

During the interview, the authors of this paper were interested to know answers to the following questions: “where can the system be placed during emergency and who should have access to the LifeRescue”. All the participants responded to these questions as follows: “access to the GUI should be given to the ERs who are working at the emergency site”. The reason for this statement was given by the fire chief *“he/she does not get orders from the sup-port room (110 room). Fire chief just asks the support room to provide additional resources whenever he/she needs during emergency response”*.

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FC has also mentioned *“he is the one who takes decisions at the emergency site.*

So, he is the one who is suitable for having the GUI access".

Table E.2: Results of the User Requirements Evaluation

User Requirement ID	User Requirement Description	Participants' Responses	
		YES	No
1	The user can connect to the system from at any place and at any time	✓	–
2	The user can get data from diverse sources in a structured form.	✓	–
3	The user can know the victims' count and their location who are inside the building.	✓	–
4	The user can know the resources' location and its details	✓	–
5	The user can get the building related information.	✓	–
6	The user can get the hazardous materials' location and its details.	✓	–
7	The user can get real time information access to the other emergency response organizations' databases.	✓	–
8	The user can get family information of the victims.	✓	–
9	The user able to know information related to victims' details.	✓	–
10	User can get trustworthy information.	✓	–
11	Users can not face information overload on the screen.	✓	–
12	Users can understand the language that is visualized on the GUI including acronyms, signs and symbols.	✓	–
13	User can see the rescuers location inside the building.	✓	–

Furthermore, participants who work as CM and SDL mentioned *"we would also like to get access to the GUI as they should also obtain the awareness of the situation to guide SDs"*. However, SDs mentioned *"if we carry small tablets with us, then we will get the information about the victims and their location. However, carrying the tablet would hinder our performances"*.

When it comes to police service participants, the police chief mentioned that "access to the LifeRescue GUI should be given to both control room (112) and police chief who are at emergency site". The reason for this statement was given by the police chief as *"he/she get orders from the control room (112). Police chief informs the control room and wait for their decisions during emergency response process"*. Police chief also mentioned that *"he waits for the decisions that are taken by the superiors at the emergency site. However, having access to the GUI can make him to recognize the suspected person"*.

4.1.4. Existing systems vs LifeRescue GUI

Firefighters do not use any kind of ICT system that can help them to acquire the needed/relevant information automatically from the emergency site. Usually, they take notes manually from the emergency site and later use the collected information to make reports in *"Microsoft word document"* after any kind of fire emergency. These reports are then sent to Directorate for Civil Protection and Emergency (DSB) [32]. All this process is done through electronic mail.

Whereas, police use a lot of ICT systems during emergency response, but they also do not have any kind of ICT system that can help them to acquire the needed information automatically from the emergency site. However, social media like twitter, Instagram and so on are being used by the police department to help them getting the awareness of the situation. However, this channel does not completely give the awareness of the situation. Generally, they collect information either manually from the emergency site or get from the fire chief. This information is then used in emergency reports that are created in the *"Microsoft word document"*.

From our interview with the participants revealed that mainly 2 ICT systems in Norwegian crisis management have been used i.e., A crisis incident management (CIM) tool used by the police, and 2) LOCUS used by the fire and rescue service, and the health service.

CIM tool [33] is a software program for crisis management support, produced by One Voice AS, a company delivering crisis management solutions for a variety of organizations. It supports aspects of crisis management such as quality assurance,

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risk and vulnerability analyses, emergency planning, training, and evaluation. The purpose of this tool is to notify police personnel when major incidents occur. It sup-ports notification and alerting of personnel through distribution lists for sending mes-sages by email, SMS, and phone. The system provides the receiver with several response alternatives which are logged, so that the sender of a message can keep track on the status of each alerted individual [34]. It is currently used by many organizations that the police collaborate closely with, among others, the Directorate for Civil Protection and Emergency Planning (DSB), The Norwegian Civil Defense, and all Norwegian municipalities and county governors.

Whereas, LOCUS is a company delivering mission-critical solutions and products to the fire and rescue service as well as to the health service, among others (e.g. transport and logistics, security service companies). Its solutions are designed to reduce time constraints through being a tool for the emergency agencies to make the right decisions in relation to resource allocation. LOCUS' solutions are used by the 110 and 113 emergency call centrals (TransFire for the fire and rescue service and TransMed for the health service) and mobile devices installed in vehicles for the tactical personnel (TransMobile 7). The detailed information about the solutions can be found in [34]. However, both ICT systems, do not provide the information requirements (see Table E.1) of the different ERs automatically from the emergency site as LifeRescue provides.

When we asked the participants for their opinion on the LifeRescue system, one participant stated as *"I like this new system and would find it helpful. In LifeRescue GUI there are not many clicks and acquiring the relevant information is not complicated at all"*. Another participant commented: *"anyhow, I think this system would be useful. Usually, I should search a lot for information during emergency response. But, in this LifeRescue, I like the visibility of the key information"*.

4.2. Quantitative analysis

During workshop session, a SUS questionnaire has been used to document the participants' opinion on system usability. The results of the SUS responses are presented in Table E.3. The SUS responses in Table E.3 are described as follows.

If the mean agreement scores are ≥4 out of 5, that means the participants Strongly Agreed that they felt confident using the LifeRescue prototype, it was easy to use and ERs would like to use. If the mean agreement scores are <3 out of 5, then the participants generally Disagreed with statements that the LifeRescue prototype was: unnecessarily complex or cumbersome (or required technical assistance), or inconsistent in format (i.e., the mean of the dissatisfaction ratings were on the range of Agree, Strongly Agree or Neutral for most answers to the positively enunciated questions and in the range of Disagree, Strongly Disagree or Neutral for most of the answers for the negatively enunciated questions).

Table E.3: The SUS Scores (Higher Score Implies Better Performance)

SUS questions	**Mean Agreement**	**SD**
Q1. I think that I would like to use this system frequently.	4.4	0.72
Q2. I found the system unnecessarily complex.	1.4	0.81
Q3. I thought the system was easy to use.	4	0.7
Q4. I think that I would need the support of a technical person to be able to use this system.	1.4	0.52
Q5. I found the various functions in this system were well integrated.	3.7	0.83
Q6. I thought there was too much inconsistency in this system.	1.8	0.78
Q7. I would imagine that most people would learn to use this system very quickly.	4.1	0.6
Q8. I found the system very cumbersome to use.	1.8	0.63
Q9. I felt very confident using the system.	3.7	0.44
Q10. I needed to learn a lot of things before I could get going with this system.	1.4	0.83
Learnability dimension (Q4 and Q10)	1.4	
Usability dimension (other 8 questions)	3.11	

4.2.1. Adjective rating

The researchers in [29, 30] used an adjective scale by dividing the SUS scores as follows: score of 0–25: *worst*, score of 25–39: *poor*, score of 39–52: *OK*, score of 52–85: *excellent*, and score of 85–100: *best imaginable*. Authors of this paper also adapted the same adjective scale in our study. The results of the overall SUS scores of each participant response are presented in the Figure E.5. Based on the

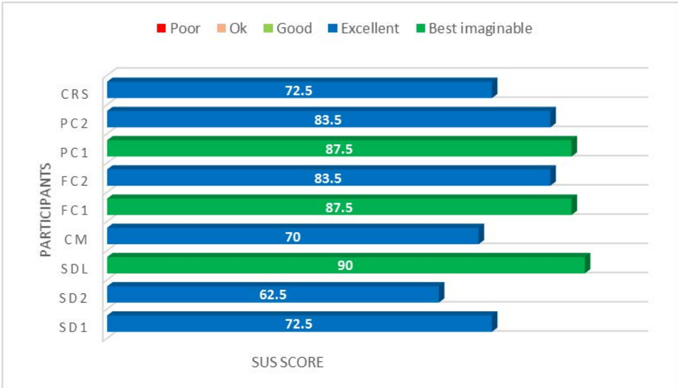

Figure E.5: The SUS Scores based on Each Participant's Response

responses given to the SUS questionnaire, the results show that all the participants have given rating above 60%. Therefore, the LifeRescue achieved "Excellent and Best imaginable" SUS rating. However, the SUS scores calculation can be found in [21]. From Figure E.6, it is observed that SDL (Smoke Diver Leader), FC1 (Fire Chief 1), PC1 (Police Chief 1) and PC2 (Police Chief 2) rated that the LifeRescue is "*best acceptable*" system which can be used to support their work during the indoor fire emergency search and rescue operation. The other participants rated the system as "*excellent*" to be used to support their work during the indoor fire emergency search and rescue operation.

4.2.2. Learnability and Usability Dimensions

In the seminal work of [35], the researcher conducted factor analysis on the SUS statement and then defined two dimensions, i.e., learnability and usability. As per their analysis, the learnability dimension includes the statement 4 and 10, while the usability dimension includes the statements 1, 2, 3, 5, 6, 7, 8, and 9 of the SUS questionnaire (see Figure E.4). The detailed explanation of these dimensions can be seen in the work [21, 35]. In this paper, the authors have also used learnability and usability dimensions to understand users views on the developed LifeRescue.

For learnability dimension, responses to the questions 4 and 10 are considered and calculated. The results of the responses to the questions 4 and 10 to understand the learnability dimension can be seen in Figure E.6. In Figure E.6, it is seen that the response for the question 4 was given 56% as SD (Strongly Disagree) and 44 as D (Disagree). For the question 10, all participants responded 78 % as SD and 22 % as NAND (Neither Agree Nor Disagree). It is because the LifeRescue was very easy to use and no technical person is needed to setup the system. The ERs are usually need to log-in to the LifeRescue web application (see Figure E.2) with

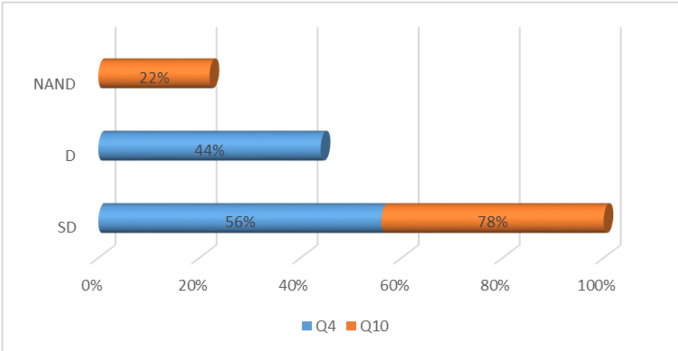

Figure E.6: Responses to the Learnability Dimension

given user name and password to acquire the emergency related information on the main screen (see Figure E.3). Therefore, with the responses, it is perceived that the LifeRescue was not much difficult to learn. Whereas, for the usability dimension,

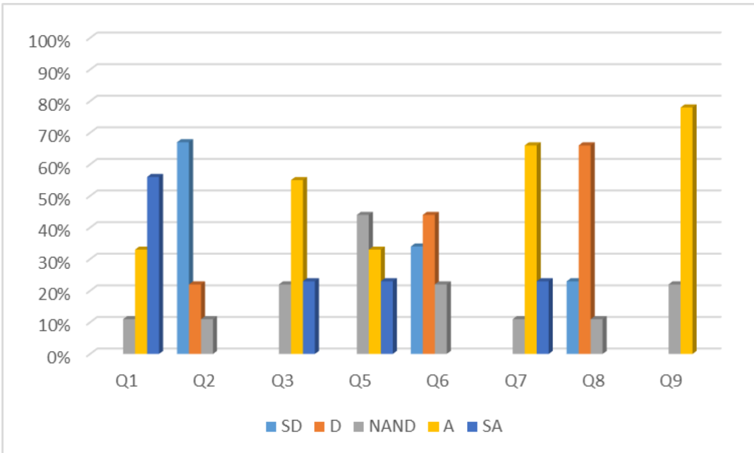

Figure E.7: Responses to the Usability Dimension

the other 8 questions are considered. The responses to these 8 questions can be seen in Figure E.7. Results reveal that all the participants responded as either SA (Strongly Agree) or A (Agree) or NAND for positive questions and SD, D or NAND for negative questions. From the results, it is again perceived as LifeRescue was easy to use. In an overall view, participants mentioned "the system is easy to learn, use and support them to achieve their goals during search and rescue operation". The participants also commented that the colors which are being used in the GUI are good enough to differentiate the different kind of victims and fire related information (see Figure E.3). Participants did not face any kind of usability problems.

V. Discussion and conclusions

Emergency response operations demand well information access to support search and rescue tasks and decision-making at the emergency site and at the command

and control center because the availability of the needed information is one of the bottlenecks [36]. However, in any kind of emergency response, upon arrival at an emergency location, first responders usually use lot of time gathering information to obtain an overview of the situation. The time for which first responders spend on gathering static and volatile situational information from affected people as well as from responsible persons at the emergency site can be reduced if they are given with accessibility or availability of the needed information [16]. Therefore, an approach was proposed which is a holistic way to access information during emergency search and rescue operations. Based on the approach, a LifeRescue information management system was developed to support different ERs for enhancing their response activities during fire emergency in a university building.

When a software system's development is complete, it is necessary to ensure that the outcome is successful. To check that, the design team must check whether the system satisfies the needs and wants of the user. To achieve this, user needs should not only be elicited by techniques such as surveys, focus groups, interviews etc., but they should also be reflected back to users via simulations in order to prototype the user requirements [37]. Therefore, in this paper, we present an evaluation of a developed LifeRescue information management system to ensure that user requirements (of different ERs in case of a fire emergency in the educational building) are met. In addition, we present the usability of the developed prototype.

To evaluate the user and usability requirements of the system, a workshop session was being held with 6 participants from fire and 3 from police departments for testing the developed LifeRescue. The workshop session was incorporated with a prototype demonstration and trail, semi-structured interview and a SUS questionnaire. The findings show that the participants felt that the developed system fits to their purposes and showed their satisfaction that the system fulfills the requirements. All participants mentioned that accessing diverse information from diverse sources was very easy. This information accessibility and availability can make them achieving the situational awareness. The participants also acknowledged that "*they prefer to use this system during any kind of fire emergency response*".

Furthermore, the SUS questionnaire results reveal that all participant gave rating above 60%. That means that the LifeRescue achieved "*Excellent and Best imaginable*" SUS rating. The results show that participants SDL, FC1, PC rated that the LifeRescue is "*best acceptable*" system which can be used to support their work during the indoor fire emergency search and rescue operation. The other participants rated the system as "*excellent*" to be used to support their work during the indoor fire emergency search and rescue operation. When it comes to learnability and usability dimensions, results of the responses to the SUS questionnaire concludes that LifeRescue that the system is easy to use and learn. So, with this obtained results, answer the sub question which was mentioned at the beginning of the paper.

Based on the results of our study, it is anticipated that our methodology can be used for all types of emergencies and fulfills user requirements. Moreover, the lessons learned from this study are two-fold: Firstly, any emergency information system should be easy to use and fast enough to provide relevant/needed information to the involved ERs upon arrival at the emergency site. Another lesson is that ERs information requirements should be met with the support of ICT i.e., integrating diverse data sources, presenting, and sharing the right information to the right people in the right format at the right time which is critical in any emergency response situation.

There were some limitations associated to this study, such as the use of a simulated test environment and a reduced number of end-users. Firstly, the workshop session was carried out with a prototype demonstration and trail in a simulated setting in-stead of a real emergency response environment. So, testing the system in a real emergency settings through a field trial would be recommended. Secondly, the reduced number of participants in the user requirement and usability evaluation can be seen as an impediment of the applicability of the findings in a larger scale. However, the participants meaningfully represented the end-users of the system and in qualitative usability studies, a small number of participants can be sufficient for having valid results [38].

Our potential future research directions will be to develop the LifeRescue by adding the features that are recommended by the participants and test the implemented prototype in a realistic fire emergency response setting for making further improvements of the system.

ACKNOWLEDGEMENTS.

We would like to owe our gratitude to the Grimstad fire and rescue service personnel, and Kristiansand police staff who supported and allocated their time for participating in the workshop session and semi-structured interviews.

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