Approaches and Solutions to Hospital Emergency Department Overcrowding Including Failure Mode and Effect Analysis as a Risk Assessment Technique of Real-time Locating System

Submitted by

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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Abstract

Emergency Departments (ED) are highly dynamic environments comprising complex multi-dimensional patient-care processes. In recent decades, there has been increased pressure to improve ED services, while taking into account various aspects such as clinical quality, operational efficiency, and cost performance. Overcrowding has become a major barrier to receiving a proper and timely emergency care in many acute hospitals throughout the world. Patients often face long waiting times to be seen and treated. Those who require admission may even wait longer. The scope of this research is to focus on ED factors that lead to overcrowding and their management. Technology is being cited as one of the management tools, specifically the utilization of Radio Frequency Identification (RFID) for tracking patients as their journey progresses through an ED.

Like any technology, RFID has potential and pitfalls. The author chose to use Failure Mode and Effect Analysis (FMEA) as a tool to explore the possible failures of RFID technology as it is utilized in one of the ED in Riyadh Military Hospital (RMH). This particular ED has been used as a case study to explore those failures and, with the use of FMEA, propose a set of recommendations to address those failures and improve the design and implementation of RFID. The experience of RMH-ED was explored through interviews and a survey in which 100 participants took part. The survey touched upon various aspects of this experience. This was due to the various roles of the surveyed staff who were involved with this technology. These roles ranged from front line clinical staff to administrative staff, management staff and technical support staff. Data analysis showed convincing evidence of the positive impact RFID had on managing ED overcrowding. However, and as expected, there are some pitfalls and failures that FMEA helped identifying and suggested potential solutions to them. RFID is a small link in the chain of other technological innovations and solutions. It is by no means capable of solving the problems associated with ED overcrowding by itself. Most of the search carried out by the author identified large variation in approaches to dealing with the issue of ED overcrowding. Those ranged from applying more human resources to altering the pathways of managing patients journey through healthcare system to applying more intermediate layers of management to ease the pressure of the Emergency departments. Other approaches included some aspects of technology such as development of early warning systems that have not been widely adopted and remained as isolated efforts.

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Glossary

AMC	Amsterdam Medical Centre
CTAS	Canadian Triage and Acuity System
D-FMEA	Design Failure Mode and Effects Analysis
ED	Emergency Department
EDO	Emergency Department Overcrowding
ENA	Emergency Nursing Association (United States of America)
FMEA	Failure Mode and Effect Analysis
GP	General Practice (United Kingdom)
HFMEA	Healthcare Failure Mode and Effects Analysis
IJEST	International Journal of Engineering Science and Technology
ISO	International Standards Organization
IUH	Innsbruck University Hospital
I.V	Intravenous (a process of drug administration through veins)
JAMA	American Medical Association
JCAHO	Joint Commission on Accreditation of Healthcare Organizations
K.S.A	Kingdom of Saudi Arabia
MIT	Massachusetts Institute of Technology
MMC	Mahkota Medical Centre (Kuala Lumpur – Malaysia)
MoH	Ministry of Health
NPSA	National Patient Safety Association (United Kingdom)
NCCSDO	NHS Service Delivery and Organizational Research and Development
NHS	National Health Service (United Kingdom)
OR	Operating Room
P-FMEA	Process Failure Mode and Effects Analysis
RMH	Riyadh Military Hospital
RFID	Radio Frequency Identification
RPN	Risk Priority Number
RTLS	Real-Time Locator Service
SME	Small and Medium Size Enterprise
SPSS	Statistical Package for Social Science
WMC	Wayne Medical Centre (United States)

Chapter I

Background and Introduction

1.1 Introduction

Emergency Departments (ED) are highly dynamic environments comprising complex multi-dimensional patient-care processes. They provide acute care to patients who present without prior appointment, either by their own means or by ambulance. Workmen's compensation plans, railway companies, and municipalities in Europe and the United States provided accident services in the late mid-nineteenth century. But the first specialized trauma care center in the world was opened in 1911 in the United States at the University of Louisville Hospital in Louisville, Kentucky, and was developed by surgeon Arnold Griswold during the 1930s. Griswold also equipped police and fire vehicles with medical supplies and trained officers to give emergency care while en route to the hospital. (Lancet vol. 2, part 2)

An ED is, typically, located on the ground floor of a hospital, with its own dedicated entrance. As patients can present at any time and with any complaint, a key part of the operation of an emergency department is the prioritization of cases based on clinical need. This process is called triage. EDs manage a variety of conditions and illnesses. The list includes, but not limited to heart attacks, trauma, mental illnesses, and acute exacerbations of respiratory illnesses like asthma. Additionally, they manage less severe illnesses and conditions. These are managed in what is commonly now known as Minor Illnesses and Injury Unit. ED overcrowding happens when the function of a department is hindered by an inability to treat all patients in an adequate manner. This is a common occurrence in emergency departments worldwide. (Aacharya, Gastmans, Denier 2011)

Overcrowding has the potential to compromise patient care and, is considered to be one of the most challenging problems facing ED and their patients today. ED overcrowding refers to an extreme volume of patients that forces the ED to operate beyond its capacity and potentially exceeding conventional nurse-to-patient ratios, providing medical care in makeshift patient care areas, and diverting ambulances to other institutions. Overcrowding has become a major barrier to receiving a proper and timely emergency care in many acute hospitals throughout the world. Patients often face long waiting times to be seen and treated. Those who require admission may even wait longer.

In this context, a failure is defined as breakdown in the workflow and patients journey through ED and on to the rest of the system (admission) or exit (discharge). When this breakdown happens, it could due to lack of integration between various sections of ED (triage, nursing assessment, investigations etc.) where it is difficult to visualize the movement and or aggregation of patients in one area or another in ED, this could represent “bottle neck” that lead to overcrowding. Having the means to integrate visualization of patients’ movement will allow early identification of such “bottle neck” and pre-emptive action to avoid worsening overcrowding.

Extensive research has been undertaken to identify causes of overcrowding, and attempts were made to develop solutions that could deal with and eliminate such causes.

There is a general consensus that the main causes of overcrowding include (Cowan et al 2004):

- Non-urgent visits
- Frequently attending patients
- Seasonal illnesses like influenza
- Inadequate staffing
- Long staying patients due to social reasons
- Hospital bed shortages

Equally, it is agreed that the ED overcrowding results in negative impact that goes beyond the ED itself to include (McCabe 2001):

- Patient mortality
- Transport delays
- Treatment delays
- Ambulance diversion
- Patients walk-out
- Financial impact

It is therefore necessary to view ED overcrowding as a reflection of the larger problem of supply and demand chain mismatches in most healthcare systems, rather than an isolated ED problem. The entire delivery system must be assessed by using reliable methods to understand, measure, and monitor system capacity. When this has been achieved, it likely to reduce the degree of supply-demand mismatch, not just in ED but also in the system as a whole. In response to the problem of overcrowding in ED, a number of solutions have been proposed and implemented with varying degrees of success. Such solutions include (Wilson et al. 2004):

- *Patient flow coordination and facilitation*. This could be achieved through measures such as establishing the role of a “bed czar” or patient flow manager. This person would be responsible for ensuring timely transfer of ED patients to assigned inpatient beds. Assigning a dedicated nurse with admissions/discharge/transfer duties who is specifically responsible for facilitating discharges to accelerate available beds for admissions. Furthermore, development of accelerated triage and registration processes based on patient's acuity could reduce waiting times.

- *Early discharge.* This can be achieved through a number of schemes. These include: Initiation of preliminary discharge by designating patients for early discharge the next day. Establishing a discharge room/lounge for inpatients who have been discharged and are awaiting transportation, medications or education. Establish a discharge coordinator position to coordinate procuring information that is required to discharge the patient. Implement monetary incentives (bonuses) and nonmonetary incentives (movie tickets or cafeteria vouchers) for physicians and nurses to promote efficient and early discharge of patients who are ready to go home.

- *Diversion management and reduction.* This requires establishing new protocols and monitoring systems to allow early warning when the system is approaching its maximum capacity and its threshold for diversion. Develop a hospital-wide diversion response protocol to focus existing resources on facilitating all appropriate patient discharges in a timelier manner. Creation of a community-wide diversion plan in collaboration with local hospitals and the community's emergency medical services unit to establish a common protocol for hospitals going on and off diversion or bypass.

1.2 Research Objectives and Layout

The scope of this research focuses on managing ED-related factors that lead to overcrowding and its management. The aim would be to provide a framework that facilitates systematic understanding of the problem and potential ways to deal with it and to attempt to prevent it from happening in the first place. Various strategies that were developed have been investigated for the purpose of this research, and to test the stipulated hypotheses and related questions outlined next.”.

1.2.1 Key Objectives

The main objective of this research is:

“To investigate the use of technology in health care, especially RFID supplemented by FMEA, as a tool for tracking and management in Emergency department overcrowding”.

The author has a close working relationship with the healthcare system in the Kingdom of Saudi Arabia (K.S.A) and was a witness to the issue of ED overcrowding both personally and professionally. This relationship resulted from the professional position occupied by the author as a biomedical engineer employed by the ministry of defense in K.S.A. After careful consideration of the problem of ED overcrowding and its negative impact on critical and sometime life-saving healthcare provision, the author decided to embark on studying the exact dimensions of this problem and to look at potential solutions. It is expected that such a task will yield vast amounts of information and likely to take far too long to conclude. Therefore, the focus will be restricted to technological solutions. This is compatible with the author’s interests and will be of direct benefit to the field of professional activities he is involved in K.S.A as stated above.

The Riyadh Military Hospital (RMH) is one example of implementing technological solutions to ED overcrowding. The RMH ED is a 100-bed department. These cover Pediatrics, Critical Care, Fast-Tracking, Resuscitation and Short Observation. The department could provide care for up to 1200 patients within a 24-hour period. It utilizes Red (critical or life threatening), Yellow (sick but not critical), Blue (fast tracked) and Green (referral to primary care) triage system. The department has a clinical staffing complement of 65. As such, it is recognized as one of the major EDs in K.S.A. This particular ED utilizes Real Time Tracing System (RTLS) to deal with the ED overcrowding. Radio Frequency Identification (RFID) system, a form of RTLS, was deployed in early 2009. It plays a role in tracking patients' flow through the ED; helps identify potential causes of delay and alert the staff to the need for action.

The RMH was commissioned with the expectation of high demand for its general services, particularly the ED due to the fact that the hospital serves as a central referral healthcare point. And a service that is originally designed to meet the military and their families healthcare needs. Additionally, the RMH facility is where difficult cases from other military healthcare centers are referred; this puts more intense pressure on its resources. This pressure is magnified by the fact that hospital does serve a large portion of the civilian community by virtue of an ethical commitment of the Ministry of defense to this population with such wide attraction of the hospital to healthcare needs. It is imperative to observe a huge input to the hospital and consequently to its ED.

RTLS/RFID seems an ideal technological way for managing ED overcrowding. It provides real-time tracking of all registered patients. This affords ED staff full visualization of what is happening in the department. Any potential bottlenecks could be anticipated and dealt with before they reach the point of obstruction in the flow of patient care. However, despite these obvious benefits of RFID systems, the author attempts to identify their ability to handle the pressure and strain of busy ED workflow. Also, can all possible pitfalls and failures of such system be anticipated and solutions are put in place in the event of such failures? To answer this fundamental question, the author proposes to use Failure Mode and Effect Analysis (FMEA). More details on FMEA are provided in chapters II and III.

This research studied the experience of the RMH with RFID/RTLS. The application of FMEA is an attempt to improve the outcome of this experience and an analysis of what could be done to minimize the effect of ED overcrowding. The combination of FMEA and RFID will rely on survey-based research directed at staff of the RMH ED. Additionally; face-to-face interviews could be used to gain more input. This will seek to establish the reasons behind the perceived success or failure of the technology with those responsible for the implementing and using the system. This research is vital so that the actual benefits of the implementation of RFID in hospitals are more clearly known. In addition, this research will provide case information, which could be used by other healthcare institutes to improve their RFID implementation programs. The FMEA findings will be analyzed and the outcomes will be looked into in a detailed manner. It is hoped that these will be helpful for potential improvements of RTLS in healthcare and in particular in solving the issue of ED overcrowding.

The author proposes the following set of questions as representative of the wide scope of this research work. It is hoped that by providing answers to these questions, the work will be able to measure the precise potentials and benefits of deploying and using RTLS solutions in easing ED overcrowding and allow anticipation or potential failure that impact negatively on the wider and more common adaption of technology, RFID and more, in solving and pre-empting ED overcrowding. This can only be beneficial to patients who will be on the receiving end of high quality healthcare.

The following is a set of questions the author considers key to this work:

1. Has the RFID solution, as a solution to ED Overcrowding, been subjected to significant practical utilization and subsequent literature reviews extensively? If so, what has such solution revealed in terms of anticipated and actual realized benefits?

2. What are the risks and disadvantages (technological and administrative) associated with the deployment of RFID in healthcare?

3. Failure Mode and Effect Analysis (FMEA) has the ability to help identify potential risks and failures and their severity within a system. How can FMEA help in identifying potential risks and failures associated with RFID when used in healthcare?

4. Assuming FMEA as a risk assessment has the potential to successfully identify RFID-associated risks and failures and help develop solutions, what could be done to improve such potential even further?

And the following hypotheses will be tested in this work:

1.2.2 HYPOTHESES:

1. RFID is an appropriate solution in health care management particularly ED overcrowding.

2. Utilization of RFID in healthcare associated to the technological advantage.

3. FMEA is more useful in identifying the risks and their consequences, when used in RFID.

To address these questions the author applied the following:

1. Literature review on the subjects of ED overcrowding, RFID technology and FMEA

2. Studying the hands-on experience of the RMH with applying RFID to deal with its ED overcrowding issue. This has been done via face-to-face interviews and online surveys

3. The obtained input resulting from the interviews and surveys have been analysed and compared with the reality of the impact RFID made on easing overcrowding

FMEA worksheet will be applied to the RMH RFID in order to assess risks associated with the system and put forward recommendations to improve it and consequently enable RFID to contribute further towards easing of ED overcrowding.

1.2.3 Research Work Layout

The author proposes the following structure as a framework for this work:

- Introduction to the issue of ED overcrowding, potential causes of overcrowding. How is overcrowding measured and when does crowding become overcrowding. And finally, the risks associated with overcrowding.

- Literature review introduces a brief summary of the main elements discussed in this research. These are FMEA and RTLS/RFID. This review will be extended to cover both medical and non-medical uses of the technologies. The author proposes to begin with the non-medical uses (for example industrial assets tracking and management).

This would show the deep roots of these technologies in non-medical spheres before they were adopted by the healthcare sector.

- Investigation of proposed solutions to the problem of ED overcrowding. Non-technological solutions will be approached briefly. However, the author will undertake detailed studying of technological solutions.

- Detailed study of RTLS as a technology as a whole. Then, emphasis will be placed on RFID as applied in healthcare. The RMH system will be detailed and used as a template representative of RFID usage in EDs.

- Methodology: As outlined above, the RFID in RMH in K.S.A was used as an example to study the experience of that institute with the implementation of RFID. This was carried out through online surveys, face-to-face and remote interviews. Detailed analysis of this system will be conducted and it will be subjected to FMEA analysis with potential pitfalls identified and potential solutions suggested. After that, the author illustrated the benefits and/or failure of the system as a whole. What lessons can be deduced? Has the RFID, as a technology, contributed to solving the problem of ED overcrowding? If so, then what made it a success? If not then what the reasons behind its failure?

- Discussion of the findings of the FMEA analysis of the RMH ED research unit. These will be contrasted against the initial aims of the project when the RMH set out to implement and use RTLS/RFID. This in turn will help the author to answer some of the key research questions outlined above.

- Conclusions and recommedations: these will be dependent on the aforementioned findings and their discussion. The recommendations are likely to enrich and elevate the current level of the knowledge about RTLS technologies in healthcare when combined with the help of analytical tools like FMEA. Furthermore, inferences could be drawn to provide solutions to ED overcrowding in the context of overall patients flow within the entire healthcare system not just within EDs.

1.3 The Current System

This section provides a view of the healthcare system in K.S.A. This is important as the fieldwork for this project takes place within this system; also the author has been involved directly in this system in his professional capacity.

Healthcare in K.S.A can be classified as a national health care system in which, the government provides health care services through a number of government agencies. Parallel to this, there is a growing role and increased participation from the private sector in the provision of health care services. The Saudi Arabian Ministry of Health (MoH) is the major government agency entrusted with the provision of preventive, curative and rehabilitative health care for the Kingdom's population. The Ministry provides primary health care (PHC) services through a network of health care centres throughout the kingdom. It also adopts the referral system which provides care for all members of society from the level of general practitioners at health centres to advanced technology specialist services through a broad base of general and specialist hospitals (220 hospitals). However, this infrastructure of hospitals and PHC does not meet the requirements of increasing numbers of patients who place an ever-increasing demand on healthcare. The MoH is considered the lead Government agency responsible for the management, planning, financing and regulation of the health care sector. Also, it undertakes the overall supervision and follow-up of health care related activities carried out by the private sector. The MoH stated on its website in 2008 that it aspires "To realise health in its comprehensive concept at all levels for individuals, families, and the society, together with working in co-operation and co-ordination with service providers from both public and private sectors to assist the elderly and those with special needs in a way as to enable them to accommodate their health situations".

Emergency Departments (EDs) are a very important and critical element in the Kingdom's population health, and indeed in any healthcare system. They represent a safety system and they have to be available 24 hours a day, for any patient who requires medical care. There has been a steady increase in the volume and acuity of patient visits to ED. With well over a 100 million of people in the US receiving emergency care annually, this rise in ED utilization has effectively saturated the capacity of EDs and emergency medical services in many communities. This overcrowding now threatens access to emergency services for those who need them the most (AAP 2004). The waiting problem in ED starts the moment a patient arrives at the reception with a complaint. This continues when the patient is either referred on to another specialty or discharged. Prolonged waiting, naturally, leads to increased patient dissatisfaction at base level and possibly clinical risk and/or fatality at the higher end of the scale. This is reflected in an increasing number of patients who leave without being seen and the mounting complaints both verbal and written. Undoubtedly, this picture repeats itself throughout other healthcare systems to varying degrees.

The author understands that solving the problem of overcrowding is multi-factorial; it involves administrative, financial, human resources and technological aspects. All these will need to be taken into account and dealt with in order to achieve a satisfactory approach and outcome to improving the issue of ED overcrowding. However, the scope of this work is to deal with and focus on the utilization of technology, namely RFID, in easing ED overcrowding. This is due to the fact, the author has direct and special interest in this field in a professional capacity. He is associated with the MoH as a biomedical and health informatics engineer. Such statement does not mean that, other factors that were stated earlier and elsewhere in this work are not equally critical to finding the solution. The author acknowledges their significance and realizes that further work by other researchers needs to be done and deal with the non-technological factors. The technological aspect of managing ED overcrowding is the focus of this work.

Chapter II

Literature Review

2.1 Introduction

In this chapter the author aims to set the boundaries of the literature review, they begin by looking at healthcare technology implementation and management. Naturally, this is likely to comprise elements beyond technology itself. Those include: human resources (doctors, nurses and administrative staff etc.), inherent human nature to resist change and availability of the infrastructure and support measures to aid the success of a new technology in achieving and delivering on what it set out to do. The review will not study these elements in detail. Instead, the focus will be directed towards the technological aspects and how these are being implemented throughout various parts the world so far to help dealing with and solving the issue of ED overcrowding.

Initially, this will be a broad look at how various regions around the world deal with ED overcrowding and the spectrum of solutions that were used to tackle the issue. This is due to the global nature of ED overcrowding problem. Carrus et al. 2010 studied this in a report published by McKinsey & Company. They state "ED overcrowding is common in countries across the globe. Patients must often wait hours before being seen by a doctor and far longer before being transferred to a hospital bed. The result is not merely inconvenience but rather a degradation of the entire experience—quality of care suffers, patients' safety is endangered, staff morale is impaired, and the cost of care is increased". Fields WE, 1999, found that one of the reasons for ED overcrowding is that in addition to caring for the acutely ill or injured patients; EDs provide basic healthcare as well which adds more strain on available resources and leads to further overcrowding.

Given the global nature of ED overcrowding, the literature review will be looking at the different perspectives overcrowding is viewed and dealt with in various healthcare systems. One perspective is to see how different approaches emphasize different aspects of overcrowding and focus on different ways of improving it. As mentioned earlier and in various places in this work, ED overcrowding is a multidimensional problem that requires a multidimensional solution. This is true for both the technological and non-technological aspects of the solution. Therefore, RFID utilization is one example of technological aspect of the solution used to solve the problem of ED overcrowding. The literature review is expected to reveal other technological solutions. Such solutions are likely to coexist to and contribute to solving the problem of ED overcrowding. This could lead to questions such as what else can these technologies are used for in order to enhance healthcare provision both in ED and throughout different parts of the system? However, this work looked at the matter of ED overcrowding only rather than looking into other healthcare related uses.

The author used a number of search methods for reviewing the literature of relevance. Those included online searches, utilization of the university's local resources and on a number of occasions ordering resources from other remote facilities when resources are not available locally. Google Scholar has been used extensively as well as linked databases. These have been referenced and acknowledged accordingly. Search criteria for this work included the following keywords: Emergency department overcrowding, healthcare technology, FMEA, RFID, RTLS, RFID in healthcare, FMEA in healthcare and RFID overcrowding.

Technology as a process of achieving an end result or product is, inherently, subject to failures. The causes for such failures are complex and multi factorial. The author aims to look into potential problems associated with the implementation and management of RTLS technology in healthcare and namely ED overcrowding. FMEA was used as a platform for assessing potential failures in RFID RTLS solution. This will help to understand why, if and when, a new technology is introduced could fail to deliver on what it initially promised. This is not saying that the technology itself is dysfunctional. Instead, it may, very well, be that the way it was implemented was suboptimal, rushed or ill thought of. Therefore, the question becomes; how can this be prevented and how can potential failures be anticipated and solutions are ready to deploy when needed?

Both RFID and FMEA are introduced and explained briefly below. The aim is to give readers of this work a clear view of these technologies and provide an understanding of their abilities, when combined, to help with the issue of ED overcrowding.

In summary, the literature review is structured as follows:

- Introduction to RFID/RTLS as a technology, understanding its origins, its basic components and discussing some of its uses in various industries. Then, looking at RFID use in healthcare.

- Introduction to FMEA and understanding its origin, its historic and current applications. Also, a literature review of any uses of FMEA in healthcare.

- Analysis of the literature findings and discussion of their relevance to the subject of this work.

2.2 Real-Time Locator Service (RTLS)

According to the International Standards Organization (ISO), RTLS are systems that provide the location of assets on a constant and recurrent basis (ISO 2006).

An RTLS is a set of radio frequency receivers and associated computing equipment used to determine the position of a transmitting device relative to the placement of the receivers. RTLS tagged objects/assets are read automatically and continuously, independent of the process that moves the tags. With RTLS, no intervention or controlled process is needed to determine asset location. Examples of real-time locating systems include tracking automobiles through an assembly line, locating pallets of merchandise in a warehouse, or finding medical equipment in a hospital.

The ISO describes four classifications of RTLS, these are:

- Locating an asset via satellite (requires line-of-sight) - accuracy to 10 m.

- Locating an asset in a controlled area, e.g. warehouse, campus, airport (area of interest is instrumented) - accuracy to 3 m.

- Locating an asset in a more confined area (area of interest is instrumented) - accuracy to tens of centimetres

- Locating an asset over a terrestrial area using a terrestrial mounted receiver over a wide area, e.g. cell phone towers - accuracy to 200 m.

The ISO states that there are two further methods of locating an object using Radio Frequency Identification (RFID), these are:

- Locating an asset by virtue of the fact that the asset has passed point A at a certain time and has not passed point B

- Locating an asset by virtue of providing a homing beacon whereby a person with a handheld can find an asset

These two methods are of interest to this work as they represent the basic concept for the RFID system used at the RMH ED.

2.2.1 Radio Frequency Identification (RFID)

Rieback et al (2006) maintain that RFID was first used in the United Kingdom to help radars distinguish friendly from enemy aircrafts during World War II. Roberti (2005) clarified this further by stating that, during the war, the Germans, Japanese, Americans and British were all using radar to warn of approaching planes while they were still miles away. There was there was no way to identify which planes belonged to the enemy and which were a country’s own pilots returning from a mission.

The British developed the first active identify friend or foe (IFF) system. They put a transmitter on each British plane. When it received signals from radar stations on the ground, it began broadcasting a signal back that identified the aircraft as friendly. RFID works on this same basic concept. A signal is sent to a transponder, which wakes up and either reflects back a signal (passive system) or broadcasts a signal (active system).

The technology remained underutilized until the early 1990s when scientist at the Massachusetts Institute of Technology (MIT) took the next leap into further development when they used RFID to track and identify objects and assets as they moved. Since then, the technology has made huge advancements in many sectors of modern life. This includes healthcare, although to a lesser extent, as reviewed below.

Generally speaking, in its simplest form an RFID system consists of three main components: a tag, a reader and a host computer or an application device as shown in Figure 1.

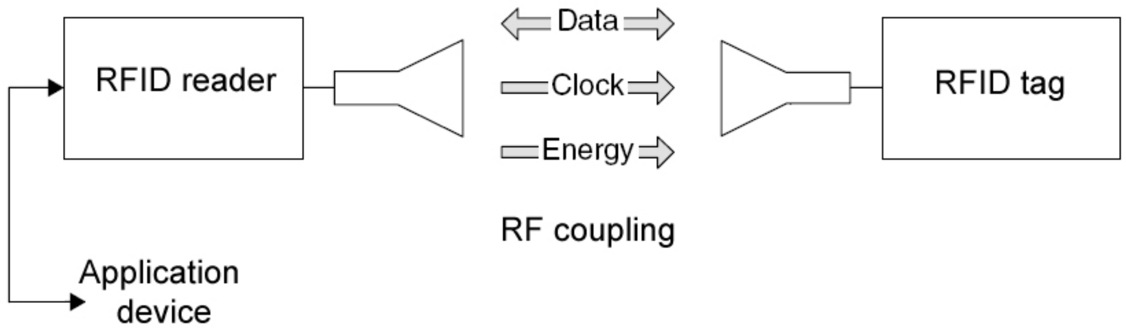

Figure 1: Basic RFID system components (Source: D. Royer. FIDIS 2009)

RFID systems can be closed or open.

- Closed system is defined for a strongly delimited environment (in terms of data exchanged and frequency power). It does not need to be compliant with other data formats or frequency allocation schemes

- Open systems, by contrast, have interfaces to other systems outside their own area of definition and may be functionally or organizationally external (Van Oranje et al 2009)

Van Oranje et al. also describe RFID systems as active or passive systems. This is based on the kind of tag, also known as transponder, structure. A transponder contains copper or aluminum antenna and a memory chip. These are covered in foil.

- A passive tag has no processing capability and no internal power source. By using innate induction properties of electromagnetic fields, the chips are turned on when an electro-magnetic reader is present

- Active transponders transmit signals of their own accord using internal power supplies and more powerful processing and memory storage facilities, which allows them to act like microcomputers. Generally speaking, active transponders can transmit data up to a maximum distance of 30 meters as opposed to a maximum of 5 meters for passive ones. Active RFID represents the essence of RTLS as it allows continuous and automatic tracking of the tagged objects or assets

Heinrich (2005) pointed out that RFID is likely to be among the most exciting and fastest-growing technologies in terms of scope of application in the next generation of business intelligence. It has potential implementation in many sectors such as aviation, building management, enterprise feedback control, healthcare and library services etc.

It can be surmised that, the principal advantages of RFID system include: non-contact and non-line-of-sight characteristics of the technology.

Tags can be read through a variety of visually and environmentally challenging conditions. With a response time of less than 100 ms, an RFID reader can read many (several hundred) tags virtually instantaneously. Tags coupled with sensors can provide important information on the state of the goods. For example, refrigerated goods can be monitored for temperature, problem areas identified and alarms raised (Roberts 2006).

2.3 RFID in Healthcare

Pappu et al (2004) stated that people in a hospital, regardless of a staff member or patient, are always changing their location and may need to be tracked. Doctors, nurses and patients may be needed in case of emergencies. Equipment also needs to be prevented from being stolen. The correct medicine must be given to the right patients along with the right amount at the right time. Thus, all the above factors affect the standard of patient care in the hospitals in order to improve management.

Van Oranje et al (2009) published their final report on the study of the requirements and options for Radio Frequency Identification (RFID) application in healthcare after conducting seven case studies of existing RFID applications. These were based in the United Kingdom, Holland, Germany Switzerland, Italy and the United States. They identified a number of factors that favour RFID deployment in healthcare settings, these include:

1. Patient safety and quality of care improvements and associated cost savings. Patient safety is increasingly recognised as a key healthcare policy area in Europe as evidence is growing on the human and financial costs associated with adverse events in acute care, prescriptions and other aspects of healthcare. Even minor disruptions or errors in care at the patient’s bedside can have severe consequences. The main reason why cost-savings are more of a driver than improvements in patient care – although the two are interrelated – is that “in actual investment/decision-making processes, it always comes down to costs” – a point highlighted with an example of hospitals seeking a solution that provides better documentation to support the hospital’s need to charge or claim an expense.

2. Organisational and financial needs and benefits such as process traceability of medical devices, objects and equipment. This ensures that, equipment and other items are available at the right time and the right place, thus saving time and money. The ability to link personnel, maintenance requests or needs, and expensive medical items

to be serviced for regular maintenance or repair was also identified as a driver of RFID dissemination in healthcare.

3. Process transparency/traceability is needed as the complexity and volume of healthcare provided to patients has been increasing with modern medical technology and innovation. The combination of these characteristics requires a greater need for patient tracking and serialisation of patient identification. One of the seven cases studied (Treviglio Caravaggio Hospital, Italy) has highlighted the operation managerial problem of patient volume and the associated increase in repetitive treatment interactions as a driver of RFID technology as the solution. Medication commissioning and preparation, medical device/product inventory and care working routines are all situations often considered to be a black box. This situation exists in healthcare because most activities and patient care are documented by hand on charts and are not as comprehensive as automated methods. In the UK, for example, it is still the case that most hospitals still admit patients by producing hand-written wristband identification, which can be illegible or incomplete. Thus, many interviewees and respondents felt that RFID technology could help to increase the quality of documentation of patient care, bring documentation closer to the patient and make information readily available in real-time. In essence, RFID can create process transparency and traceability without which real improvements in the process of patient care. The issue of process transparency as a main driver of RFID dissemination in healthcare has been identified in several case studies: namely, Jena, AMC and Geneva. In the Geneva case, process transparency was an issue driving the use of RFID for asset tracking and for the pharmacy. RFID was used to track biological swabs from operating theatre to laboratories, reduce transportation time and wrong-destination “as well as [clarify] responsibilities.” In the pharmaceutical context, the driving force of the RFID application was a motivation “to increase quality and traceability of chemotherapy preparations”.

4. Government policy and private sector interests have been found to be potential enabler and driver of RFID, depending on the policy. More specifically, the driving influence of government occurs through the provision of financial incentives or by directl mandates that favour RFID adoption. In terms of enabling factors, a ‘pro-innovation’ government health policy can be aimed at establishing favourable conditions and assisting small and medium size enterprises (SMEs) in developing and piloting an RFID application to improve processes of care. As clearly emphasised in the context of the one of the case studies at Wayne Memorial Hospital – USA where government regulations acted as an incentive for the adoption of RFID technology to the extent that these applications provide organisations with a tool to comply with regulations. The role of government policy in fostering RFID was particularly evident in another case study in The Netherlands. Here, the Government was a clear driver by leading the initiative of an RFID application, but the recipient never took ownership. This case study represented an example of a government pushing RFID, but ‘missing the point’ which can lead to a failed test, reputational damage, and possibly a setback in the deployment of the technology. This raised a set of important points for government policies such as the need for fostering stakeholder involvement in order to maintain alignment between the interests of the various involved actors and the expected functionalities of the RFID system.

Heavy promotion and hype of RFID (through Government innovation campaigns, innovative companies, the media etc.) can drive its use in healthcare, as hospitals may want to give an image of innovativeness. One interviewee from Wayne Memorial Hospital, stated that “there was increasing use and hype associated with Radar Find.” Another interviewee remarked that the market for RFID in healthcare in Europe was “past the hype” and “ready for mass-market commercial deployment.” What this quote suggests is that publicity in the form of “hype” is perhaps most relevant as a driver at the early stages of deployment (i.e. not mass scale) and that there is a cycle of hype. However, the hype can also have negative impacts, as (hyped) negative opinion-making creates insecurity and image problems which limit investment.

5. System capacity – management structure. The report of Van Oranje et al has highlighted two examples related to the larger issue of system capacity as a driver of RFID dissemination in healthcare. System capacity refers to features of the management structure either at a local site level, or at a regional level. At a local level, it has been shown how the "technologically-enlightened management team, simpler management structure, involving fewer levels and a capacity to quickly make decisions" can strongly influence the dissemination of RFID in healthcare in particular, but also technology more generally. Similarly, the latter example shares features with another example of regional level system capacity. As explained by one of the experts, Canada would be an interesting RFID market to follow because "it has teeth (regional health authorities in most of the provinces are coordinated) and it has the money. It also has a tradition in healthcare to be driven by proof of concept and evidence-based medicine."

   Although these two examples may not indicate that system capacity is a key issue in the suite of drivers of RFID demand in a health context, several sources reviewed for this project stress the importance of understanding the wider environment in which RFID is disseminated from a structural perspective. In fact, bureaucratic management structures constituted a critical uncertainty, discussed in two sections below, of future RFID innovation and dissemination in terms of limited system capacity of top heavy administration in the UK's NHS.

Equally, Van Oranje et al in the same report noted that, while RFID has the ability to benefit the healthcare sector; there are a number of obstacles that could hinder it from delivering such benefits. These obstacles were summarized as:

1. The limited availability of wireless infrastructure and connectivity problems was one of the reasons why staff at the Amsterdam Medical Centre (AMC) was not convinced that RFID technology would be the suitable solution to reduce the administrative burden and produce a flawless measurement of processes, particularly given the fact that wireless communication is not available in the Operating Room (OR). As an interviewee from the California Healthcare Foundation remarked, "the physical infrastructure of hospitals does create dead zones and this needs to be remembered." Similarly, in locations where wireless infrastructure is available, the "connection problem" and reliability under certain software applications

2. Interference between different wireless frequencies present a critical obstacle to RFID dissemination in healthcare because healthcare provision should not cause harm to the patient and RFID interference is a risk to patient safety. In the AMC case, early measurements of interference showed it to be a critical issue of concern and resulted in one of three pilots not being conducted as originally planned. In the Geneva case interference posed major reading problems, whilst in the University Hospital Jena – UK case the same was decided after publication of the Journal of American Medical Association (JAMA) article highlighting the obstacle of interference.

There are two main aspects of interference that could prevent tracking of materials fully and in real-time:

- interference with certain medical devices in OR, or technical installations (e.g. elevators, air-conditioning, etc.)
- interference between passive and active RFID signals, whereby active tags overrule passive ones.

The general consensus is that the technical issue of interference and physical constraints can be considered an obstacle to RFID use in healthcare and is still an issue for specific instruments in hospitals. However, some experts felt that this particular obstacle could and would be overcome interference in the long run when new technologies and the low power 900MHz bandwidth become available.

3. Difficulty of physical integration and attaching RFID tags and their size or the size of the hand-held readers can be an obstacle to RFID implementation in healthcare. Size was an issue identified in four different case studies by Van Oranje et al (AMC, Jena, Geneva and Wayne Medical Center (WMH)). Medication ampoules are one example; they cannot be tagged due to their design or tag size. Thus, having the “right size” for users is a key obstacle to RFID dissemination in healthcare and can mean that in some cases (AMC), RFID cannot serve as a single solution when there are multiple requirements of RFID to operate at two different frequencies that each requires a different size tag. Physical attachment of RFID tags to moving objects or to objects with varying temperatures is problematic when objects cannot be tagged by design or when attached tags are not secure. For example, one case found it is difficult to glue to frozen surfaces such as frozen blood plasma. Another found that RFID does not

work on metal surfaces such as metal-coated bags; and yet another found that most of the tags were sticky tags that easily broke.

4. Cost of the technology means that, the current market of RFID technology is such that RFID tags are more costly than other technologies used to support healthcare delivery and processes, such as barcodes. This was identified as an issue repeatedly. The result of the "relatively high cost of RFID" meant, in some cases, either pilot failure or a move towards a cheaper solution, the higher price differential between the cost of barcode and the cost of RFID has meant that, in the Birmingham case, the cost factor was one reason for re-quoting the system to a client hospital that only wants barcode-tagged wristbands rather than both and cost also seemed to lead to initial "reluctance at the Trust Board level" to pilot the application. The cost obstacle concerns a general issue of emerging technologies, similar to the high costs of the first mobile phones. Hence, as one respondent in to study in Birmingham case noted, "until there is mass production to bring down the price of RFID tags, cost will remain a barrier to general implementation." Another issue to confront is the non- dropping costs of readers." contrast, the Delphi survey showed that, overall, tag costs were perceived as being of low importance (relative to other barriers) but harder to overcome as an obstacle. Across the different stakeholders it was felt that tag prices are coming down and will not be a major barrier in the future and that as long as there is a solid business case (proving return on investment) costs are not much of an issue. However cost may still be a difficult obstacle for a number of reasons.

RFID requires "pervasive network coverage" such as integrating antennas into walls (e.g. for baby protection systems) and major costs are related to building/construction costs, running replacement services, and electricity as well as costs linked with accuracy such that room-level granularity with RFID "can only be achieved with choke-points due to physical laws, which add costs." Hospitals are not ready to carry the costs and are not yet convinced of the benefits. True costs need to be calculated by tagged item and by application, which requires professional planning for which care providers may not always be well equipped. System failure is a cost, and the challenges of effective back up remain unresolved.

5. Identifying and addressing privacy concerns are an issue with a clear human element that surround and hamper RFID dissemination in healthcare. In particular, the perception of risks to privacy was a clear issue that in some cases presented a real barrier to RFID use, but in all cases. In their survey Van Oranje et al revealed how privacy was one of the three most important barriers to RFID applications. However, it was felt that it could be relatively easy to overcome compared to other barriers. One example of how this apparent barrier of privacy concerns can be overcome is most evident in the Jena case. Here, data protection "was considered by design and motivated the decision to limit information stored on the tag." More importantly, the processes for data protection were defined "in cooperation with a number of stakeholders to ensure that concerns were properly addressed." But while these collaborative decisions may have produced a positive effect on perceptions of privacy risks in this case, the same approach in another case or context may not produce a similar effect – herein lays the critical uncertainty of this issue. More generally, social perceptions of RFID technology and cultural norms were issues felt by the largest per cent of respondents (35percent) to have less importance as a barrier but the hardest barrier to overcome. While the collected evidence offer no specific insight into why this result was found, one could argue that social perceptions and cultural norms encompass a range of issues that have perhaps been given less attention or prominence as issues of privacy which have been at the forefront of ethics committees and public debate.

    Moreover, the greater the generality of this issue, and the more diffuse is the problem of perception as a barrier, the more difficult it becomes to find a solution. Despite the difference in relative importance and relative ease of overcoming the barrier between perceived privacy concerns and other social perceptions/cultural norms, three cases and eight interviewees stressed the role of human perceptions about RFID technology, its potential benefits and its monitoring as critically influencing RFID use and dissemination in healthcare. As the AMC case demonstrates, suspicion of the consequences of staff tracking and timing of communication are key uncertainties surrounding the use of RFID. The Jena case showed that discussing RFID actually creates mistrust of the healthcare provider among patients who are confronted with the possibilities of medical error which they had not considered before (i.e. RFID as a solution to a problem/risk that they thought/hoped did not exist).

6. Reliability – data loss or poor quality Data captured by RFID tags must be absolutely reliable in order for subsequent analysis to be of any use. The AMC case showed, if the tracking of waste products is incomplete due to lack of reliability of recording, or poor quality tags, then there is no way to interpret data captured. Incomplete reliability of RFID captured data makes subsequent analysis and understanding difficult, and creates mistrust in the system. The importance of quality of information was well recognised in the Geneva case. The importance of reliability in this case was highlighted by the consequence cost of error management was identified as a barrier to RFID. The survey found that reliability and data integrity were two of the three most important barriers to use and dissemination of RFID in healthcare. In one extreme, it was suggested that when RFID applications use derived location systems to determine where tags are physically, they can generate up to 40% incorrect information" or error messages. But, even when the data quality of RFID tags has an overall error rate of 1-2%, this is considered this to be "prohibitively high" as demonstrated by the Jena case. Given that the practice of medicine aims to follow the creed of "First, Do No Harm". Although data loss or poor quality data constitute a critical uncertainty in their own right, one expert noted a dependence of reliability on achieving data integration; this means that RFID is reliable when properly integrated.

Finally, achieving full accuracy is stated by a number of interviewees as one of the biggest RFID problems for use and dissemination, since costs are linked with accuracy and the issue therefore affects the return on investment. "There is an inverse relationship between accuracy and costs. Thus, the challenge is to find a way to improve accuracy without increasing costs given that better granularity and performance and higher cost are correlated. Apart from costs associated with technological improvements, higher costs are the result of increased human resources. In the Geneva case, the formalisation and validation of all processes by users (e.g. clinicians, nurses, specialists, etc.), upon which data reliability critically depends, required considerable time investment. In addition to clinical process validation, other human resources are needed with enough technical skills to localise the actual errors.

6. Adoption and user compliance with the use of RFID in healthcare can be hampered critically by individuals who do not fully adopt the application in their work practices; this is because RFID and other technologies generally depend on the human-enabled element for use in healthcare. The survey conducted by Oranje et al showed that, “user-friendliness” was perceived as the most important enabler by care providers, whereas industry respondents considered it less important. The study also revealed a number of ways in which user compliance with an application could be less than optimal and these included, but are not limited to, staff frequently forgetting to wear tags; having to remove patient wristbands for certain routines; recharging batteries of hand-held readers; losing components of the RFID application, needing to slide the status tag indicator key and having information and related analysis that is not “simple and intuitive for the end-user.” This last point also relates to the critical uncertainty of user resistance to change insofar as hospital staff may lack the necessary technical skill to work with complex applications. User non-adoption occurs when the RFID application causes any interruptions to routine care work or creates any additional tasks, and this compliance issue is particularly true for nurses who are already overloaded and this new technology is distracting them from nursing. Any new system should consider legacy issues, organisational processes and structures, staff skills with which it will interact into account.

The final report of Van Oranje et al detailing the seven case studies led to the observation that, while acknowledging the obstacles and the need to overcome them, assets and patients tracking are among the most promising benefits of RFID in healthcare.

2.3.1 RFID Implementation in Healthcare Facilities

In the process of literature review and the use of RFID in healthcare, the author reviewed a reasonable number of examples where RFID was implemented in healthcare facilities. The aim is to highlight some of the practical benefits and gains as described by those facilities. Three particular examples were chosen as they span a reasonable length of time with the use of RFID in healthcare and represented different geographical healthcare systems. The review of these experiences revealed some of the issues and shortcomings associated with such implementations. Those examples cover a number of settings and are not being restricted to EDs.

2.3.1.1 Mahkota Medical Centre MMC

MMC is a private medical services provider in Kuala Lumpur- Malaysia. Maternity services if one of the services MMC offers. Some parents of newborn babies successfully challenged the security of the center by “simulating” abduction with their own babies. This prompted the management to implement an RFID system where, newborns are tagged with latex-free and waterproof bracelet that can be adjusted to their ankle. In the event of unauthorized removal of a newborn, the nurse station is notified by an alarm within seconds and the maternity staff could take action immediately at the right location. After a 9-month experience with the system, MMC management stated that this additional service is well accepted by the parents and staff.

2.3.1.2 Heartlands Hospital HH

Bacheldor 2007 reports that the U.K.'s National Patient Safety Association (NPSA) identified cases in which doctors have operated on incorrect sites on their patients' bodies. The term "correct site surgery," NPSA coined, refers to operating on the correct side of the patient and/or the correct anatomical location or level (such as the correct finger on the correct hand). The NPSA's National Reporting and Learning System pilot study, conducted in 28 acute NHS organizations between September 2001 and June 2002, recorded 44 patient-safety incidents related to the wrong procedure, site, operating list, consent or patient name and notes. A further period of testing and development, between November 2002 and April 2003, identified 15 patient-safety incidents linked to surgery at the wrong site. Of these, the NPSA reported, two led to the incorrect procedure.

HH is a public sector hospital in Birmingham – UK. It implemented the Safe Surgery System RFID wristband solution in its thoracic and ENT surgical departments (Bacheldor 2007). The aim was to track surgical patients and procedures they were having done and to help improve patient safety by ensuring that each patient receives the proper care. The “Safe Surgery System” software uses a series of so-called traffic lights, which change from red to green as pre-operative checks are performed. Once all pre-operative checks have been completed and the patient is ready for surgery. When the patient is sent to the surgical ward, an RFID interrogator in the ward reads that person's wristband to retrieve the appropriate patient record, including the planned procedure. In addition, the Safe Surgery System records post-operative procedures. Once the patient is discharged, the RFID-enabled wristband is discarded.

2.3.1.3 Innsbruck University Hospital (IUH)

Wessel (2010)states that IUH in Innsbruck - Austria has installed two RFID-based alarm systems to track workers at its facility who may be confronted with aggressive patients. One system is used by emergency department employees who deal with potentially dangerous situations, such as those involving drunken individuals who come to the hospital for care, while the other is intended for attendants at the psychiatric ward. Both deployments depend on Wi-Fi-enabled battery-powered RFID tags and RTLS software. A caregiver concerned for his or her safety can press a button on the palm-size device, and the system will locate that worker within the building and notify colleagues also carrying the device to come to his or her assistance. The employee knows the help signal was sent upon hearing a beep. IUH extended the system to track psychiatric-ward patients to ensure that they do not leave secure areas of the hospital or the surrounding campus. The system will be able to detect if a patient is alone or accompanied by a staff member or visitor, by finding another tag located near that worn by the patient. If the patient is alone—that is, if no other alarm devices are detected nearby—the system alarm will sound if the patient leaves the perimeter of the secure area.

2.3.1.4 Summary of Benefits and Risks of Using RFID

Based on the literature review, it is possible to summarize some of the benefits of using RFID Systems in healthcare as follows:

- Constant ability to track the location and progress of individual patient
- Ability to monitor the location of doctors and nurses in the hospital in order to ensure optimal use of resources
- Tracking the location of expensive and critical instruments and equipment
- Restrict access to controlled drugs of those of special hazardous nature by unauthorized staff
- Monitor and track unauthorized personnel who should not be present around high-risk areas
- Facilitate triage processes by restricting access to authorized staff and "approved" patients during medical emergencies, epidemics, terrorist threats, and other times when demands could threaten the hospital's ability to effectively deliver services
- Use the patient's RFID tag to access patient information for review and update through a hand-held computer

In contrast to the above benefits, it would be useful to mention some of the risks associated with the utilization of RFID. Van der Togt and colleagues (2008) said RFID caused interference with medical equipment in 34 of the 123 tests they performed. It would seem that on the one hand, while the idea of RFID is to improve patient safety and hospital efficiency, on the other hand, it could be undermining both. It was concluded that, in a controlled nonclinical setting, RFID induced potentially hazardous incidents in medical devices. Implementation of RFID in the critical care environment should require on-site EMI tests and updates of international standards.

2.4 Failure Mode and Effects Analysis (FMEA)

Failure mode and effects analysis (FMEA) is a proactive tool developed to identify, evaluate and prevent product and/or process failures (Bluvband 2009).

The Department of Defense in the United States described FMEA is a systematic way of assuring that every conceivable potential failure of a design/process has been considered with the objective of minimizing the probability of failure (Anleitner 2010). Since then, FMEA methodology became more wide spread and is now, extensively, used in a variety of industries including semiconductor processing, aerospace, food service, plastics, software, and healthcare.

The United States armed forces formally introduced FMEA in the late 1940s for military usage (Rausand 2005). Later on, the technique was applied in aerospace development to avoid costly errors. Subsequently the technique was quickly adopted widely by the industry. Implementation of FMEA in healthcare is relatively new according to Latino (2004) who maintains that, many healthcare risk managers first heard about FMEA when the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) released its Leadership Standards and Elements of Performance Guidelines in July 2002.

Figure 2.2 below shows the author's representation of how the FMEA process follows cyclical format. This is a modified representation based on the original image proposed by Leggett (2011). The components of the cycle are explained in details below. Detection (Detect) of the fault represents the staring point of FMEA cycle. Naturally, the other stages follow until the cycle is completed. It is then, repeated to study the impact of any actions takes in reducing the original fault(s).

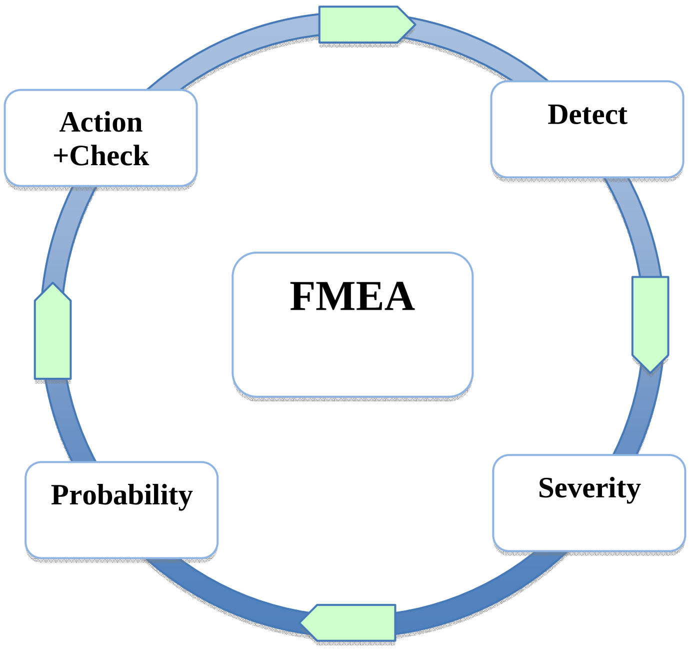

Figure 2 FMEA Cycle (author's representation)

2.4.1 Procedure of Building a FMEA Cycle

Crow states that the presence of certain conditions would improve and speed up the process. These conditions include:

- Description of the product/process and its function
- Clear understanding and articulation of the product or process under consideration is important to have clearly articulated.
- Consider both intentional and unintentional uses since product failure may lead to injuries, losses or even litigation

1. Identify Failure Mode. A failure mode is defined as the manner in which a component, subsystem, system, process, etc. could potentially fail to meet the design intent

2. Describe the effects of those failure mode. For each failure mode identified the designers of the systems should determine what the ultimate effect will be

3. Establish a numerical ranking for the severity of the effect. A common industry standard scale uses 1 to represent no effect and 10 to indicate very severe with failure affecting system operation and safety without warning. This enables the engineer to prioritize the failures and address the real big issues first

4. Identify the causes for each failure mode. A failure cause is defined as a design weakness that may result in a failure. The potential causes for each failure mode should be identified and documented

5. Establish a probability factor. A numerical weight should be assigned to each cause that indicates how likely that cause is (probability of the cause occurring). A common industry standard scale uses 1 to represent not likely and 10 to indicate inevitable

6. Identify Current Controls (design or process). Current Controls (design or process) are the mechanisms that prevent the cause of the failure mode from occurring or which detect the failure before it reaches the Customer. The engineer should now identify testing, analysis, monitoring, and other techniques that can or have been used on the

same or similar products/processes to detect failures. Each of these controls should be assessed to determine how well it is expected to identify or detect failure modes. After a new product or process has been in use previously undetected or unidentified failure modes may appear. The FMEA should then be updated and plans made to address those failures to eliminate them from the product/process

7. Determine the likelihood of Detection. Detection is an assessment of the likelihood that the Current Controls (design and process) will detect the Cause of the Failure Mode or the Failure Mode itself, thus preventing it from reaching the Customer.

8. Review Risk Priority Numbers (RPN). The Risk Priority Number is a mathematical product of the numerical Severity, Probability, and Detection ratings:

   RPN = (Severity) x (Probability) x (Detection)

   There is no standard for the choice of scale ranking, but, generally, FMEA team prefers ranking of 1 to 10,because it provides ease of interpretation, and, at the same time, accuracy and precision (Stamatis, 1995) to prioritize items than require additional quality planning or action.

9. Determine Recommended Action(s) to address potential failures that have a high RPN. These actions could include specific inspection, testing or quality procedures; selection of different components or materials; de-rating; limiting environmental stresses or operating range; redesign of the item to avoid the failure mode; monitoring mechanisms; performing preventative maintenance; and inclusion of back-up systems or redundancy

10. Assign Responsibility and a Target Completion Date for these actions. This makes responsibility clear-cut and facilitates tracking

11. Indicate Actions Taken. After these actions have been taken, re-assess the severity, probability and detection and review the revised RPN's. Are any further actions required?

12. Update the FMEA as the design or process changes, the assessment changes or new information becomes known.

Crow (2002) described building a FMEA cycle as below. The author found that, this description is generally shared among various authors, researchers and manufacturers.
The author followed similar path when building the FMEA sheet for this work.

Figure 3 below shows a graphical representation of a simple FMEA sheet. It highlights the steps mentioned above. As mentioned above the author followed a similar process in building the FMEA relevant to this work. There will some variations to reflect the healthcare nature of this sheet.

Failure Mode and Effects Analysis (FMEA) Worksheet

Page:		of	

System, Product, or Process:		Owner:		Date:	

Background				Rating				Countermeasure			Results			
Description	Potential Failure Mode	Potential Effect of Failure	Root Causes	SEV	OCC	DET	RPN	Owner	Due / Done	Action	SEV	OCC	DET	RPN

Figure 3: Sample FMEA Sheet (Velaction 2009)

2.4.2 Types of FMEA

Generally speaking, FMEA exists in two forms. There are Designs and Process FMEA. Both types are described briefly below. Both types of FMEA use Severity, Occurrence and Detection to produce a rating of risk, although the definitions of the ranking scale for each will be different depending on application, and should be tailored to the specific business setting under investigation.

2.4.2.1 Design FMEA

McDermott et al (2009) stated that, Design FMEA (D-FMEA) is used to analyze products before they are released to manufacturing. It considers all possible failures modes that might occur within a product or artifact. This focuses on how the product will behave during use by its intended customer and seeks to identify design deficiencies that will result in safety hazards, product malfunction or shortened product life.

D-FMEA will normally break the product into its constituent parts, in order to consider what function each will serve and what impact an individual component failing will have on the system as a whole. This requires knowledge of dependency relationships among components, both under normal operations and under external perturbations (Pillay and Wang, 2002). A product is normally represented schematically as a block diagram or structural component tree to aid this process.

The purpose of D-FMEA is to ensure that the system meets the customer expectations and performs to the design intent. With this goal in mind the key outputs of a D-FMEA include the identification of failure at the product development phase, which in turn enables a priority for design improvement actions to eliminate potential design deficiencies and safety concerns, and provides a documented rationale for any recommended design changes. Through the identification of critical and significant product characteristic, the D-FMEA also serves to inform about control requirements and will provide information for product design verification and testing. The design team or engineers, usually, assume the responsibility for D-FMEA at the stage of the product's life.

Though the process of establishing Design and Process FMEA might be separate activities, the outcomes are intrinsically related. Stamatis (2003) states that it is preferred that a D-FMEA should be performed before P-FMEA, and that the design information should be made available in order to aid the progress of the Process FMEA. Conceptually this is appropriate as FMEA serves to map the causal chain from end user right back to the root cause (i.e. the initiating cause of a causal chain) during the manufacturing or assembly process. It is fairly common to find that the causes identified in the Design FMEA represent the Failure Mode in the Process FMEA.

2.4.2.2 Process FMEA

Process FMEA (P-FMEA) analyses manufacturing and assembly deficiencies and allows consideration of how the process could fail to achieve an intended design. Consequently, how such failure might affect the customers of that process. Such customers can be both external customers (end user) and internal customers (the next process or team). The process attributes of manpower, equipment, material, methods, and environment represent the major sources of potential failure modes, and addressing these causes will form the basis for reducing risk. Each of these attributes has its own components, which may react individually, in tandem, or as an interaction to create a failure. Because of this complexity, completing a Process FMEA is considered more complicated and time consuming than a design FMEA (Stamatis, 2003). Process FMEA serves to identify process deficiencies, offers a prioritized corrective action plan, and documents the rationale for process changes. It also identifies critical and significant process and product characteristics enabling the development of control plans, which outline the measures in place to ensure process control and product quality assurance. Responsibility for the Process FMEA should normally fall to the engineer or team who has (technical) authority. This might include the manufacturing, industrial or technical process engineer associated with the manufacturing or assembly process.

2.4.3 Implementations of FMEA

The author identified a number of FMEA implementations in the industrial sector. These have been chosen as a representative list rather a fully inclusive one as FMEA process is far reaching and is used in almost in aspects of industrial designs.

2.4.3.1 FMEA Implementation in the Food Industry

Scipioni (2002) describes how one food company Elled SpA used FMEA methodology design and implementation as a tool to assure products quality, and as a mean to improve operational performance of the production cycle. Scopioni states that the FMEA team members focused on the study of wafer biscuit production lines. Such work permitted the company to increase knowledge and control capacity on processes and products. The generated data can be used as a useful technical database for future update of FMEA in Elled SpA and as a model of FMEA design for similar company. In a similar fashion described above, Scopioni summarizes the application of FMEA to a production cycle: analysis of the process or product in every single part, list of identified potential failures, evaluation of their frequency, severity(in terms of effects of the failure to the process and to the surroundings) and detection technique, global evaluation of the problem and identification of the corrective actions and control plans that could eliminate or reduce the chance of the potential failures.

Scopioni concluded, “This task cannot be achieved on an individual basis because FMEA is a team function”. In the analyzed case, the FMEA team included some members of the internal staff knowledgeable and experienced in the product or process. They were the Production Manager, the Quality Assurance Manager, the Mechanical Manager, the Maintenance Operators and the Group Leads, and on external member, the FMEA expert, with the task of coordinate team activities based on the implementation of FMEA theory and the data collected during the work.

2.4.3.2 FMEA Implementation in Medical Device Technology

Wetterneck et al (2006) described how "The Hospital" a Mid-Western, tertiary care, academic medical center, had previously implemented robotic dispensing and point-of-care bar-coded medication administration system to improve the medication-use process.

A multidisciplinary team conducted a FMEA process to guide the implementation of a smart Intravenous (IV) pump that was designed to prevent errors that could be committed during programming of the pump. The smart IV pump was equipped with a dose-error reduction system that included a pre-defined drug library in which dosage limits were set for each medication. Monitoring for potential failures and errors occurred for three months post implementation of FMEA. Specific measures were used to determine the success of the actions that were implemented as a result of the FMEA. The FMEA process at the hospital identified key failure modes in the medication process with the use of the old and new pumps, and actions were taken to avoid errors and adverse events. IV pump software and hardware design changes were also recommended. The FMEA team identified 13 of the 18 failure modes that were reported in practice after pump implementation. A beneficial outcome of FMEA was the development of a multidisciplinary team that provided the infrastructure for safe technology implementation and effective event investigation after implementation. With the continual updating of IV pump software and hardware after implementation, FMEA can be an important starting place for safe technology choice and implementation. Wetterneck concluded that, FMEA was useful in identifying potential problems in the medication-use process with the implementation of new smart IV pumps. Monitoring for system failures and errors after implementation remains necessary.

2.4.3.3 FMEA: Methodology, Design and Implementation in a Foundry

Kumar et al. (2011) described how FMEA was used as a tool to assure products quality and as a mean to improve operational performance of the process. The work was developed in an Indian foundry Ghatge – Patil industries. The foundry produces ductile iron castings such as car brake drums, transmission cases, cylinder heads and flywheel housing. Internal staff members were chosen as FMEA team members. They were asked to focus on the study of core manufacturing process.

Kumar et al. described, the by now familiar steps, that applying FMEA to a process means following a series of successive steps: analysis of the process in every single part, list of identified potential failures, evaluation of their frequency, severity and detection technique, global evaluation of problem, and identification of the corrective actions that could eliminate or reduce the chance of potential failures. The design and subsequent implementation of FMEA in this foundry has permitted it to detect which were the most probable and serious problems or causes in the core making process responsible for core rejection. The methodology operated by the FMEA team allowed the foundry to study and analyze every single step of core making process and to achieve an exhaustive knowledge and improvement of product and process and substantial cost savings can be realized. The improvements obtained by the implementation of the recommended actions thus reduce the individual RPN and the global risk level of the process. Thus reduces costly liability of the core making process that was not performing as promised. FMEA, in this case, aided to improve and plan preventive and schedule maintenance of the process equipment. Thus, it improved operational performance of the core making process. The criteria used to evaluate these problems or causes are the amount of damage caused to the production in terms of core rejection or lost production volume and subsequent monitory loss.

2.5 Approaches to ED Overcrowding

As discussed above, ED overcrowding is a problem that crosses geographical boundaries and is common to ED departments irrespective of their degree of development. The following is review of the different approaches followed by various healthcare systems. Those were chosen as representative of their geographic, economic and political characteristics, the review encompasses of the majority of approaches adopted globally.

2.5.1 Resource Utilization and Triage

Triage is defined here as the process of categorizing ED patients according to their need for medical care, irrespective of their order of arrival or other factors including sex, age, socioeconomic status, insurance status, residential status, nationality, race, ethnicity or religion.

Nour El Din (2006) conducted a study of ED utilization and its impact on hospital running cost and the flow of patients throughout the system. Based on the results of this study, he recommended to get the approval of the hospital administration on the reported bed complement and to use this bed complement consistently for reporting hospital utilization statistics. Also, he recommended the implementation of a number of mechanisms to improve occupancy rates and reduce their fluctuations, especially in male units, therefore reducing the overall hospital costs. These measures include identifying units that should be downsized or aggregated to achieve consistent optimal occupancy rates and developing optimal patient placement rules across the reorganized units.

Rehmani et al (2007) studied the utilization of an emergency department of a hospital in the eastern region of Saudi Arabia for a period of three years in an effort to identify factors leading to overcrowding and ways of dealing with them. They concluded that emergency department utilization increased during the study period, with almost no change in the proportions for triage category. The number of patients requiring hospital admission increased, as did the length of their stay. Nearly 60% of emergency visits are for Canadian Triage and Acuity Scale(CTAS) categories IV and V care, where in category IV patients need to be seen by a physician within 60 minutes 85% of the time and in category V patients need to be seen by a physician within 120 minutes 80 % of the time. There were a significant number of patients with multiple visits to ED. They recommend the strengthening of the primary health care in that institution and a designated “Fast Track” in ED for the expeditious management of low acuity patients.

Elkum et al (2009) set out to investigate the waiting time for patients before seeing a physician in the emergency department of a tertiary care hospital in Riyadh, Saudi Arabia. They analyzed routinely collected data from 2187 patients to determine the association between selected patient characteristics and waiting time. They found that the median waiting time between triage and being seen by a physician was 35.0 min (range1.0–325.0 min). Age, day of arrival, times of arrival and triage category were significantly associated with waiting time. Interestingly, older patients and those arriving on Sundays and Wednesdays waited longer. Variability in waiting times could be addressed by more standardized triage policies, but may also be influenced by other clinical or non-clinical factors that require further investigation.

Qureshi (2010) attempted to identify other aspects of the daily workflow in ED that could reduce overcrowding. He describes ED is one of the most important components of the health delivery system. The review evaluates some of the international literature on triage in order to provide evidence-based data for the medical community in Saudi Arabia specifically and the Eastern Mediterranean region generally. Triage involves an assessment to prioritize ED patients in need of immediate care, in accordance with clinical severity and time urgency, compared with patients with less urgent illnesses who can wait longer to be seen or who need referral to a more appropriate health care setting. Qureshi concluded that Triage, applied strictly using standard principles in EDs, psychiatric settings and health disaster situations, remains a complex issue. Primary and secondary decisions by triage nurses and physicians and related health outcomes are influenced by a variety of internal factors related to triage personnel and external factors related to the operational mechanisms of the ED.

Triage nurses use a constellation of factors to make triage decisions and initiate emergency care, including personal capacity, experience, intuition, pre-hospital information and communication with colleagues.

In Saudi Arabia, nurses mostly have no involvement in triage decision-making. Yet the time has now come for health policy-makers to reflect seriously on the phased application of a nurse triage system across EDs in all health settings. The issue of frequent ED visits by patients might be solved ,and patients' satisfaction improved, by managing patient waiting times better and briefing patients at presentation and at discharge. Qureshi suggested that auditing triage decisions and consequent health outcomes is a useful activity as it addresses an important quality indicator of healthcare in ED settings. The United Kingdom is a representative of ED overcrowding in Europe and the way it is dealt with. The author is aware that variations exist among the different European nations. However, the U.K was chosen as a model that is most likely to be influential.

Proudlove et al. (2003) looked at issue of solving ED overcrowding from a management point of view, bed management (BM) that is. They attributed long ED waiting times largely to the lack of a" buffer" of empty inpatient beds, which could absorb the backlog of decisions to admit, particularly overnight and at weekends. Such backlogs cannot start to be cleared until general hospital activity resume again in themorning.BM should be seen as part of operational capacity management and the narrow sense of bed finding. It plays a key part in establishing and maintaining a stock of empty beds. Contributions to demand management include promoting the appropriate use of beds, gate-keeping General Practice (GP) urgent referrals, influencing the volume, timing and placement of electives to match expected capacity (that is, discharges, emergencies, and opening/closing beds). The outcome of the study was that supply management measures include: establishing and maintaining a discharge focus. It was observed that operational capacity management is very poorly developed in most acute hospitals and faces many major cultural and political barriers, particularly in relation to the interaction between the surgical and medical side. However, and despite this there is great potential though to move to anticipatory and coordinated planning, and current initiatives may hold the key to achieving the reduced levels of occupancy necessary for the efficiency gains required to enable the hospital system to be meet the responsiveness demanded of it in the healthcare system in the UK.

In a similar theme to that of Qureshi (2010) Terris et al. (2004) looked at how a consultant led triage could help making an impact on ED overcrowding. The consultant and a senior ED nurse, known as the IMPACT team, staffed the triage area for four periods of four hours per week, for three months between December 2001 and February 2002. Patients

normally triaged by a nurse in this area instead had an early consultation with the IMPACT team. Data were collected on all patients seen by the IMPACT team. The number of patients waiting to be seen (for triage with major and minor illnesses) was assessed every two hours during the IMPACT sessions and at corresponding times when no IMPACT team was operational. The study concluded that by using a senior clinical team for initial patient consultation, the numbers of patients waiting fell dramatically throughout the ED. Many patients can be effectively treated and discharged after initial consult by the IMPACT team.
Patient flow modeling is another area of focus that has been looked into as a means of managing the length of stay in ED and across an entire healthcare system.

Marshall et al. (2005) studied that latest trends dealing with patient flow through the healthcare system by modeling and simulations. They believe that the future of modeling patient activity in healthcare can be built on the successes of current models and the currently evolving hybrid approaches. One view is to consider the modeling techniques as forming a toolbox of data mining, data analysis, and operational research and artificial intelligence methods. This toolbox would facilitate preliminary data preparation and initial statistical analysis with advanced methods for modeling health care resources and inference techniques for providing further predictions. The reported complexities of health care systems coupled with the availability of vast amounts of health related data necessitate the inter-disciplinary collaboration of research in this area.

Cooke et al. (2004) prepared a report to the National Coordinating Centre for NHS Service Delivery and Organizational Research and Development (NCCSDO) in which they systematically reviewed present innovations in reducing attendances and waits in ED in the UK. The report was extremely detailed and looked into vast sums of data, most of which are beyond the scope of this work. However, the author chose the following conclusions as points of interest.

- It is possible to divert some emergency 999 calls to advice lines (the safety of such systems is still being evaluated)
- The role of paramedics in either discharging patients from scene or deciding on appropriate destinations has not been adequately studied to confirm its safety and effectiveness in the UK

- Primary care gate keeping can reduce emergency department attendance but its safety is unknown. Walk-in centers and NHS Direct (national telephone helpline) have not been demonstrated to reduce attendances at EDs

- Fast track systems for minor injuries or illnesses reduce waits, ideal configurations should include senior staff

- Attendance by the elderly, those with chronic disease and those with multiple attendances may be reduced by various interventions; trials are needed in this area, including the role of social workers

- Patient education is unproven in most areas except chronic disease management

The above recommendations show that approaching the issue of ED overcrowding should be multifaceted and must take into account the complex reasons leading to it. Consequently, solving the problem of ED overcrowding should be multifactorial and must combine all tools and methods. It is clear that, there is no one solution that solves all.

2.5.2Early Warning and Forecasting

Hoot (2006) discusses establishing an early warning system as a way of preventing ED overcrowding and avoid reaching a crisis point. A crisis period of ED overcrowding has been defined as a period when ambulances are diverted to nearby hospitals. Hoot describes an early warning system as one that must incorporate two components: a clear definition of a crisis period (as above) and means of predicting crises.

To assess the utility of the early warning system, a cost function must be associated with the alarms generated. This will depend on how the institution responds to alarms. It must take into account the costs incurred by calling in reserve staff or opening additional treatment bays, and it must consider the benefit achieved by maintaining efficient operations in the ED. This benefit may take the form of increased revenue for the hospital or intangible societal benefits arising from improved access to emergency care. The intervention policy and cost function must be developed jointly with ED administrators. These elements are necessary to determine the optimal operating point of the system, so that the expected utility will be maximized.

Further work by Hoot et al. (2009) attempted to develop a tool that helps forecasting ED overcrowding. The result was called Forecast ED. The following variables were recorded for each patient visit to estimate parameters for, and to generate forecasts by, the Forecast ED tool: (1) time of initial registration at the ED, (2) time placed into an ED treatment bed, (3) time of hospital bed request, if applicable, (4) time of discharge from the ED facility, (5) triage category assigned to the patient, (6) whether the patient left without being seen, and (7) whether the patient was admitted to the hospital. Each institution collected these data from ED patient-tracking information systems. It was successfully used for five different sites. Its forecasts were more reliable, better calibrated, and more accurate at 2 hours than at 8 hours. The reliability and calibration of the tool were similar between the original development site and external sites; the boarding count was an exception, which was less reliable at 4 of 5 sites. The Forecast ED tool generated potentially useful forecasts of input and throughput measures of ED crowding at 5 external sites, without modifying the underlying assumptions.

As mentioned earlier in this work, ED overcrowding should not be looked at in isolation from the rest of the hospital. Schull et al. (2001) conducted a longitudinal study of the impact of hospital restructuring on EDs. The study incorporated 20 hospitals and lasted for 10 years. It showed that hospital restructuring might worsen ED overcrowding. While the total number of patients visits remained fairly steady over the study interval, five EDs out of 20 (25%) closed following restructuring. This compares with an 8% reduction in the number of EDs in the United States over five years from 1994 to 1999. These five EDs treated 15% of all Toronto ED patients in the last year that they were open. In addition, the rate at which EDs closed may have exacerbated overcrowding: the first three EDs were closed within seven months of each other, and the other two followed within the next two and a half years. The rapid pace of closures may not have allowed the remaining EDs to expand services or improve efficiency rapidly enough. Thus, it is concluded that rapid restructuring of hospitals may seem to be cost-effective; it tends to lead overcrowding of EDs as a way of compensation for lost services elsewhere in the system.

In statement of its position on ED overcrowding (Journal of Emergency Nursing 2006), the Emergency Nurses Association (ENA) of the USA identified a number of reasons for the problem such as: Crowding is a systems issue that results from increased input as well as inefficient patient flow throughout the hospital. Initiatives to reduce and eliminate factors that contribute to crowding must have a broad focus and should address both operational and policy issues on a systems level. Institutional leaders, including nurses, physicians, and administrators, must be committed and involved in implementing patient flow and other initiatives to improve hospital and ED capacity in an effort to eliminate ED crowding and ensure safe, quality patient care. The ED must work with and receive support from all components of the health care system to improve the efficient disposition of emergency patients. Emergency department crowding is a hospital-wide problem caused by factors that extend far beyond the institution itself. The ENA concludes that when ED crowding occurs, the number of patients in need of care outweighs the availability of resources, potentially resulting in diminished quality and safety of patient care and increased stress and dissatisfaction of staff. Efforts to examine issues of input, throughput, and output in order to optimize patient flow throughout the hospital system are vital for addressing factors that lead to ED crowding. Therefore, it is imperative that institutions identify and implement best practices for addressing hospital and ED crowding on a systems level.

The design of the FMEA sheet used in this work took into account the nature of the work iself, which is related to healthcare services that are reliant on technology, namely RFID. Potential failure modes have been identified as a result of field observations, discussions that took place with medical and technical staff at RMH and project supervisors, and the as a result of reviewing RFID systems while preparing the literature review. Data was then gathered from the field by the author who visited the MoH ED and observed utilization of RFID in practice. Based on those observations, the literature review of FMEA and RFID as discussed in chapter two, and consideration of various designs of FMEA that have been considered, the final choice of the FMEA sheet design was made as shown below in Figure 4. The design of the FMEA sheet for this work shares its main features with similar sheets that have been studied by the author, and applies to the identification of potential failures in systems that blend technology and human actions such as ED and common problem of overcrowding.

Chapter III

Research Methodology

3.1 Introduction

In this chapter the author intends to introduce the design of the research methodology. Based on the nature of the problem being looked into, emergency department overcrowding, qualitative research has been adopted as a framework. The nature of such framework and the reasons for adopting it are detailed below. A number of elements have been chosen and built into the framework. These include: surveys, interviews (face-to-face and remote) and visits to the site where an RFID system has been implemented and utilized for over a period of 18 months as discussed in Chapter 1. RFID represents the solution being studied as one of the methods in dealing with ED overcrowding. FMEA has been chosen as a method for exploring potential weaknesses and gaps in RFID in healthcare. By its nature, application of FMEA allows for anticipating failures and preparing solutions for them. As mentioned elsewhere, the combination of RFID and FMEA in this way may lead to a more robust application of RFID in ED overcrowding.

It is appropriate, at this juncture, to remind the reader of the research questions that have been discussed in Chapter 1:

1. Has RFID, as a solution to ED Overcrowding, been reviewed extensively? If so, what has such review revealed in terms of anticipated and actual realized benefits?
2. What are the risks and disadvantages (technological and administrative) associated with the deployment of RFID in healthcare?
3. Failure Mode and effect analysis (FMEA) has the ability to help identify potential risks and failures and their severity within a system. How can FMEA help in identifying potential risks and failures associated with RFID when used in healthcare?
4. Assuming FMEA as a risk assessment has the potential to successfully identify RFID-associated risks and failures and help develop solutions; what could be done to improve such potential even further?

3.2 Qualitative and Exploratory Research

Qualitative research is an unstructured research methodology based on small samples that provides insights and understanding of the problem setting (Dung 2006).

Another definition of qualitative research is that it is a method of inquiry employed in many different academic disciplines, traditionally in the social sciences, but also in market research and further contexts (Denzin 2005). Qualitative research often categorizes data into patterns as the primary basis for organizing and reporting results. Qualitative researchers typically rely on the following methods for gathering information: Participant Observation, Non-participant Observation, Field Notes, Reflexive Journals, Structured Interview, Semi-structured Interview, Unstructured Interview, and Analysis of documents and materials (Marshall 1998).

The Office of National Statistics in the United Kingdom states that, qualitative methods play an important part in developing, maintaining and improving survey quality by assessing vital issues that field pre-tests and pilot surveys alone cannot address (Wilmot et al. 2005). They are better able to identify the problems experienced by respondents in answering questions because they place a more systematic and in-depth spotlight on each question and its administration, as well as routing and instructions. Wilmot et al. state that the benefits of qualitative pre-field testing include:

- Improvement of reliability of responses
- Improvement validity of responses
- Reducing non-response (both unit and item)
- Reducing processing error and need for imputation
- Improving cost efficiency

Qualitative research provides an understanding of how or why things are as they are. Here the discussion between the interviewer (or moderator) and the respondent is largely determined by the respondent's own thoughts and feelings. The interview tends to be longer than a quantitative interview and fewer interviews are conducted (Confianzys 2011).

Qualitative research is designed to reveal a target audience’s range of behavior and the perceptions that drive it with reference to specific topics or issues. It is agreed that the results of qualitative research are descriptive rather than predictive (Guidry 2006). Exploratory research is a form of qualitative research. It is often used to look into a problem that has not been clearly defined and helps determine the best research design, data collection method and selection of subjects (Schutt 2006). Also, according to Schutt, exploratory research often relies on secondary research such as reviewing available literature and/or data, or qualitative approaches such as informal discussions with consumers, employees, management and more formal approaches through in-depth interviews, focus groups, projective methods, case studies or pilot studies. The results of exploratory research are not usually useful alone for decision-making, but they can provide significant insight into a given situation. Although the results of qualitative research can give some indication as to the "why", "how" and "when" something occurs. Schutt states that, exploratory research has the goal of formulating problems more precisely, clarifying concepts, gathering explanations, gaining insight, eliminating impractical ideas, and forming hypotheses. Schutt adds that, exploratory research can be performed using a literature search, surveying certain people about their experiences, focus groups, and case studies. Exploratory research may develop hypotheses, but it does not seek to test them. Exploratory research is characterized by its flexibility.

Given the properties of the qualitative and exploratory research, it is clear that they would represent an ideal platform onto which the author can build this research work. To explain further, qualitative research would enable studying the experience of the emergency department at the Riyadh military hospital with RFID and its ability to help deal with overcrowding at the department. Qualitative and mixed research can be conducted via the utilization of a number of tools. These include: surveys, interviews or observations. Since qualitative research is flexible as indicated above, one can opt to use any combination of these tools as appropriate in order to research the question at hand.

The author used such flexibility and elected to combine a number of effective research tools as discussed below.

3.3 Qualitative Surveys

Qualitative surveys are used to gather facts about people's beliefs and experiences in certain jobs, about a being service offered or any other activities. The design of the survey should allow participants the freedom to express their views in response to the questions asked without any influence or clues from the interviewer (Robson 2002). The questions are usually open ended. This allows the respondents to write either positive or negative responses based on the type of questions. The data gathered in this way is helpful if the researchers seek to understand how people feel about certain issues; for example: experiences in using certain products, getting services offered by practices, hospitals, and restaurants. Responses from the participants could influence the services provider to adapt different strategies in designing certain products to suit the needs of users or receivers. Qualitative surveys are flexible and could be worded in different ways to allow participants to give responses in their own words compared to a "yes or no."

The author chose and designed a survey to help in understanding how RFID is perceived by its users as a method to reduce ED overcrowding. A total number of 100 potential participants have been identified with the help of the director of the ED at the Riyadh military hospital. They gave their explicit consent to participate in the survey. Given the number of participants and the logistics and costs involved in disseminating the surveys to them, the author made use of the knowledge base within the available online services that will facilitate contacting the participants, allow them to anonymously respond to the survey and keep track of the percentage of participation. Additionally, these services offer real-time continuous analysis of the responses as they arrived. Screenshots of the online survey are provided in the Appendix.

The participants have been identified through almost all the spectrum of workers at the ED department at the Riyadh military hospital. These include management staff, technical staff, nurses and physicians who work in ED.

3.3.1 Online Qualitative Survey

The author chose to use an online secure and widely used service to gather data from the participants in this research work. This is due to the fact that, at the time of data gathering, the author resided in the United Kingdom while the participants worked in the MoH ED in Saudi Arabia. This geographic distance and the busy medium in which the participants worked made using online data gathering timesaving and more convenient for all stakeholders. The online qualitative surveys set out to explore the experience of the staff with the ED overcrowding, its impact on healthcare services and the use of RFID system as they experienced it at various levels according to their work assignment.

The author approached the design of the survey by utilizing an online service (Survey Monkey) . It affords a flexible design for almost any purpose and a good number of forms for collection of data. This includes pre-defined questions that the author adapted to the research topic, one of multiple choices, free text answers or a combination of those possibilities. The design of the survey is minimalist to avoid any distractions or confusion. A number of screen shots have been captured and presented in the appendix section of this work. Respondents were presented with a total of 29 statements which, have been divided in the these areas:

- Causes of ED Overcrowding
- Effects of ED Overcrowding
- Management of ED Overcrowding
- Applied and implemented solutions to ED overcrowding
- RFID as a solution to easing overcrowding

Participants were asked to give their points of views through pre-defined options for each of these statements. Table 1 shows areas discussed above and the breakdown on the statements as put to the participants.

Table (1): Survey Statements

Causes of ED Overcrowding
1. I believe overcrowding is caused by inappropriate visits made by patients who do not require emergency care 2. I believe ED overcrowding is caused by lack of appropriate number and skills level of staffing in the department 3. I believe ED overcrowding is caused by Access Block (ED patients needing admission, cannot be admitted due to lack beds in the department of destination) 4. I believe ED overcrowding is caused by poorly designed facilities and lack of space in the department 5. I believe ED overcrowding is caused by overcomplicated management policies and care pathways 6. I believe ED overcrowding is caused by out-dated clinical patient tracking systems
Effects of ED Overcrowding on Patients
7. I believe ED overcrowding causes extended pain and suffering 8. I believe ED overcrowding is a risk for poor outcomes 9. I believe ED Overcrowding causes ACTUAL poor outcome 10. I believe ED overcrowding causes dangerous delayed diagnosis and treatment 11. I believe ED Overcrowding causes significant patient dissatisfaction
Management of ED Overcrowding
12. I believe ED overcrowding can be reduced when the issue is viewed with the context of overall pressure on the entire healthcare system 13. I believe ED overcrowding can be reduced by increasing the number and expertise of ED staff 14. I believe ED overcrowding can be reduced by better design of the way patients flow through the department (forms and paperwork) 15. I believe ED overcrowding can be reduced by educating the public about the proper use of ED resources 16. I believe ED overcrowding can be reduced by applying/implementing technological solutions
Applied and implemented solutions to ED overcrowding
17. I believe ED overcrowding can be reduced by having a dedicated bed-management team to tackle the issue of Access Block. 18. Consultant or Senior ED nurse lead triage could help making an impact on ED overcrowding 19. Diverting some of the emergency calls to advice help lines enabling Paramedics to assess and discharge at the scene could help reduce ED visits 20. An early warning system that could alert to the development of overcrowding could help management prepare and apply resources to prevent overcrowding 21. I believe ED overcrowding can be solved by implementing technological innovations such as Radio Frequency Identification of patients and assets
RFID Tagging as a potential solution in easing ED Overcrowding
22. I found the RFID system too complicated to use 23.The RFID system does not always function the way it is supposed to 24.The RFID system made our department less crowded than before we started using it 25.The RFID system should not be relied upon as the only solution to ED Overcrowding 26.The training I received on using the system was adequate 27.The technical support I received/continue to receive was adequate 28.The ED patients did not like wearing the RFID tags 29.The RFID should be extended throughout the whole hospital system

3.4 Interviews

The purpose of qualitative research interviews is to understand something from the subject's point of view and to uncover the meaning of their experiences (Kvale 1996). Interviews allow people to convey to others a situation from their own perspective and in their own words. Kvale continues and describes interviews as conversations with structure and purpose. Such structure and purpose are defined and controlled by the researcher. Semi structured interviews are conducted on the basis of a loose structure consisting of open-ended questions that define the area to be explored, at least initially, and from which the interviewer or interviewee may diverge in order to pursue an idea in more detail (Britten 1995).

In a similar fashion, the author identified a number of personnel at the ED department at the Riyadh military hospital and pursued their consent to conduct semi-structured interviews with them. These personnel were chosen based on the fact that they fulfill high-level management roles and are generally decision-makers. They have been involved in the process of using the RFID system in the ED department from the planning to the implementation phases. The outcome of such interviews will be analyzed in a similar fashion to that of the qualitative surveys while allowing for some differences such as extended personal and professional views of interviewees. In a similar fashion to the data collection from surveys, interviewees will remain anonymous and their responses will be standardized. The total number of interviewees is 10; they include the head of the ED department. The nature and scope of the questions dealt with during the interviews are similar to those shown to participants when they respond to the online survey. This makes standardization easier, and provides a contrast between the details obtained from the survey and those obtained from interviews.

3.5 FMEA Sheet Design

As discussed above, the process of creating a FMEA cycle requires designing a FMEA sheet. The author followed the principles of designing a basic sheet as shown in the literature review chapter. Given the nature of this work which covers the process of managing ED overcrowding; the author chose P-FMEA as the basis for approaching the design of the FMEA sheet. This is despite the fact that P-FMEA is complicated and time consuming (Stamatis 2003). Such choice has been made, as P-FMEA is able to simulate and accommodate complex processes like healthcare and namely the all to often fast moving, pressurized and work environment like an ED.

The design took into account the nature of the work, which is related to healthcare services that are reliant on technology, namely RFID. Potential failure modes have been identified as a result of field observations, discussions that took place with medical and technical staff at RMH and project supervisors, and the as a result of reviewing RFID systems while preparing the literature review. Data was then gathered from the field by the author who visited the MoH ED and observed utilization of RFID in practice. Based on those observations, the literature review of FMEA and RFID as discussed in chapter two, and consideration of various designs of FMEA that have been considered, the final choice of the FMEA sheet design was made as shown below in Figure 4. The design of the FMEA sheet for this work shares its main features with similar sheets that have been studied by the author, and applies to the identification of potential failures in systems that blend technology and human actions such as ED and common problem of overcrowding.

The main features of P-FMEA include: focus on the potential process-related failures and their causes, the assumption that the design is sound and that the development of recommended actions is targeted at eliminating the root cause of the potential failure. The sheet shows the potentials capabilities of FMEA in detailing components of processes.

RMH ED RFID FMEA

Key Process Step	Potential Failure	Effects of failure	Severity	Potential Causes	Frequency	Current Controls	Detectability	Risk Priority Number	Actions Recommended	Responsibility	Actions Taken	Severity	OCC	DET	RPN
What is the Process Step?	In what ways can the Process Step fail?	What is the impact of failure on the Key Output?	How **Severe** is the effect?	What causes the Key Input to go wrong?	How **often** does cause or FM **occur**?	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can the Cause or the Failure Mode be detected?		What are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?	Note the actions taken. Include dates of completion.				
								0							0
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Figure 4: FMEA Sheet related to this work

At this stage the work managed to describe FMEA, some of its applications in the medical and other fields. A FMEA sheet has been established to which future researchers who would follow up on this work could apply the survey data to it later.

3.6 Study subjects:

A sample of 100 subjects (ED clinicians, nurses, para medical staff and technical staff) from the Military hospital had constituted as study subjects of this survey.All these subjects have participated in the online survey.

3.7 Pilot study:

A pilot study was carried out using 20% of the sample, so as to observe the correctness of the responses and test and retest correlation was calculated to assess the initial validity of an instrument.

3.8 Statistical methods:

Descriptive statistics (mean, standard deviation and proportion) are used to summarize each item of an instrument. Pearson chi-square test was used to compare the difference in the distribution between observed responses and expected responses for 29 items of 5 factors. Scale reliability was assessed using Cronbach's alpha statistic. Construct validity of the instrument was assessed through convergent and discriminate validity by using correlation matrix. Principal component factor analysis with varimax rotation was performed, to come up with the significant loadings of each factors of an instrument. The cross loadings will be detected if any. A p-value of < 0.05 will be considered as statistically significant. Bar diagrams was used to show the distribution of 5-point scale responses of each of the items of the 5 factors. All statistical analysis will be carried out using SPSS Pc+ version 19.0 statistical software.

Chapter IV

Results

4.1. Validity and Reliability of Questionnaire

The author achieved the validity and reliability of the instrument of the research "The Application of FMEA Risk Assessment technique in RTLS implementation in health care improvement" by using Factor analysis and Cronbach's alpha for the whole scale and each dimension of the instrument.

The following flow chart explains the methods used to assess the validity and reliability of the validation instrument:

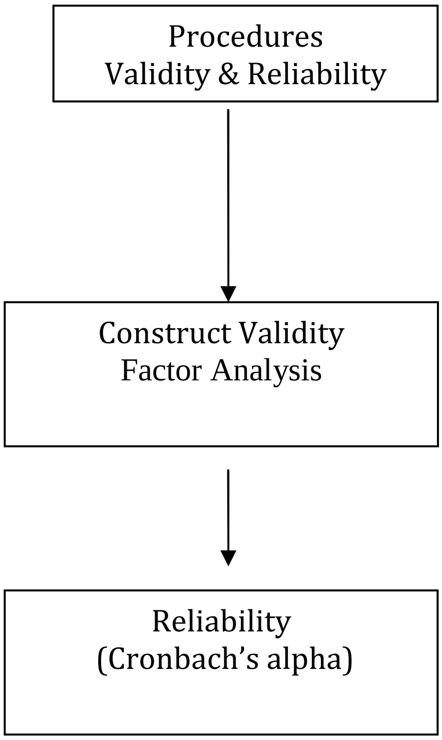


Figure 5: Flow chart validation

4.1.1 Construct Validity of an Instrument (Confirmatory Factor analysis)

Construct validity refers to the degree to which the items on an instrument relate to the relevant theoretical construct. Construct validity is a quantitative value rather than qualitative distinction between valid and invalid. It refers to the degree to which the intended independent variable (construct) related to the proxy independent variable (indicator variable). When an indicator consists of multiple items, factor analysis will be used to determine construct validity.

The correlation among the 29 items of an Instrument showed highly statistical significant correlation.

Table 2: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.666
Bartlett's Test of Sphericity	Approx. Chi-Square	1002.590
	df	406
	Sig.	.000

4.1.2 Kaiser-Meyer-Olkin (KMO) and Bartlett's Test

The KMO measures the sampling adequacy which should be greater than 0.5 for a satisfactory factor analysis to proceed. Looking at the above table (Table 2), the KMO measure is 0.666. From the same table, we can see that the Bartlett's test of sphericity is significant. That it’s associated probability is less than 0.05. In fact, it is actually <0.0001. This indicates that the correlation matrix is not an identity matrix.

Table 3: Communalities of each of the items of 5 Factors

	Initial	Extraction
Factor1(Item1)	1.000	.532
Factor1(Item2)	1.000	.482
Factor1(Item3)	1.000	.452
Factor1(Item4)	1.000	.615
Factor1(Item5)	1.000	.693
Factor1(Item6)	1.000	.632
Factor2(Item1)	1.000	.568
Factor2(Item2)	1.000	.591
Factor2(Item3)	1.000	.599
Factor2(Item4)	1.000	.645
Factor2(Item5)	1.000	.588
Factor3(Item1)	1.000	.533
Factor3(Item2)	1.000	.480
Factor3(item3)	1.000	.626
Factor3(Item4)	1.000	.478
Factor3(Item5)	1.000	.407
Factor4(Item1)	1.000	.512
Factor4(Item2)	1.000	.563
Factor4(Item3)	1.000	.583
Factor4(Item4)	1.000	.196
Factor4(Item5)	1.000	.418
Factor5(Item1)	1.000	.583
Factor5(item2)	1.000	.498
Factor5(Item3)	1.000	.447
Factor5(Item4)	1.000	.436
Factor5(Item5)	1.000	.610
Factor5(item6)	1.000	.489
Factor5(Item7)	1.000	.465
Factor5(Item8)	1.000	.516

The above table (Table 3) of communalities shows how much of the variance in the variables has been accounted for by the extracted factors. For instance over 53.2% of the variance in Item1 of Factor1 (Reasons for ED overcoming) is accounted for while 61% of the variance in Item5 of Factor5 (Radio frequency identification (RFID) tagging is accounted for.

Table.4: Total Variance of 5 Factors

Total Variance Explained			
Component	**Initial Eigen values**		
	Total	**% of variance**	**Cumulative%**
1	5.830	20.102	20.102
2	3.422	11.801	31.904
3	2.180	7.516	39.420
4	2.100	7.241	46.661
5	1.704	5.874	52.535

4.1.3 Total Variance Explained

The above table shows all the factors extractable from the analysis along with their Eigen values, the percent of variance attributable to each factor, and the cumulative variance of the factors. Notice that the first factor accounts for 20.102% of the variance, the second 11.801%, the third 7.516%, the fourth 7.241% and the 5^{th} factor 5.874%.

4.1.4 Scree Plot

The scree plot is a graph of the Eigen values against all the factors. The graph is useful for determining how many factors to retain. The point of interest is where the curve starts to flatten. It can be seen that the curve begins to flatten between factors 6 and 7. Also note that factor 7 has an Eigen value of less than 1, so only 5 factors have been retained.

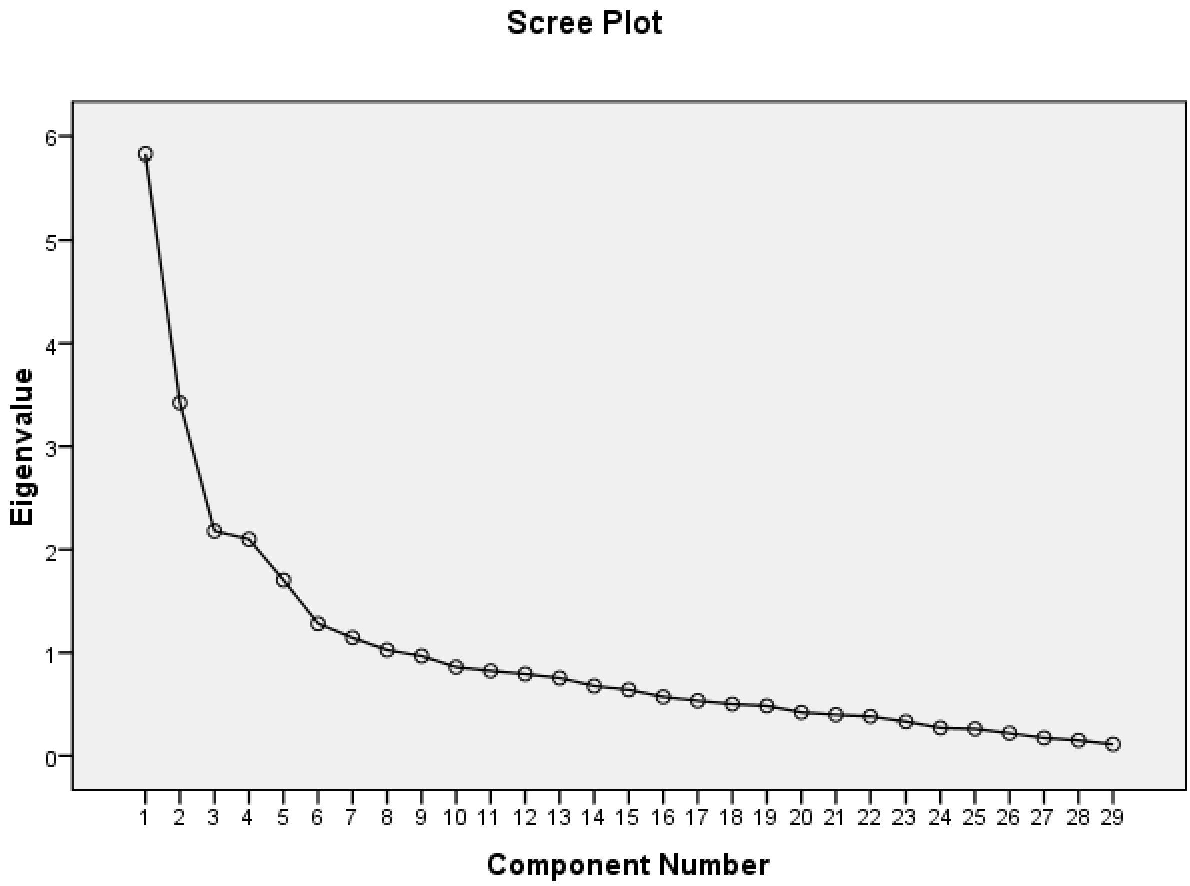


Figure.6: Scree plot for Factor extraction

4.1.5 Component (Factor) Matrix

The table below (Table 5) shows the loadings of the 29 variables (items) on the 5 factors extracted. The higher the absolute value of the loading, the more the factor contributes to the variable. The loading indicates all the factors have contributed to each of its items. But the Factor 3 (Managing ED overcoming) Factor 4(Applied and implemented solutions to ED overcoming) and Factor 5 (Radio frequency identification (RFID) tagging) loadings were overlapping each other. This is due to the construct and meaning of some of the items under these three factors.

Table.5: Rotated Component Matrix

	Component				
	1	2	3	4	5
Factor1(Item1)	.066	.408	.067	.161	**.575**
Factor1(Item2)	.006	.021	.402	-.436	**.360**
Factor1(Item3)	-.047	.440	.127	.018	**.489**
Factor1(Item4)	.003	-.026	.169	-.308	**.700**
Factor1(Item5)	.040	.100	-.032	.010	**.825**
Factor1(Item6)	.048	.226	-.002	.003	**.761**
Factor2(Item1)	-.102	**.594**	-.354	-.252	.128
Factor2(Item2)	.104	**.752**	-.058	.068	.081
Factor2(Item3)	.402	**.635**	-.142	.105	-.064
Factor2(Item4)	.189	**.692**	.223	.282	.031
Factor2(Item5)	-.052	**.736**	-.144	.086	-.122
Factor3(Item1)	.193	.292	-.039	**.623**	-.144
Factor3(Item2)	**.399**	-.182	.526	.026	-.099
Factor3(item3)	**.638**	.005	.163	**.412**	.149
Factor3(Item4)	.399	.110	.200	**.499**	-.132
Factor3(Item5)	.146	.155	.184	**.569**	-.060
Factor4(Item1)	**.559**	-.014	-.025	.443	.048
Factor4(Item2)	**.644**	-.027	-.038	.381	-.036
Factor4(Item3)	**.612**	.082	.071	.361	-.257
Factor4(Item4)	**.288**	.187	-.049	.268	.065
Factor4(Item5)	**.305**	.118	.174	.122	-.515
Factor5(Item1)	.114	.166	**.367**	.070	.635
Factor5(item2)	-.095	.081	**.626**	.191	.232
Factor5(Item3)	-.069	-.074	**-.067**	**.647**	.119
Factor5(Item4)	-.059	.275	**.270**	.195	-.496
Factor5(Item5)	.018	-.017	**.778**	.050	-.050
Factor5(item6)	.013	-.315	**.569**	-.093	-.239
Factor5(Item7)	.047	-.054	**-.362**	-.031	.572
Factor5(Item8)	.107	-.075	**.686**	-.085	-.146

4.1.6 Reliability (Internal consistency) of an Instrument:

Reliability refers to the ability of an instrument (questionnaire) to consistently measure an attribute and how well the items fit together conceptually. One of commonly used estimator of reliability is Internal consistency reliability.

The following tables provide the item analysis of each of the 5 factors of the instrument and the analysis of whole instrument.

Table 6 Item statistics of FACTOR 1: Causes for ED overcrowding

Factor 1	**Scale Mean if Item Deleted**	**Scale Variance if Item Deleted**	**Cronbach's Alpha if Item Deleted**
Item			
1	15.19	11.323	.693
2	16.02	12.337	.702
3	15.33	10.404	.602
4	15.57	8.855	.580
5	15.53	8.252	.535
6	15.63	8.639	.541

The internal consistent reliability of 6 items for factor1 was assessed by calculating cronbach's α. From the above table it can be observed that the α values was ranging from 0.535 to 0.702 for 6 items, where items 3, 4, 5 and 6 the values were lower than the significant acceptable level of 0.70, whereas items 1 and 2 values were having significant level of 0.70. But the average measure of cronbach's α value of all the 6 items under the Factor1 is 0.660, with its 95% confidence interval of 0.539 to 0.759.

Table.7: Intra class Correlation Coefficient of Factor1

Factor 1	Intra-class Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Average Measures	.660	.539	.759	2.945	89	445	.000

Table.8: Item statistics of FACTOR 2: Effect of ED overcoming on patients

Factor 2	**Scale Mean if Item Deleted**	**Scale Variance if Item Deleted**	**Cronbach's Alpha if Item Deleted**
Item			
1	14.06	6.368	.778
2	14.64	5.468	.693
3	14.61	5.521	.712
4	14.61	5.701	.737
5	14.17	5.758	.715

The internal consistent reliability of 5 items for factor2 was assessed by calculating cronbach's α. From the above table it can be observed that the values were ranging from 0.693 to 0.778 for 5 items, where all the 5 items were having significantly acceptable level of 0.70. And the average measure of Cronbach's α value of all the 5 items under the Factor2 is 0.770, with its 95% confidence interval of 0.686 to 0.838.

Table.9: Intra class Correlation Coefficient of Factor2

Factor 2	Intra class Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Average Measures	.770	.686	.838	4.357	89	356	.000

Table.10 Item statistics of FACTOR 3: Managing ED overcoming

Factor 3	**Scale Mean if Item Deleted**	**Scale Variance if Item Deleted**	**Cronbach's Alpha if Item Deleted**
Item			
1	13.28	5.079	.637
2	13.31	5.722	.677
3	12.86	5.361	.571
4	12.57	5.417	.562
5	12.08	5.601	.567

The internal consistent reliability of 5 items for factor3 was assessed by calculating cronbach's α. From the above table it can be observed that the values was ranging from 0.562 to 0.677 for 5 items, where α values were having lower than significantly acceptable level of 0.70. But the average measure of cronbach's α value of all the 5 items

Table.11 Intra class Correlation Coefficient of Factor3

Factor 3	Intra class Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Average Measures	.655	.528	.756	2.900	89	356	.000

Under the Factor3 is 0.655, with its 95% confidence interval of 0.528 to 0.756.

Table.12 Item statistics of FACTOR 4: Applied and implemented solutions to ED overcrowding

Factor 4	**Scale Mean if Item Deleted**	**Scale Variance if Item Deleted**	**Cronbach's Alpha if Item Deleted**
Item			
1	13.24	4.973	.603
2	13.36	4.614	.581
3	13.30	4.752	.618
4	13.09	5.543	.741
5	12.34	6.453	.705

The internal consistent reliability of 5 items for factor4 was assessed by calculating cronbach's α. From the above table it can be observed that the α values was ranging from 0.581 to 0.741 for 5 items, where items 1,2 and 3 values were lower than the significant acceptable level of 0.70, whereas items 4 and 5 values were having significant level of 0.70. But the average measure of cronbach's α value of all the 5 items under the Factor4 is 0.704, with its 95% confidence interval of 0.595 to 0.791.

Table.13: Intra class Correlation Coefficient of Factor 4

Factor 4	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Average Measures	.704	.595	.791	3.381	89	356	.000

Table.14: Item Statistics of FACTOR 5: Radio Frequency identification (RFID) tagging

Factor 5	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Cronbach's Alpha if Item Deleted
Item			
1	19.98	7.797	.418
2	19.79	7.090	.337
3	18.51	8.859	.480
4	18.98	8.584	.489
5	19.44	6.564	.303
6	19.56	7.665	.393
7	18.84	10.133	.585
8	20.14	7.833	.372

The internal consistent reliability of 8 items for factor5 was assessed by calculating cronbach's α. From the above table it can be observed that the values were ranging from 0.303 to 0.585 for 8 items, where values were lower than the significant acceptable level of 0.70. But the average measure of cronbach's α value of all the 6 items under the Factor5 is 0.466, with its 95% confidence interval of 0.282 to 0.618.

Table.15: Intra class Correlation Coefficient

Factor 5	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Average Measures	.466	.282	.618	1.873	89	623	.000

Table.16: Reliability of Whole Instrument (Item statistics)

	Scale Mean if Item Deleted	**Scale Variance if Item Deleted**	**Cronbach's Alpha if Item Deleted**
Factor 1			
1	87.74	93.361	.802
2	88.58	99.662	.813
3	87.89	90.841	.791
4	88.12	90.378	.797
5	88.09	86.419	.787
6	88.19	86.919	.786
Factor 2			
1	87.24	99.715	.813
2	87.83	93.511	.798
3	87.80	91.038	.792
4	87.80	89.937	.790
5	87.36	95.917	.804
Factor 3			
1	88.47	90.387	.795
2	88.50	92.680	.799
3	88.04	89.886	.789
4	87.76	91.602	.793
5	87.27	93.906	.798
Factor 4			
1	88.12	91.637	.793
2	88.23	90.675	.792
3	88.18	89.586	.790
4	87.97	92.976	.800

5	87.22	96.130	.801
Factor 5			
1	89.01	94.079	.801
2	88.82	95.361	.804
3	87.54	97.195	.807
4	88.01	95.831	.806
5	88.48	94.387	.804
6	88.59	98.739	.812
7	87.88	100.491	.816
8	89.18	96.485	.804

The internal consistent reliability of 29 items of all the 5 factors was assessed by calculating cronbach's α. From the above table it can be observed that the values were ranging from 0.786 to 0.816 which were more than the significant level of 0.70. But the average measure of cronbach's α value of all the 29 items is 0.805, with its 95% confidence interval of 0.742 to 0.859.

Table.17: Intra class Correlation Coefficient of all items

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Average Measures	.805	.742	.859	5.128	89	2492	.000

4.2 Data Analysis of Responses

The data of 90 (out of 100) study subjects who were responded using an on online accessible survey and unstructured interviews was analyzed. The online data gathering and survey system assigns a unique identification number to each participant and personal computer so that it insures one response by one user. Also, the author has been able to assign a number of automatic rules that control data gathering, collating similar data and obtain basic statistical data in raw format.

The survey covered 29 items; these were grouped under five main headings including:

- Causes of ED overcrowding
- Effects of overcrowding on ED patients
- Management of ED overcrowding
- Applied and implemented solutions to ED overcrowding
- RFID as a potential solution for ED overcrowding

The responses were on a 5-point scale.

4.2.1 Causes of ED Overcrowding

Analysis of the six items covered under this heading shows that, the first reason of ED crowding (I believe that overcrowding is caused by inappropriate visits made by patients who do not require emergency care) had the distribution of responses, where 33.3% of study subjects had responded as “possibly”, 30% as “one of the reasons” 17.8% as definitely and 18.9% as not sure. The distribution of these responses was not statistically significantly different (X^2 = 6.62, p = 0.085). The second reason of ED overcrowding (I believe ED crowding is caused by lack of appropriate number of skills level of staffing in the department) responses of study subjects were, 10% as “not correct”, 26.7% as “not sure”, 53.3% as “possibly” and 10% as “one of the reasons”, and there is highly statistically significant difference in the distribution of these responses (X^2 = 45.2, p <0.0001). The third reason of factor ED crowing (I believe ED overcrowding is caused by Access Block (ED patients needing admission, cannot be admitted due to lack beds in the department of destination) responses were distributed as 14.4% “not sure”, 45.6% “possibly”, 33.3% “one of reasons” and 6.7% definitely. There is statistically significant difference in the distribution of responses(X^2 = 38.822, p <0.0001). Similarly, the distribution of responses for the fourth reason (I believe ED overcrowding is caused by poorly designed facilities and lack of space in the department), the fifth reason (I believe ED overcrowding is caused by overcomplicated management policies and care pathways) and the sixth reason (I believe ED crowding is caused by outdated clinical patient tracking systems) were statistically significant different (X^2 = 33.11, p <0.0001; X^2 = 17.22, p =0.002; and X^2 = 24.33, p <0.0001). For reason four, 41.1% of study subjects had responded as “one of the reasons”, for reason five, 31.1% had responded as “possibly”, whereas for reason six, 33.3% had responded as “possibly”. From the above analysis, it can be inferred that the reasons for ED overcrowding were due to deficiencies in infrastructure, lack of manpower, inappropriate management of skills and partly due to inappropriate visits by patients who do not require emergency care. The statistical analysis above is summarized in tables 18,table 19 and figures7 to 12, below.

Table 18: Distribution of responses of subjects for Causes of ED overcrowding

Factor 1	Number Responded	%
Item 1		
2-Not sure	17	18.9
3-possibly	30	33.3
4-one of the reasons	27	30.0
5-definitely	16	17.8
Item 2		
1-Not correct	9	10.0
2-Not sure	24	26.7
3-possibly	48	53.3
4-one of the reasons	9	10.0
Item 3		
2-Not sure	13	14.4
3-possibly	41	45.6
4-one of the reasons	30	33.3
5-definitely	6	6.7
Item 4		
1-Not correct	10	11.1
2-Not sure	19	21.1
3-possibly	19	21.1
4-one of the reasons	37	41.1
5-definitely	5	5.6
Item 5		
1-Not correct	9	10.0
2-Not sure	17	18.9
3-possibly	28	31.1
4-one of the reasons	26	28.9
5-definitely	10	11.1
Item 6		
1-Not correct	7	7.8
2-Not sure	22	24.4
3-possibly	30	33.3
4-one of the reasons	24	26.7
5-definitely	7	7.8

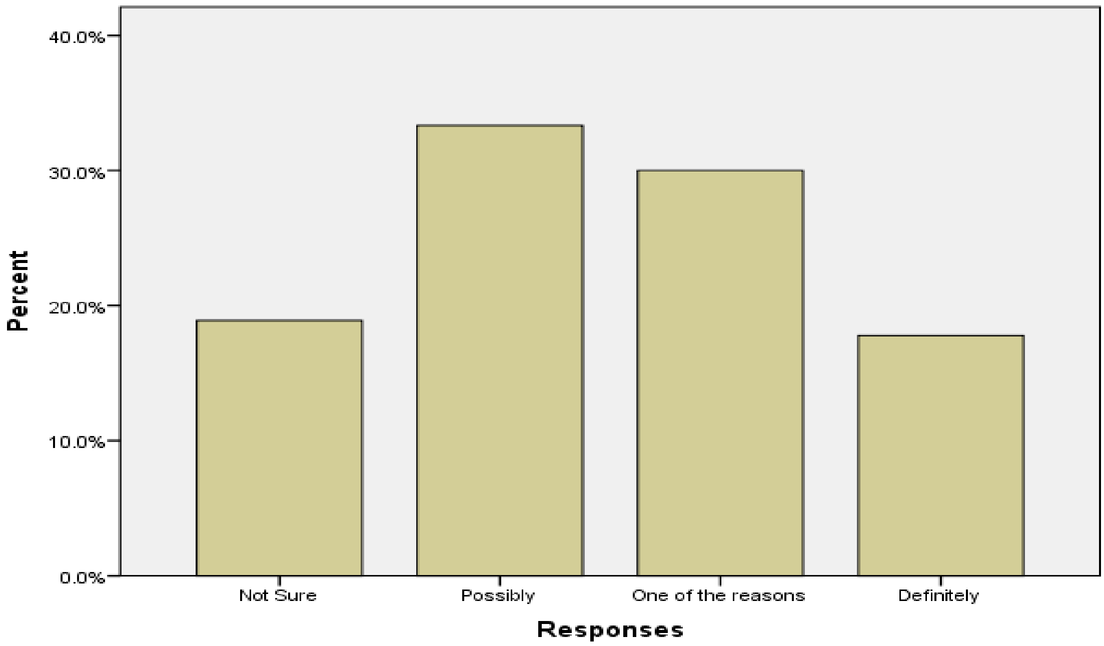


Figure.7: Distribution of 5-point scale responses for the Item 1 (Overcrowding is caused by inappropriate visits made by patients who do not require emergency care) of causes of ED overcrowding

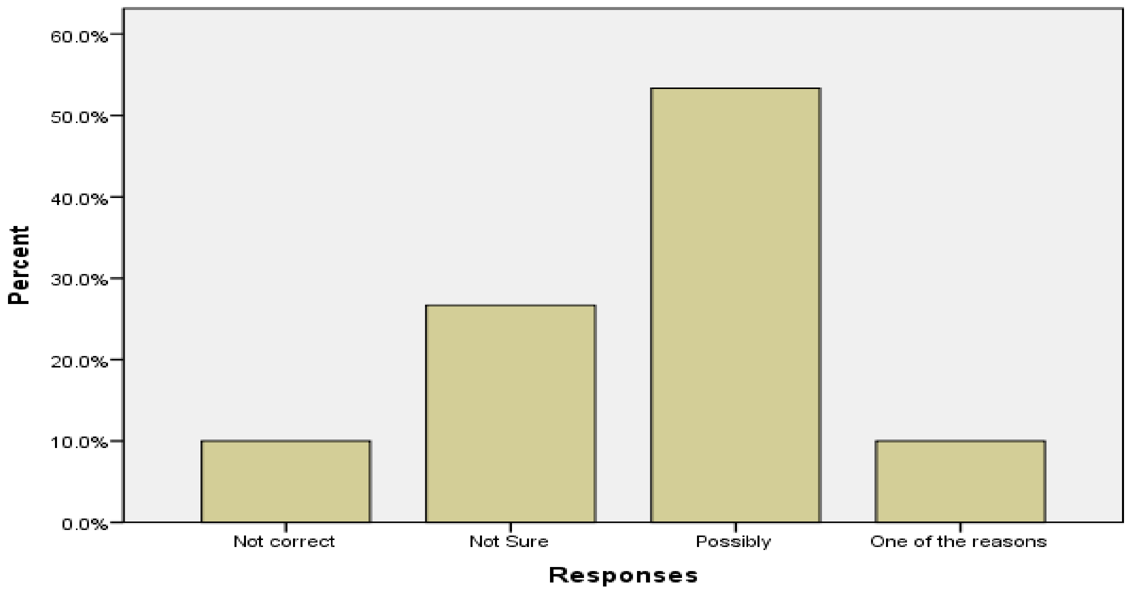


Figure. 8: Distribution of 5-point scale responses for the Item 2 (Overcrowding is caused by lack of appropriate number and skills level of staffing in the department) of causes of ED overcrowding

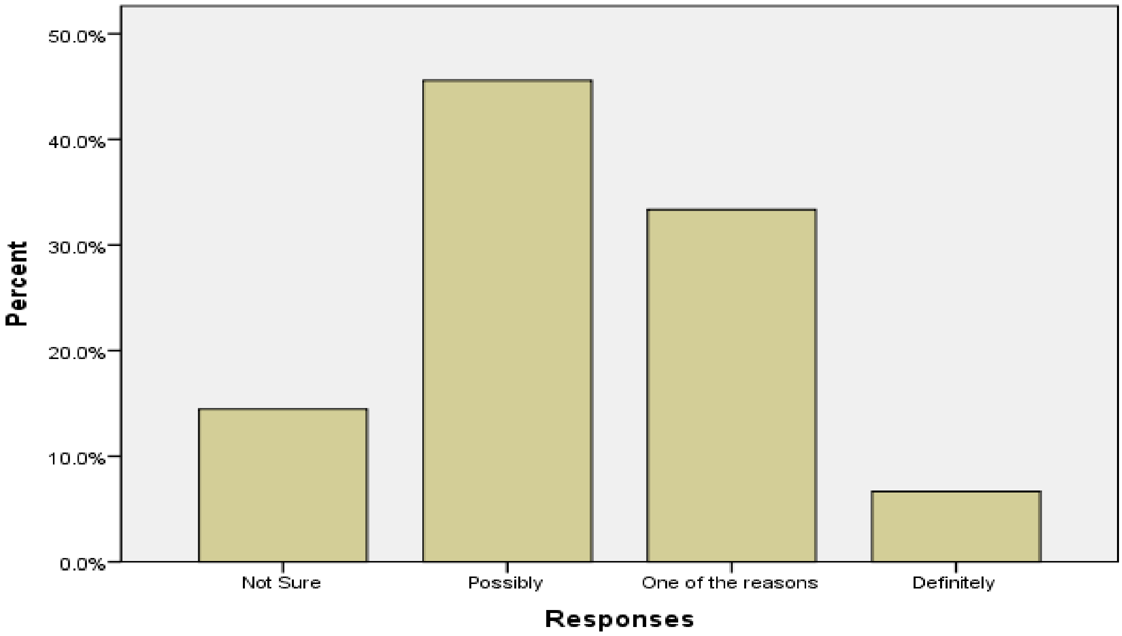


Figure. 9: Distribution of 5-point scale responses for the Item 3 (Overcrowding is caused by Access Block i.e. ED patients needing admission, cannot be admitted due to lack of beds in the department of destination) of causes of ED overcrowding

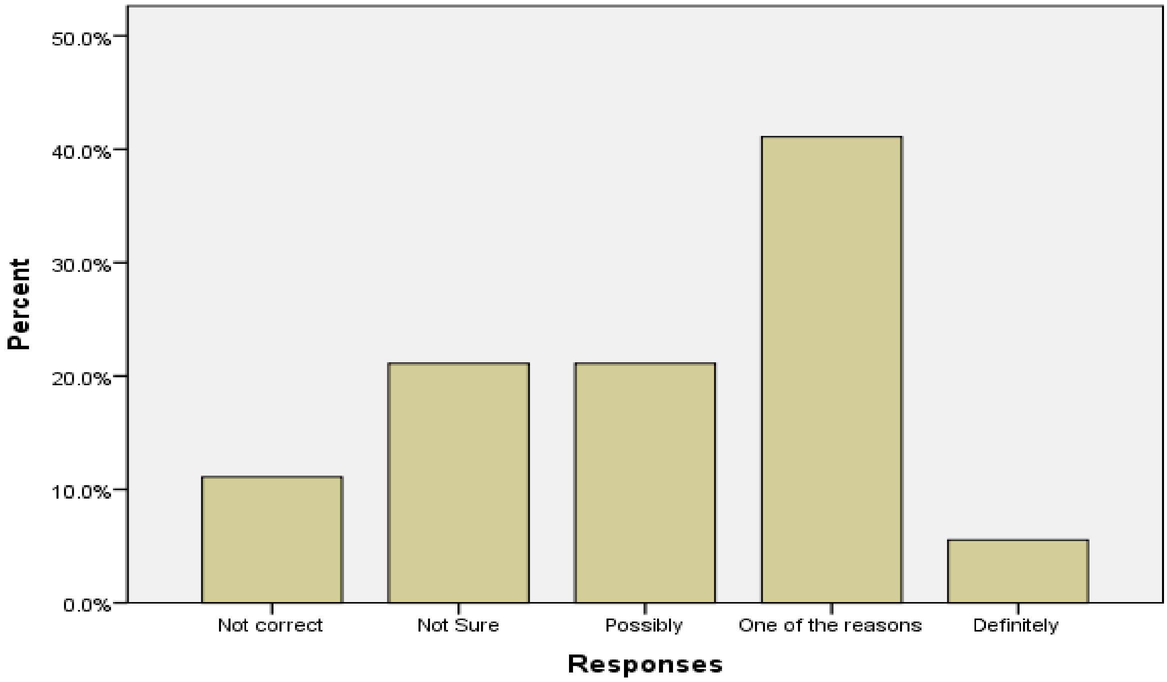


Figure. 10: Distribution of 5-point scale responses for the Item 4 (Overcrowding is caused by poorly designed facilities and lack of space in the department) of causes of ED overcrowding

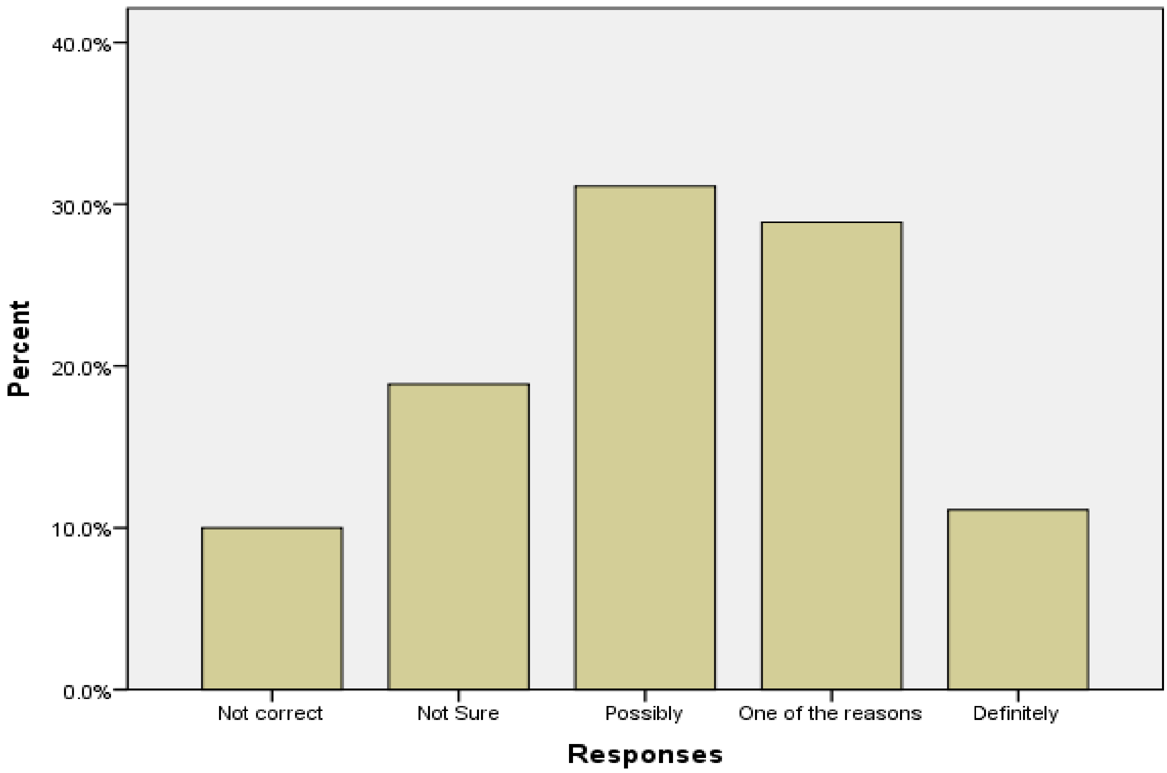


Figure. 11: Distribution of 5-point scale responses for the Item 5 (Overcrowding is caused by overcomplicated management policies and care pathways) of causes of ED overcrowding

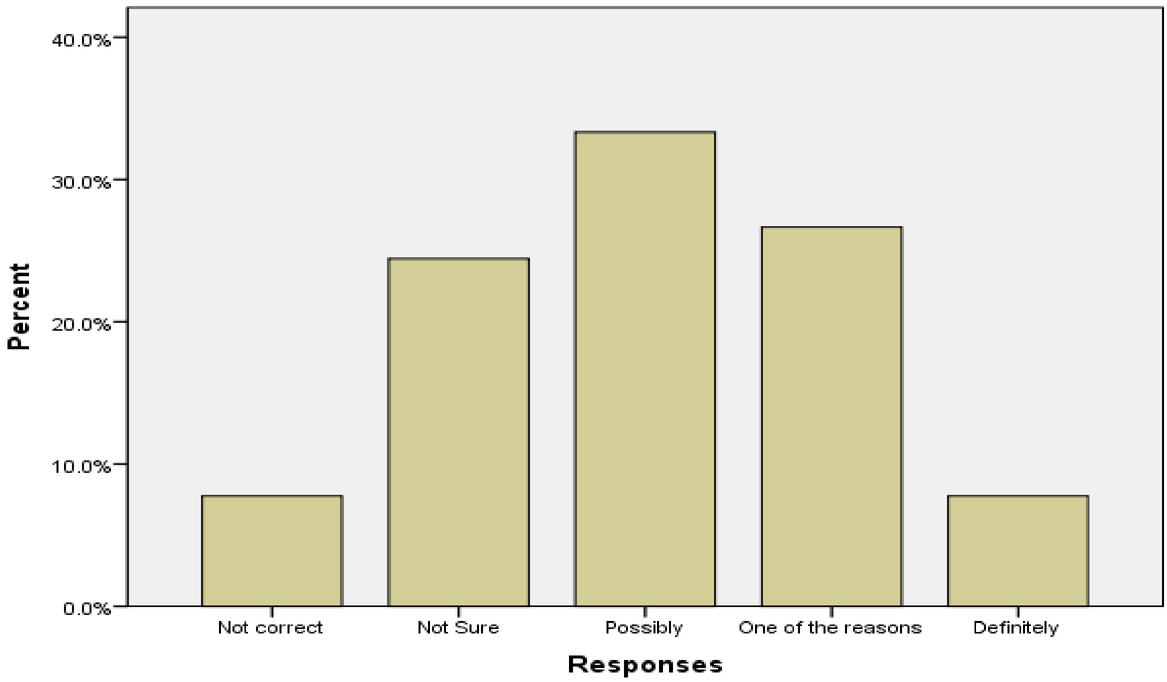


Figure. 12: Distribution of 5-point scale responses for the Item 6 (Overcrowding is caused by outdated clinical patient tracking system) of causes of ED overcrowding

Table 19: Testing of responses of subjects for each item for Causes of ED overcrowding

Factor 1	Observed N	Expected N	Residual	X^2 value	P value
Item 1					
2-Not sure	17	22.5	-5.5	6.622	.085
3-possibly	30	22.5	7.5		
4-one of the reasons	27	22.5	4.5		
5-definitely	16	22.5	-6.5		
Item 2					
1-Not correct	9	22.5	-13.5	45.200	<0.0001
2-Not sure	24	22.5	1.5		
3-possibly	48	22.5	25.5		
4-one of the reasons	9	22.5	-13.5		
Item 3					
2-Not sure	13	22.5	-9.5	33.822	<0.0001
3-possibly	41	22.5	18.5		
4-one of the reasons	30	22.5	7.5		
5-definitely	6	22.5	-16.5		
Item 4					
1-Not correct	10	18.0	-8.0	33.111	<0.0001
2-Not sure	19	18.0	1.0		
3-possibly	19	18.0	1.0		
4-one of the reasons	37	18.0	19.0		
5-definitely	5	18.0	-13.0		
Item 5					
1-Not correct	9	18.0	-9.0	17.222[b]	.002
2-Not sure	17	18.0	-1.0		
3-possibly	28	18.0	10.0		
4-one of the reasons	26	18.0	8.0		
5-definitely	10	18.0	-8.0		
Item 6					
1-Not correct	7	18.0	-11.0	24.333	<0.0001
2-Not sure	22	18.0	4.0		
3-possibly	30	18.0	12.0		
4-one of the reasons	24	18.0	6.0		
5-definitely	7	18.0	-11.0		

4.2.2 "Effects of ED overcrowding on patients"

Analysis of the five reasons covered under this heading is summarized in table20, table21 and figures 13 to 17. It shows the distribution of the responses of 90 study subjects. The distribution of responses measured on a 5-point scale for all the 5 items are highly statistically significantly different (X^2 = 34.0, p <0.0001; X^2 = 49.911, p =0.002;X^2 = 54.267, p <0.0001;X^2 = 33.644, p <0.0001 and X^2 = 43.244, p <0.0001).

For the first reason (I believe ED overcrowding causes extended pain and suffering), 45.6% had responded as "one of the reasons", for the second reason (I believe ED overcrowding is a risk for poor outcomes), 55.6% had responded as "possibly", for the third reason (I believe ED overcrowding causes actual poor outcomes), 57.8% had responded as "possibly", for the fourth reason (I believe ED overcrowding causes dangerous delayed diagnosis and treatment), 48.9% as "possibly", whereas for the fifth reason (I believe ED overcrowding causes significant patient dissatisfaction), 52.2% as "one of the reasons".

This heading of "Effect of ED overcrowding on patients" had measured appropriately all possible effects of ED overcrowding on patients, where higher proportion of study subjects had responded positively as ("possibly" and "one of the reasons") to all the five effects (five items).

Table.20: Distribution of responses for each item for the Effect of ED overcrowding on patients

Factor 2	Number Responded	%
Item 1		
2-Not sure	2	2.2
3-possibly	23	25.6
4-one of the reasons	41	45.6
5-definitely	24	26.7
Item 2		
2-Not sure	8	8.9
3-possibly	50	55.6
4-one of the reasons	22	24.4
5-definitely	10	11.1
Item 3		
2-Not sure	7	7.8
3-possibly	52	57.8
4-one of the reasons	18	20.0
5-definitely	13	14.4
Item 4		
2-Not sure	10	11.1
3-possibly	44	48.9
4-one of the reasons	25	27.8
5-definitely	11	12.2
Item 5		
2-Not sure	4	4.4
3-possibly	22	24.4
4-one of the reasons	47	52.2
5-definitely	17	18.9

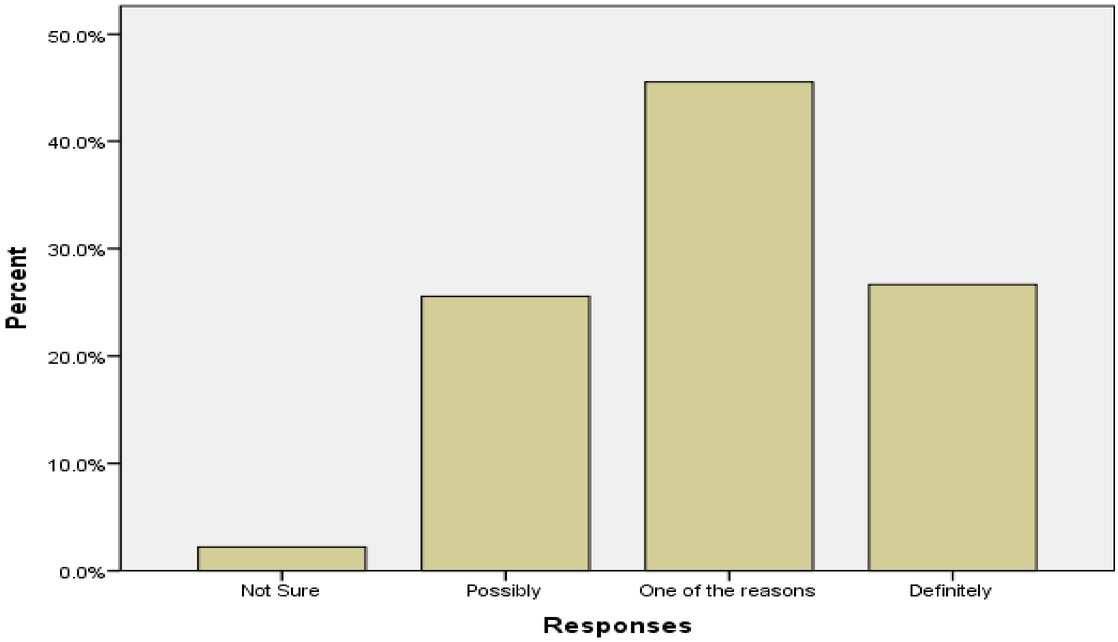


Figure.13: Distribution of 5-point scale responses for the Item 1 (ED overcrowding causes extended pain and suffering) of Effects of ED overcoming on patients

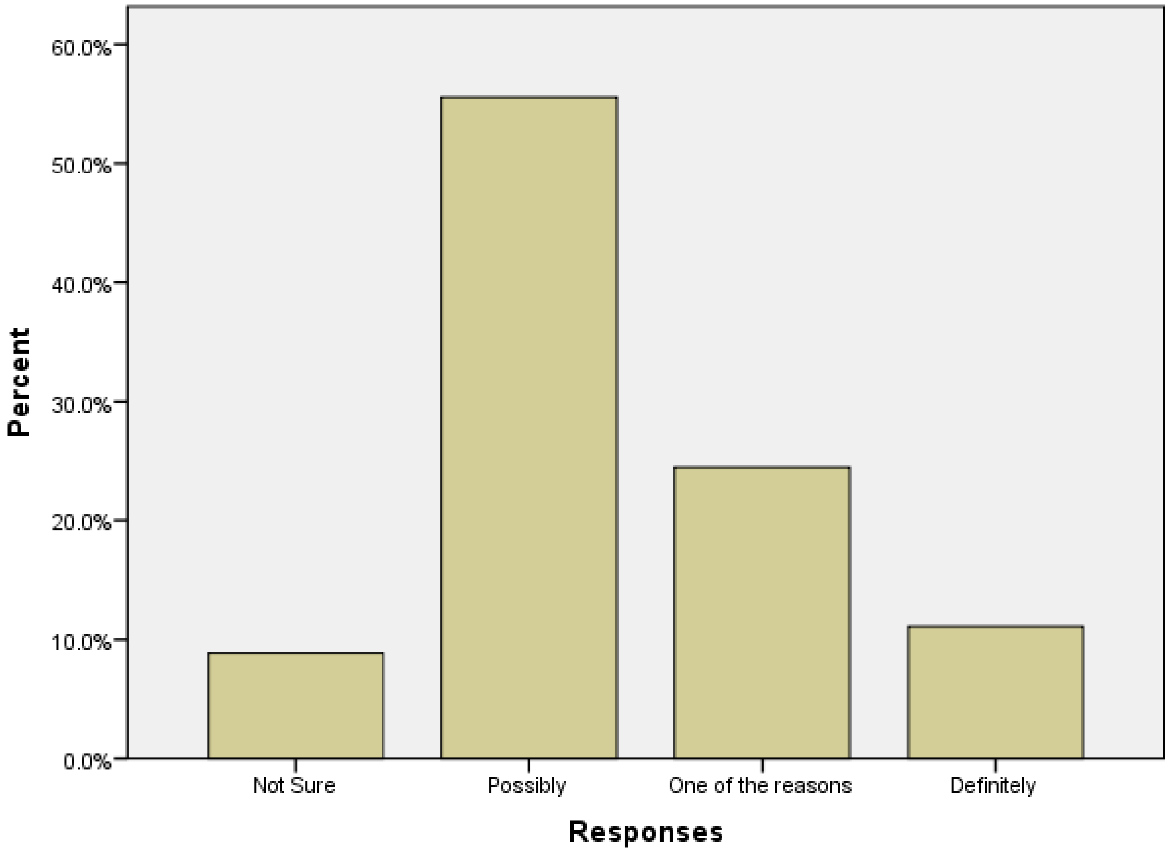


Figure. 14: Distribution of 5-point scale responses for the Item 2 (ED overcrowding is a risk for poor outcomes) of Effects of ED overcoming on patients

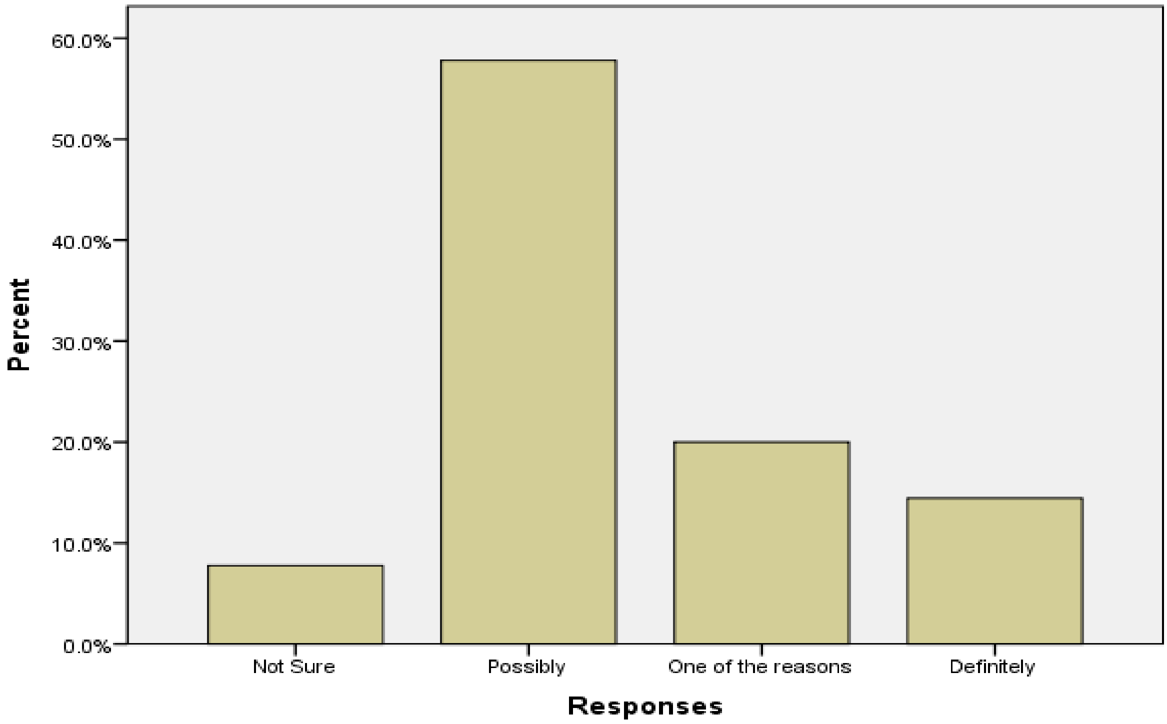


Figure. 15: Distribution of 5-point scale responses for the Item 3 (ED overcrowding causes ACTUAL poor outcomes) of Effects of ED overcoming on patients

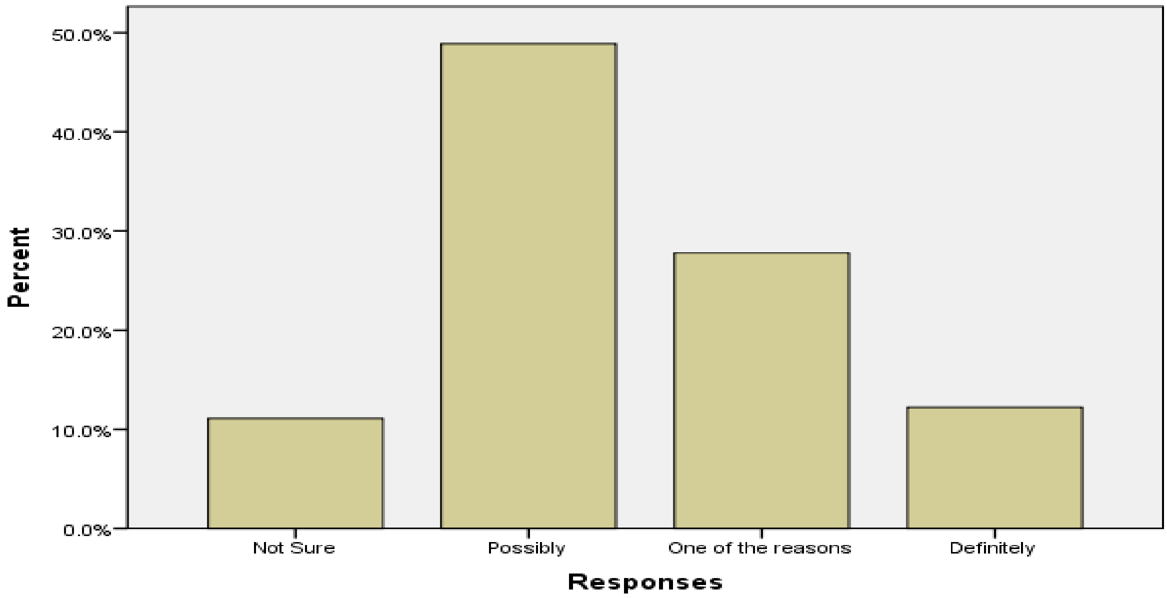


Figure. 16: Distribution of 5-point scale responses for the Item 4 (ED overcrowding causes dangerous delayed diagnosis and treatment) of Effects of ED overcoming on patients

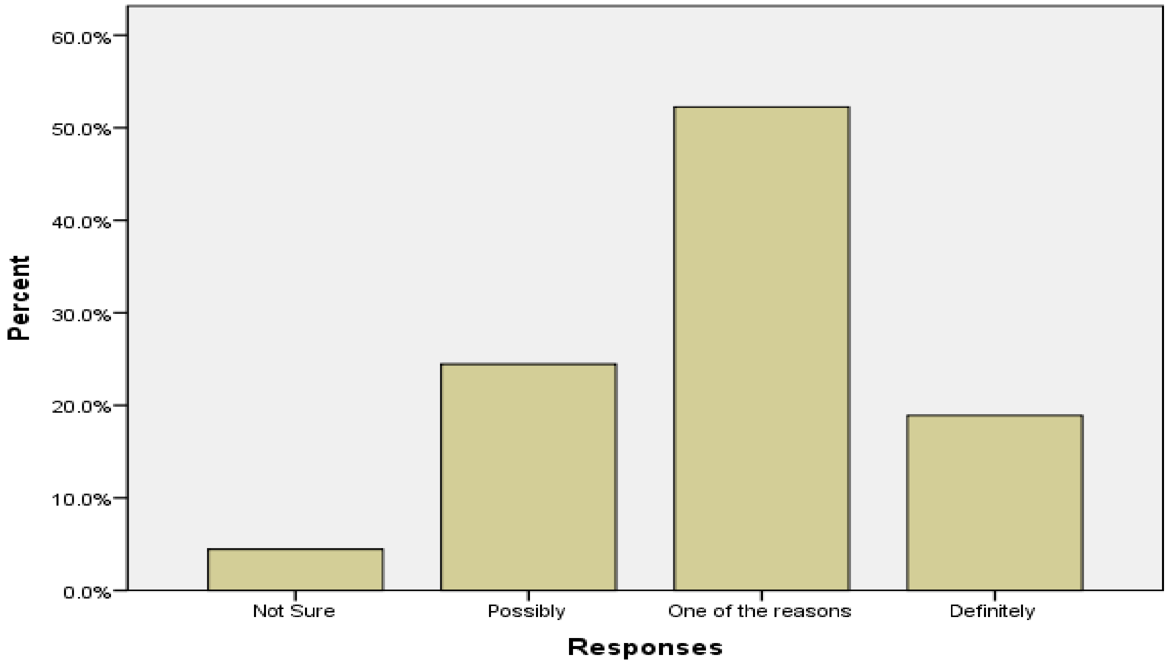


Figure. 17: Distribution of 5-point scale responses for the Item 5 (ED overcrowding causes significant patient dissatisfaction) of Effects of ED overcoming on patients

Table 21: Testing of responses of subjects for each item for the effect of ED overcrowding on patients

Factor 2	Observed N	Expected N	Residual	X^2 value	P value
Item 1					
2-Not sure	2	22.5	-20.5	34.000	<0.0001
3-possibly	23	22.5	.5		
4-one of the reasons	41	22.5	18.5		
5-definitely	24	22.5	1.5		
Item 2					
2-Not sure	8	22.5	-14.5	49.911[a]	<0.0001
3-possibly	50	22.5	27.5		
4-one of the reasons	22	22.5	-.5		
5-definitely	10	22.5	-12.5		
Item 3					
2-Not sure	7	22.5	-15.5	54.267	<0.0001
3-possibly	52	22.5	29.5		
4-one of the reasons	18	22.5	-4.5		
5-definitely	13	22.5	-9.5		
Item 4					
2-Not sure	10	22.5	-12.5	33.644	<0.0001
3-possibly	44	22.5	21.5		
4-one of the reasons	25	22.5	2.5		
5-definitely	11	22.5	-11.5		
Item 5					
2-Not sure	4	22.5	-18.5	43.244	<0.0001
3-possibly	22	22.5	-.5		
4-one of the reasons	47	22.5	24.5		
5-definitely	17	22.5	-5.5		

4.2.3 Management of ED overcrowding

Analysis of this heading is summarized in tables 22,&23 and figures 18 to 22 below. It shows the distribution of the responses of 90 study subjects for the five items under the heading of the survey used in this study.

The distribution of responses measured on a 5-point scale for all the 5 items are highly statistically significantly different (X^2 = 31.778, $p < 0.0001$;X^2 = 40.111, $p < 0.001$;X^2 = 29.733, $p < 0.0001$;X^2 = 40.578, $p < 0.0001$ and X^2 = 11.667, $p < 0.0001$). For the first item (I believe ED overcrowding can be reduced when the issue is viewed with the context of overall pressure on the entire healthcare system), 34.4% had responded as "possibly", for the second item (I believe ED overcrowding can be reduced by increasing the number and expertise of ED staff), 35.6% had responded as "possibly", for third item (I believe ED overcrowding can be reduced by better design of the way patients flow through the department (forms and paper work), 38.9% had responded as "possibly", for fourth item (I believe ED overcrowding can be reduced by educating the public about the proper use of ED resources), 44.4% as "possibly", whereas for fifth item (I believe ED overcrowding can be reduced by applying/implementing technological solutions), 50% as "one of the reasons".

For this, factor of "Management of ED overcrowding" the study subjects had responded in higher proportion as "possibly" to the 4 ways (items) and as "one of reason" to the fifthmethod (item) of managing overcrowding of ED. Here, the study subjects were not "definite" in their views, because all the 5 items, under this factor were related to administrative feasibility of managing ED overcrowding.

Table 22: Distribution of responses of subjects for the management of ED overcrowding

Factor 3	Number Responded	%
Item 1		
1-Not correct	9	10.0
2-Not sure	30	33.3
3-possibly	31	34.4
4-one of the reasons	15	16.7
5-definitely	5	5.6
Item 2		
1-Not correct	8	8.9
2-Not sure	31	34.4
3-possibly	32	35.6
4-one of the reasons	17	18.9
5-definitely	2	2.2
Item 3		
2-Not sure	21	23.3
3-possibly	35	38.9
4-one of the reasons	32	35.6
5-definitely	2	2.2
Item 4		
2-Not sure	8	8.9
3-possibly	40	44.4
4-one of the reasons	35	38.9
5-definitely	7	7.8
Item 5		
3-possibly	25	27.8
4-one of the reasons	45	50.0
5-definitely	20	22.2

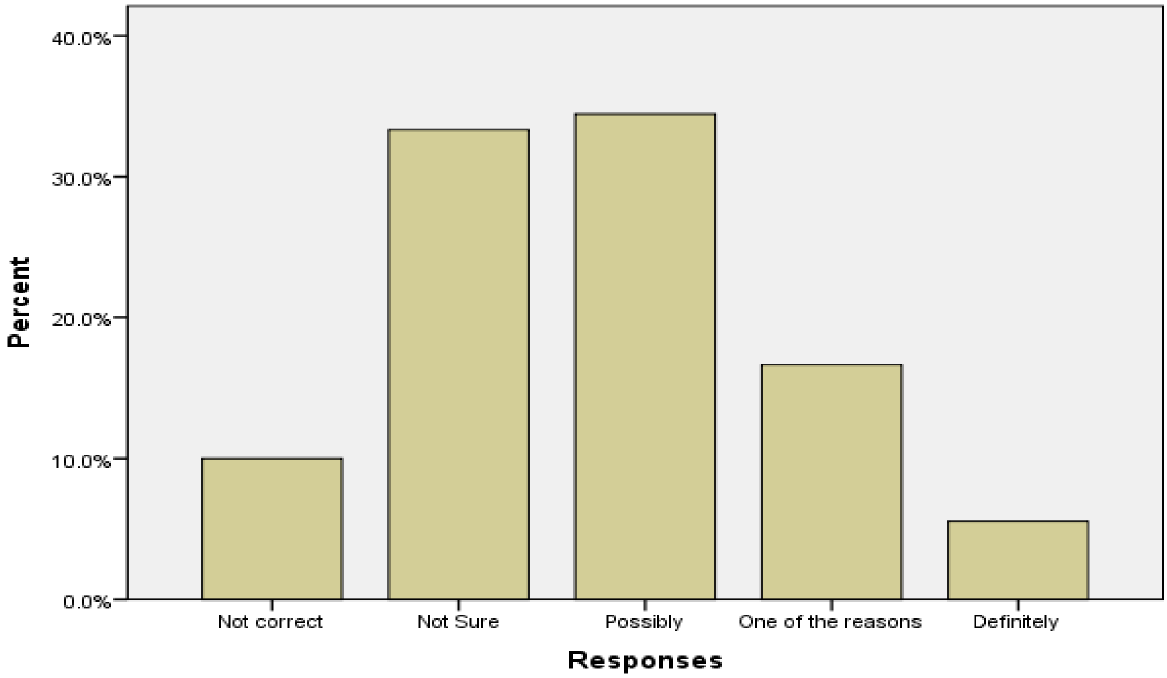


Figure. 18: Distribution of 5-point scale responses for the Item 1 (ED overcrowding can be reduced when the issue is viewed with the context of overall pressure on the entire healthcare system) of Management of ED Overcrowding

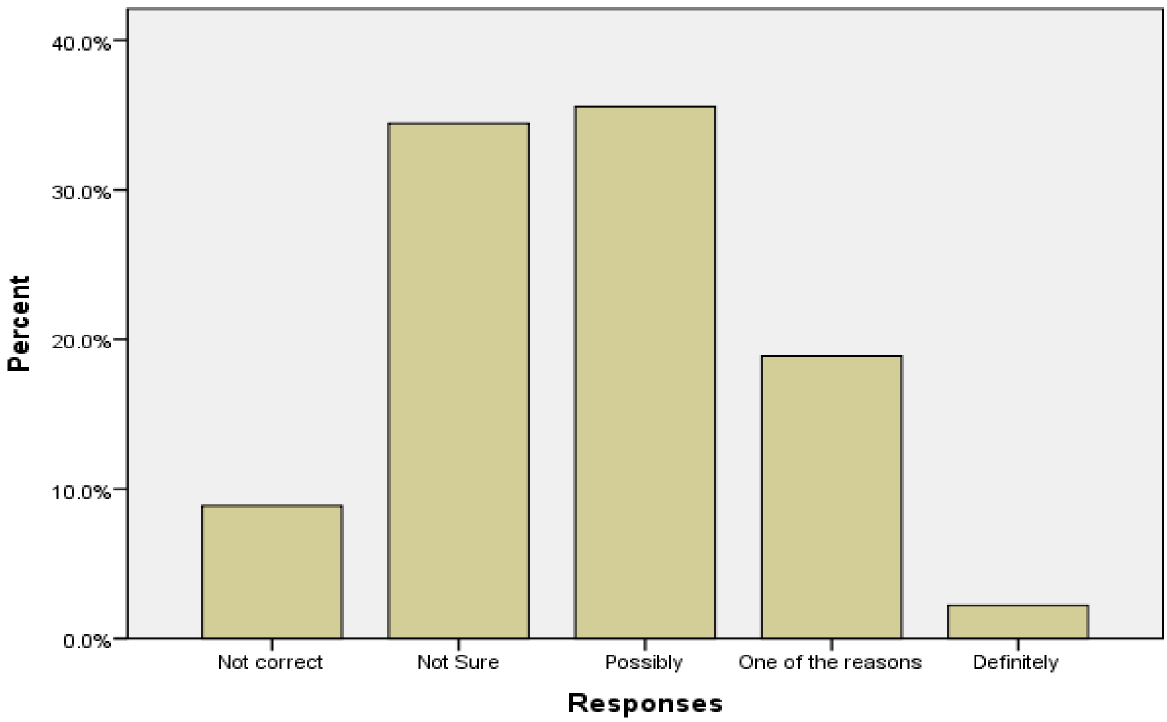


Figure. 19: Distribution of 5-point scale responses for the Item 2 (ED overcrowding can be reduced by increasing the number and expertise of ED staff) of Management of ED Overcrowding

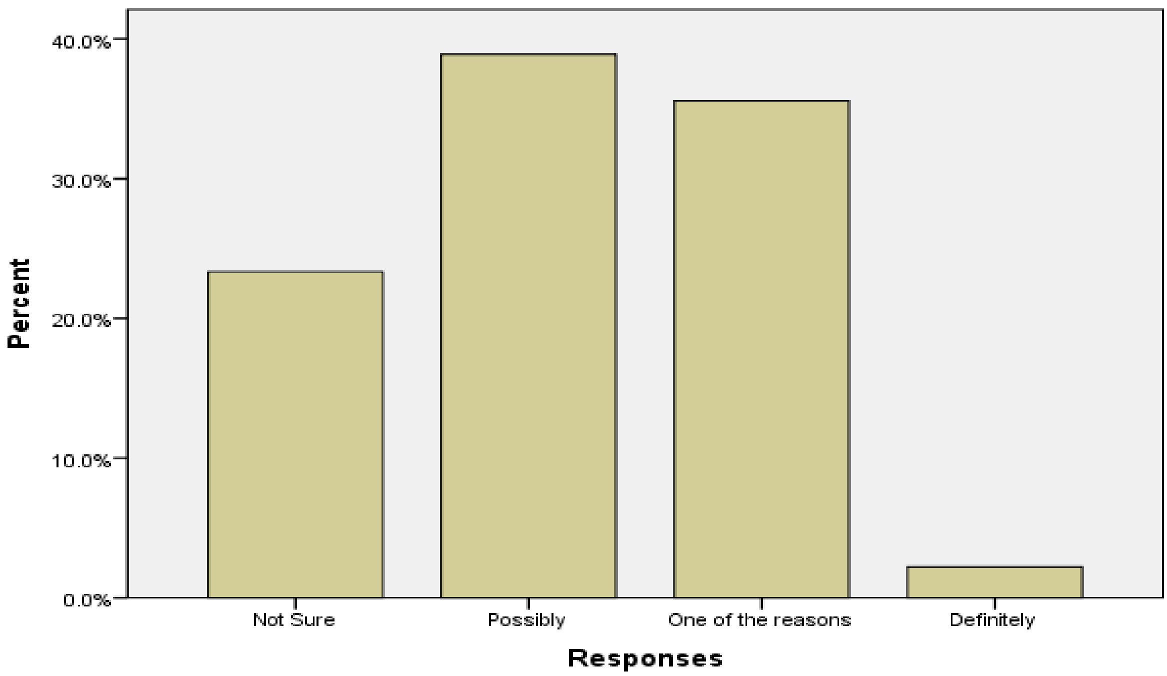


Figure. 20: Distribution of 5-point scale responses for the Item 3 (ED overcrowding can be reduced by better design of the way patients flow through the department i.e forms & paper work) of Management of ED Overcrowding

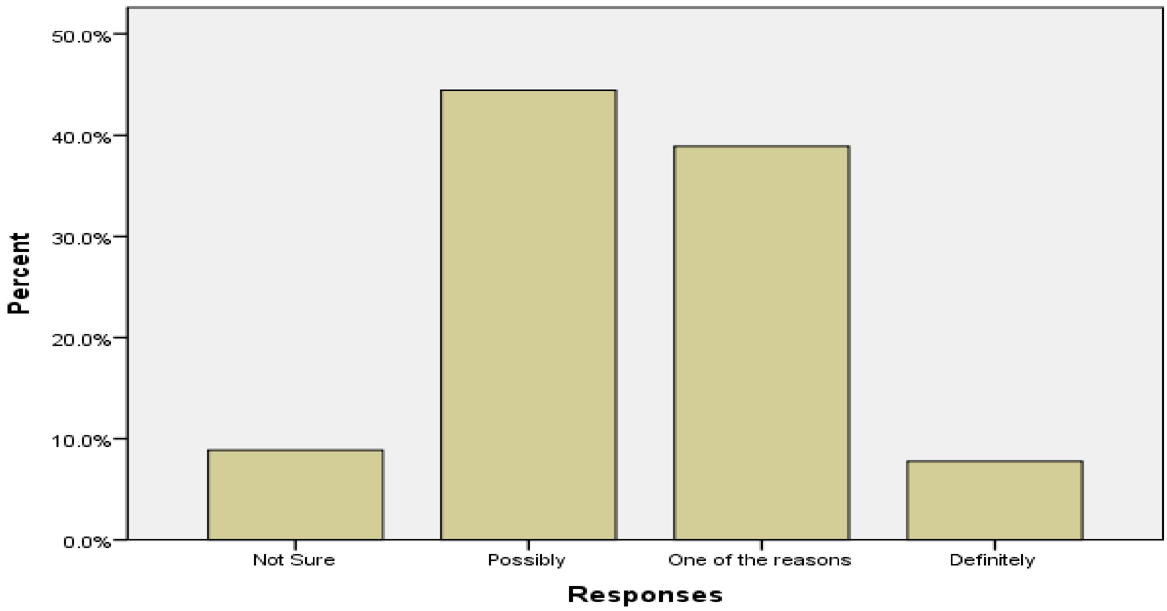


Figure. 21: Distribution of 5-point scale responses for the Item 4 (ED overcrowding can be reduced by educating the public about the proper use of ED resources) of Management of ED Overcrowding

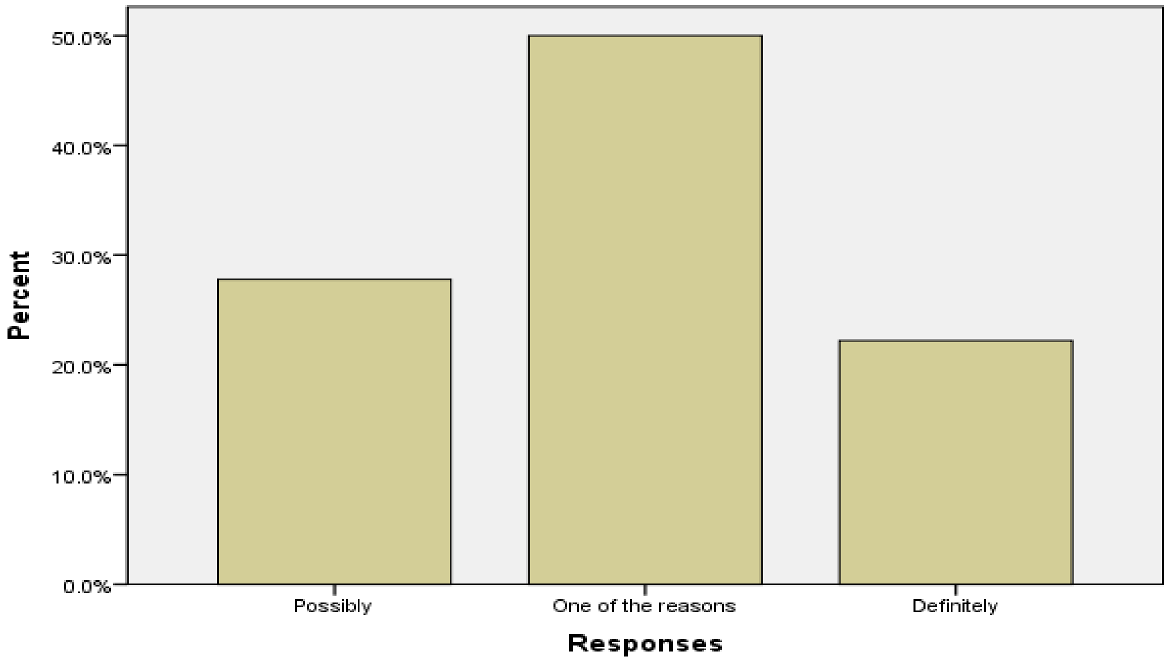


Figure. 22: Distribution of 5-point scale responses for the Item 5 (ED overcrowding can be reduced by applying / implementing technological solutions) of Management of ED Overcrowding

Table 23: Testing of responses of subjects for each item of Management of ED Overcrowding

Factor 3	Observed N	Expected N	Residual	X^2 value	P value
Item 1					
1-Not correct	9	18.0	-9.0	31.778	<0.0001
2-Not sure	30	18.0	12.0		
3-possibly	31	18.0	13.0		
4-one of the reasons	15	18.0	-3.0		
5-definitely	5	18.0	-13.0		
Item 2					
1-Not correct	8	18.0	-10.0	40.111	<0.0001
2-Not sure	31	18.0	13.0		
3-possibly	32	18.0	14.0		
4-one of the reasons	17	18.0	-1.0		
5-definitely	2	18.0	-16.0		
Item 3					
2-Not sure	21	22.5	-1.5	29.733	<0.0001
3-possibly	35	22.5	12.5		
4-one of the reasons	32	22.5	9.5		
5-definitely	2	22.5	-20.5		
Item 4					
2-Not sure	8	22.5	-14.5	40.578	<0.0001
3-possibly	40	22.5	17.5		
4-one of the reasons	35	22.5	12.5		
5-definitely	7	22.5	-15.5		
Item 5					
3-possibly	25	30.0	-5.0	11.667	.003
4-one of the reasons	45	30.0	15.0		
5-definitely	20	30.0	-10.0		

4.2.4 "Applied and implemented solutions to ED overcrowding"

Analysis of this aspect of the survey is summarized in table 24, table 25 and figures 23 to 27. The distribution of the responses of the 90 study subjects to the 5 items under this heading was measured on a 5-point scale for all the 5 items and were found to be highly statistically significantly different ($X^2 = 67.778$, $p < 0.0001$;$X^2 = 53$, $p < 0.001$;$X^2 = 21.378$, $p < 0.0001$;$X^2 = 41.333$, $p < 0.0001$ and $X^2 = 54.467$, $p < 0.0001$).

For the first item (I believe ED overcrowding can be solved by having a dedicated bed-management team to tackle the issue of Access Block), 47.8% had responded as "possibly", for the second item (Consultant or Senior ED nurse lead triage could help making an impact an ED overcrowding), 40% had responded as "possibly", for the third item (Diverting some of the emergency calls to advice help lines enabling paramedics to assess and discharge at the scene could help reduce ED visits), 37.8% had responded as "possibly", for the fourth item (An early warning system that could alert to the development of overcrowding could help management prepare and apply resources to prevent overcrowding), 40% as "possibly", whereas for the fifth item (I believe ED overcrowding can be solved by implementing technological innovations such as Radio Frequency Identification of patients and assets), 70% as "one of the reasons".

For this, factor of "Applied and implemented solutions to ED overcrowding" the study subjects had responded in higher proportion as "possibly" to the four solutions (items) and as "one of the reason" to the fifth solution (item) of Applied and implemented solutions to ED overcrowding.

Here, the study subjects were not "definite" in their views, because all the 5 items, under this factor were related to hospital management system, which includes adequate infrastructure, administrative feasibility, and availability of appropriate manpower with efficient management skills.

Table 24: Distribution of responses of subjects for each item on Applied and implemented solutions to ED overcrowding

Factor 4	Number Responded	%
Item 1		
1-Not correct	1	1.1
2-Not sure	19	21.1
3-possibly	43	47.8
4-one of the reasons	25	27.8
5-definitely	2	2.2
Item 2		
1-Not correct	1	1.1
2-Not sure	28	31.1
3-possibly	36	40.0
4-one of the reasons	22	24.4
5-definitely	3	3.3
Item 3		
2-Not sure	29	32.2
3-possibly	34	37.8
4-one of the reasons	22	24.4
5-definitely	5	5.6
Item 4		
1-Not correct	1	1.1
2-Not sure	19	21.1
3-possibly	36	40.0
4-one of the reasons	25	27.8
5-definitely	9	10.0
Item 5		
3-possibly	14	15.6
4-one of the reasons	63	70.0
5-definitely	13	14.4

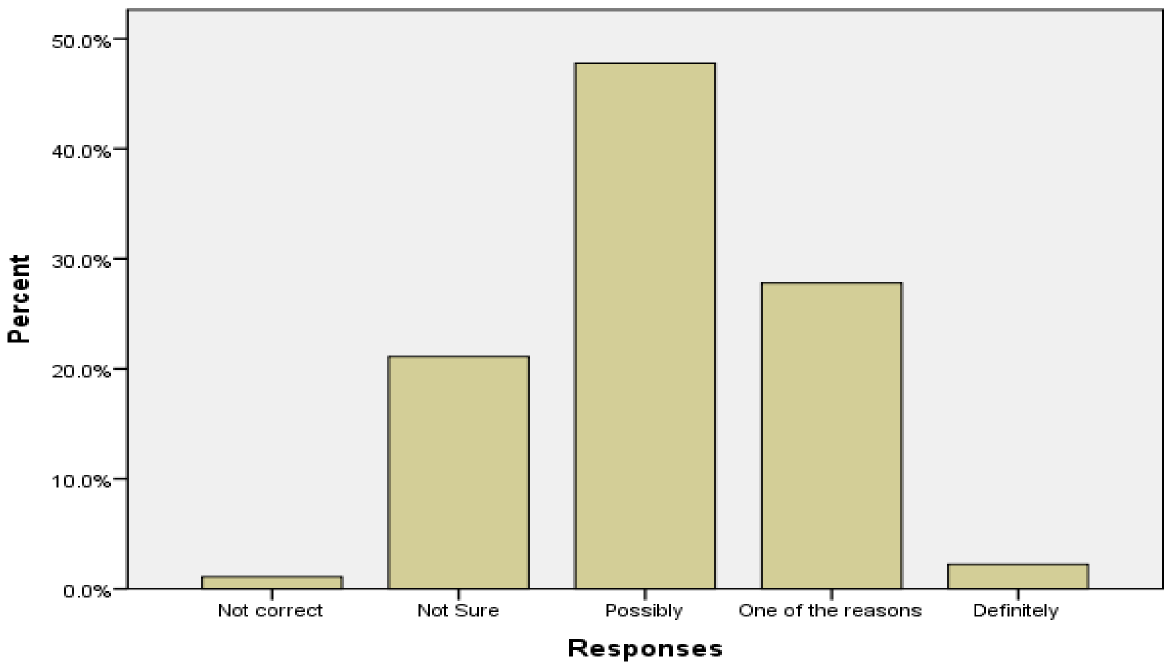


Figure. 23: Distribution of 5-point scale responses for the Item 1 (ED overcrowding can be reduced by having a dedicated bed-management team to tackle the issue of Access Block) of Applied and implemented solutions to ED Overcrowding

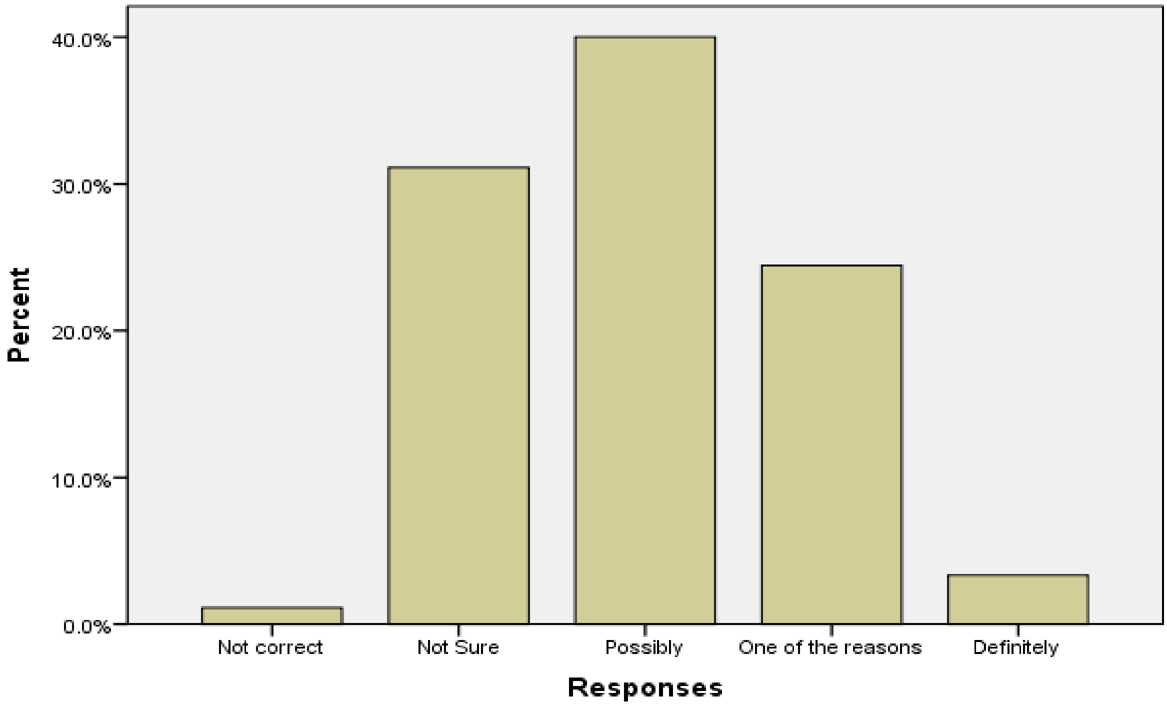


Figure. 24: Distribution of 5-point scale responses for the Item 2 (Consultant or Senior ED nurse lead triage could help making an impact on ED overcrowding) of Applied and implemented solutions to ED Overcrowding

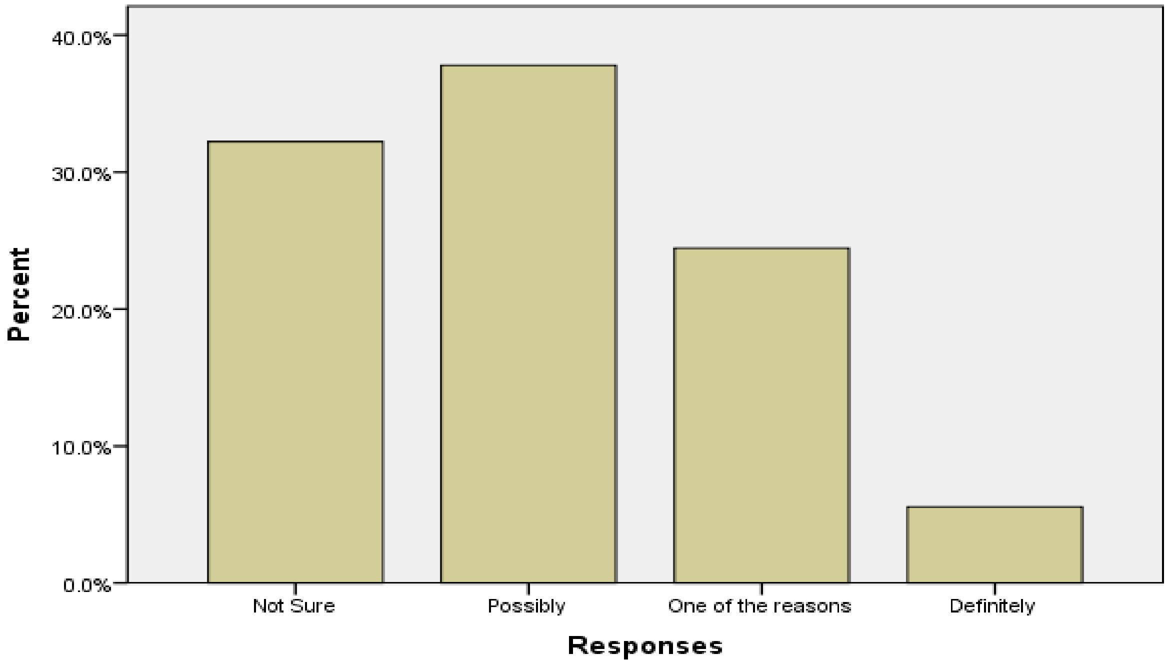


Figure. 25: Distribution of 5-point scale responses for the Item 3 (Diverting some of the emergency calls to advice help lines enabling paramedics to assess and discharge at the scene could help reduce ED visits) of Applied and implemented solutions to ED Overcrowding

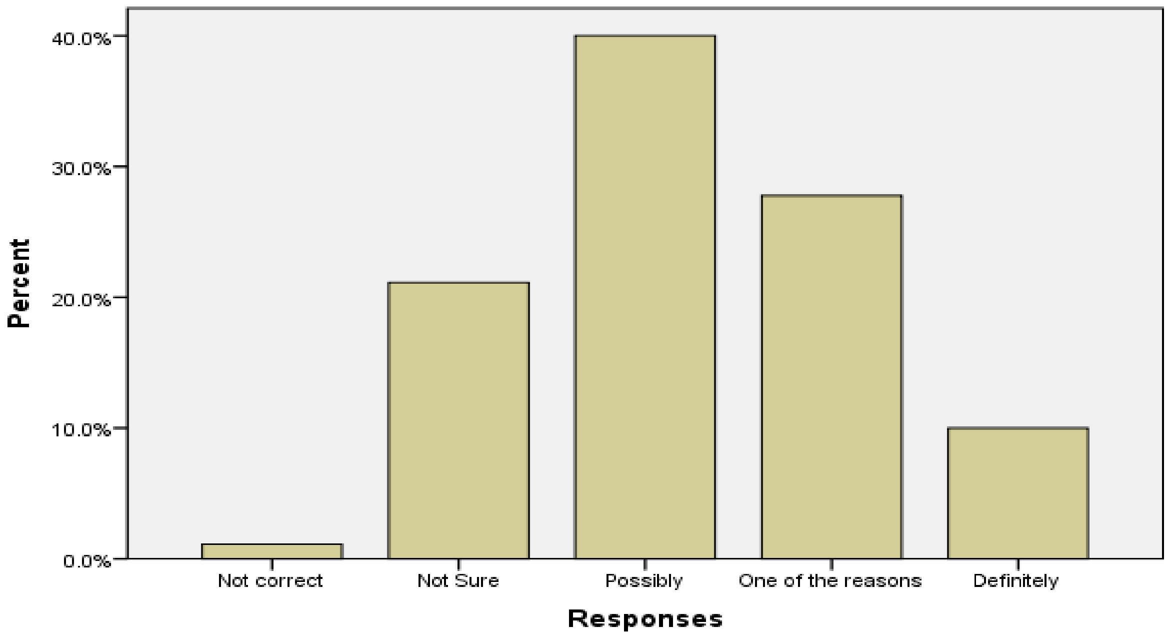


Figure. 26: Distribution of 5-point scale responses for the Item 4 (An early warning system that could alert to the development of overcrowding could help management prepare and apply resources to prevent overcrowding) of Applied and implemented solutions to ED Overcrowding

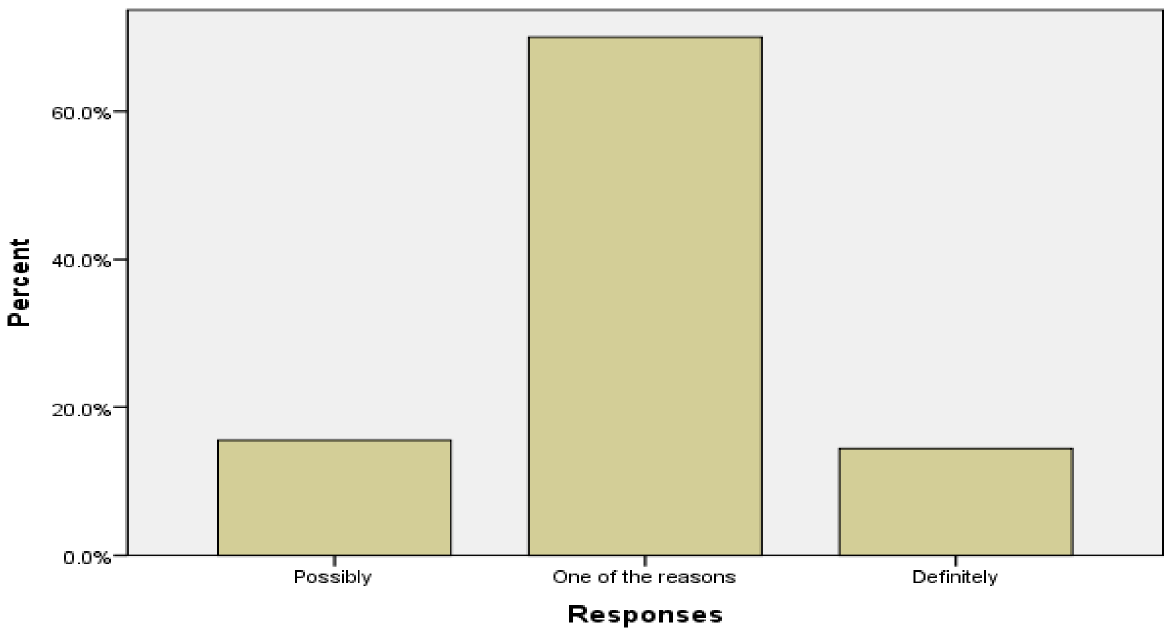


Figure. 27: Distribution of 5-point scale responses for the Item 5 (ED overcrowding can be solved by implementing technological innovations such as Radio frequency identification of patients and assets) of Applied and implemented solutions to ED Overcrowding

Table 25: Testing of responses of subjects for each item of Applied and implemented solutions to ED overcrowding

Factor 4	**Observed N**	**Expected N**	**Residual**	**X2 value**	**P value**
Item 1					
1-Not correct	1	18.0	-17.0	67.778	<0.0001
2-Not sure	19	18.0	1.0		
3-possibly	43	18.0	25.0		
4-one of the reasons	25	18.0	7.0		
5-definitely	2	18.0	-16.0		
Item 2					
1-Not correct	1	18.0	-17.0	53.000	<0.0001
2-Not sure	28	18.0	10.0		
3-possibly	36	18.0	18.0		
4-one of the reasons	22	18.0	4.0		
5-definitely	3	18.0	-15.0		
Item 3					
2-Not sure	29	22.5	6.5	21.378	<0.0001
3-possibly	34	22.5	11.5		
4-one of the reasons	22	22.5	-.5		
5-definitely	5	22.5	-17.5		
Item 4					
1-Not correct	1	18.0	-17.0	41.333	<0.0001
2-Not sure	19	18.0	1.0		
3-possibly	36	18.0	18.0		
4-one of the reasons	25	18.0	7.0		
5-definitely	9	18.0	-9.0		
Item 5					
3-possibly	14	30.0	-16.0	54.467	<0.0001
4-one of the reasons	63	30.0	33.0		
5-definitely	13	30.0	-17.0		

4.2.5 "RFID Tagging as a potential solution in easing ED Overcrowding"

Analysis of this aspect of the survey is summarized in table 26, table 27 and figures 28 to 35. It shows the distribution of the responses of 90 study subjects for the 8 items under the heading of (RFID tagging) of the survey.

The distribution of responses measured on a 5-point scale for all the 8 items are highly statistically significantly different (X^2 = 70.444, $p < 0.0001$; X^2 = 22.622, $p < 0.001$; X^2 = 44.933, $p < 0.0001$; X^2 = 61.222, $p < 0.0001$; X^2 = 43.444, $p < 0.0001$; X^2 = 66.778, $p < 0.0001$; X^2 = 59.667, $p < 0.0001$; and X^2 = 109.9, $p < 0.0001$).

For the first item (I believe the RFID is too complicated to use), 52.5% had responded as "Not sure", for the second item (The RFID system does not always function the way it is supposed to), 40% had responded as "Not sure", for the third item (The RFID system made our department less crowded than before we started using it), 51.1% had responded as "one of the reasons", for the fourth item (The RFID system should not be relied upon as the only solution to ED overcrowding), 45.6% as "possibly", for the fifth item (The training I received on using the system was adequate), 38.9% as "one of the reasons" for the sixth item (The technical support I received/continue to receive was adequate), 45.6 % as "possibly" for the seventh item (The ED patient did not like wearing/using the RFID tags), 40% as "one of the reason" and for the eighth item (The RFID should be extended throughout the whole hospital system), 72.2 % as " Not sure".

For this, factor of "Radio frequency identification (RFID) tagging" the study subjects had responded in higher proportion as "Not sure" to the 4 items, as "one of the reason" to 2 items and as "possibly" to the remaining 2 items. Here, the study subjects were not "definite" in their views, because all the 8 items, under this factor were related to the knowledge application, and utility of RFID in managing ED overcrowding.

Table 26: Distribution of responses of subjects for each item of Radio frequency identification (RFID) tagging as a potential solution in easing ED overcrowding

Factor 5	**Number Responded**	**%**
Item 1		
1-Not correct	17	18.9
2-Not sure	47	52.2
3-possibly	19	21.1
4-one of the reasons	5	5.6
5-definitely	2	2.2
Item 2		
1-Not correct	14	15.6
2-Not sure	36	40.0
3-possibly	31	34.4
4-one of the reasons	9	10.0
Item 3		
2-Not sure	6	6.7
3-possibly	28	31.1
4-one of the reasons	46	51.1
5-definitely	10	11.1
Item 4		
1-Not correct	5	5.6
2-Not sure	10	11.1
3-possibly	41	45.6
4-one of the reasons	30	33.3
5-definitely	4	4.4
Item 5		
1-Not correct	6	6.7
2-Not sure	35	38.9
3-possibly	30	33.3
4-one of the reasons	15	16.7
5-definitely	4	4.4
Item 6		
1-Not correct	7	7.8
2-Not sure	32	35.6
3-possibly	41	45.6
4-one of the reasons	8	8.9
5-definitely	2	2.2
Item 7		
1-Not correct	2	2.2
2-Not sure	12	13.3
3-possibly	35	38.9
4-one of the reasons	36	40.0
5-definitely	5	5.6
Item 8		
1-Not correct	13	14.4
2-Not sure	65	72.2
3-possibly	10	11.1
5-definitely	2	2.2

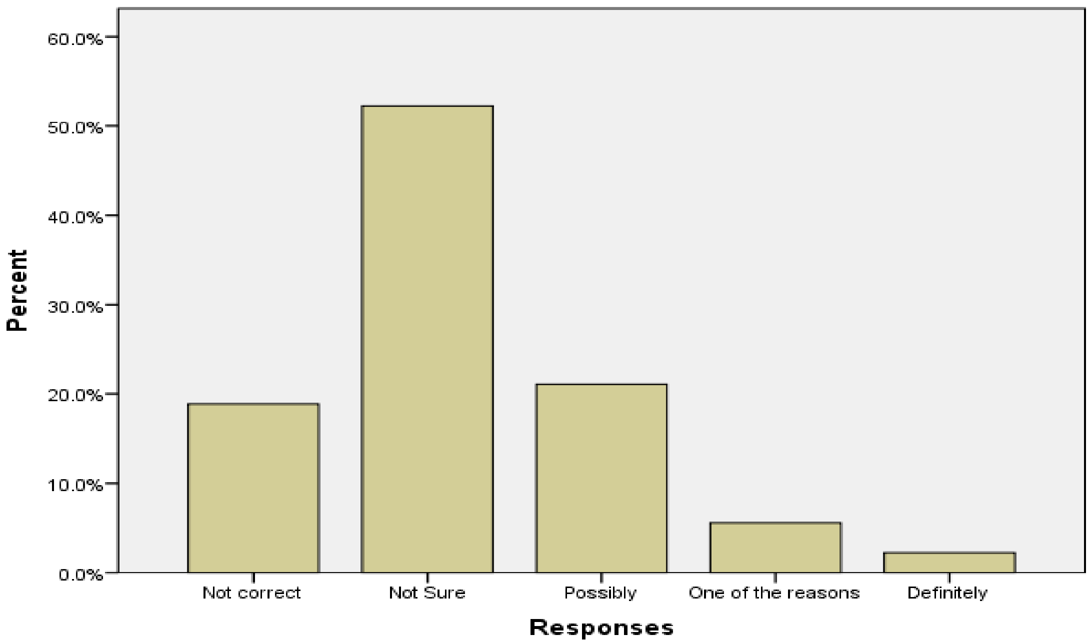


Figure. 28: Distribution of 5-point scale responses for the Item 1 (RFID system too complicated to use) of RFID Tagging as a potential solution in easing ED Overcrowding

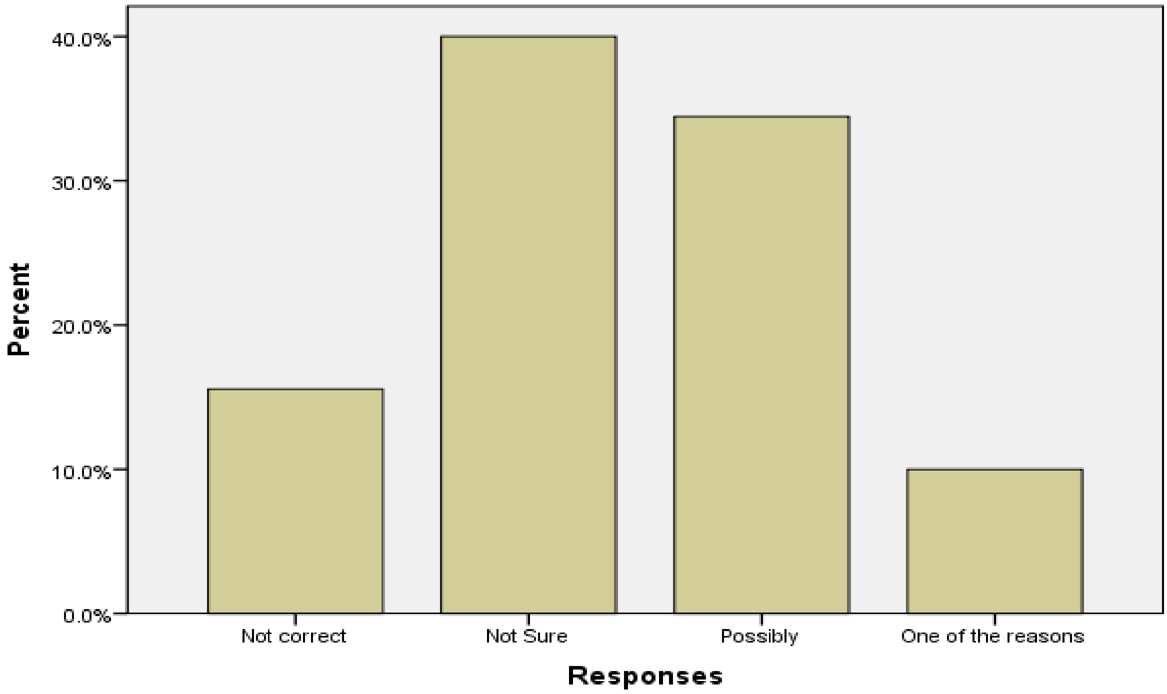


Figure. 29: Distribution of 5-point scale responses for the Item 2 (The RFID system does not always function the way it is supposed to) of RFID Tagging as a potential solution in easing ED Overcrowding

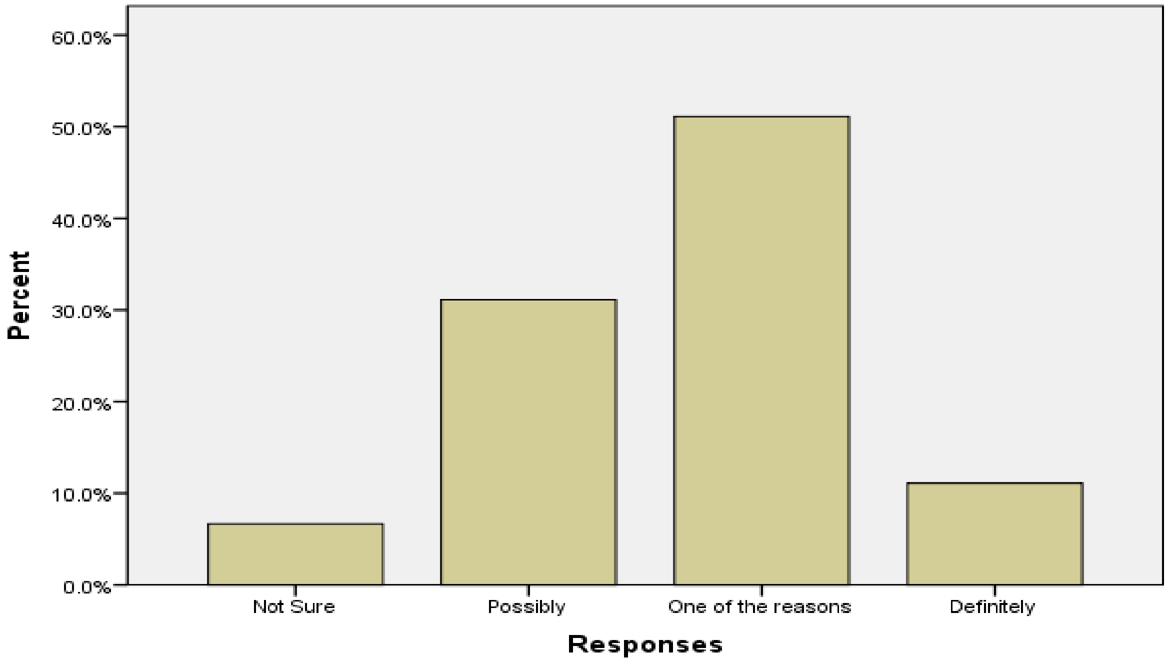


Figure. 30: Distribution of 5-point scale responses for the Item 3 (The RFID system made our department less crowded than before we started using it) of RFID Tagging as a potential solution in easing ED Overcrowding

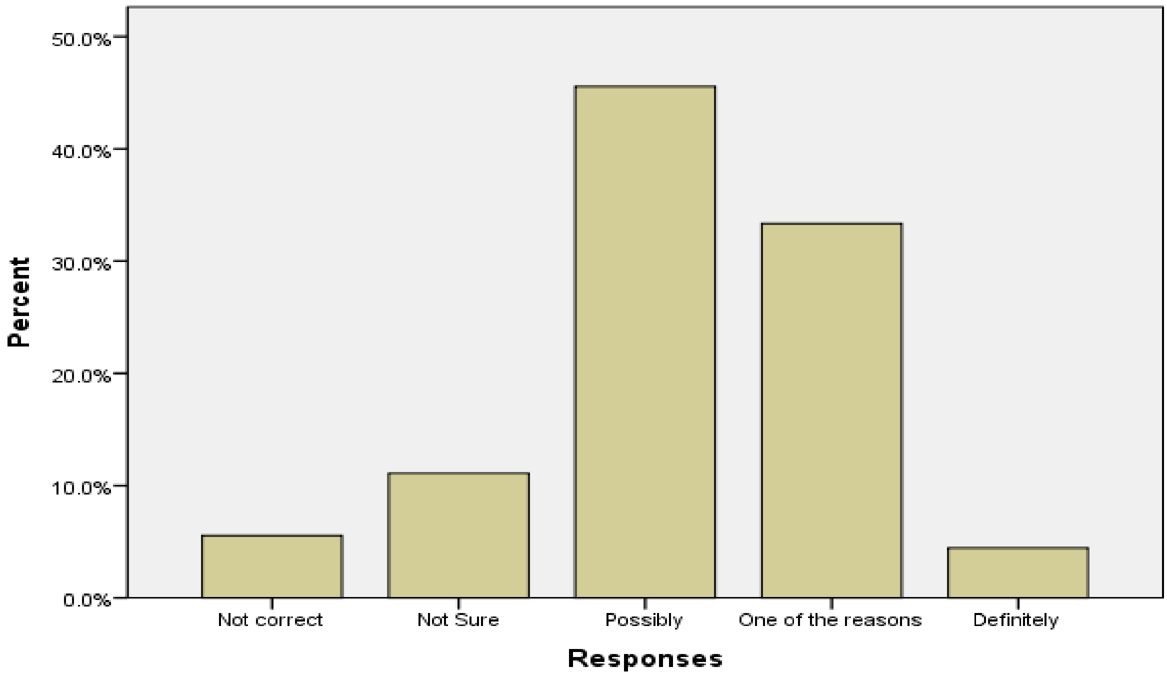


Figure. 31: Distribution of 5-point scale responses for the Item 4 (The RFID system should not be relied upon as the only solution to ED Overcrowding) of RFID Tagging as a potential solution in easing ED Overcrowding

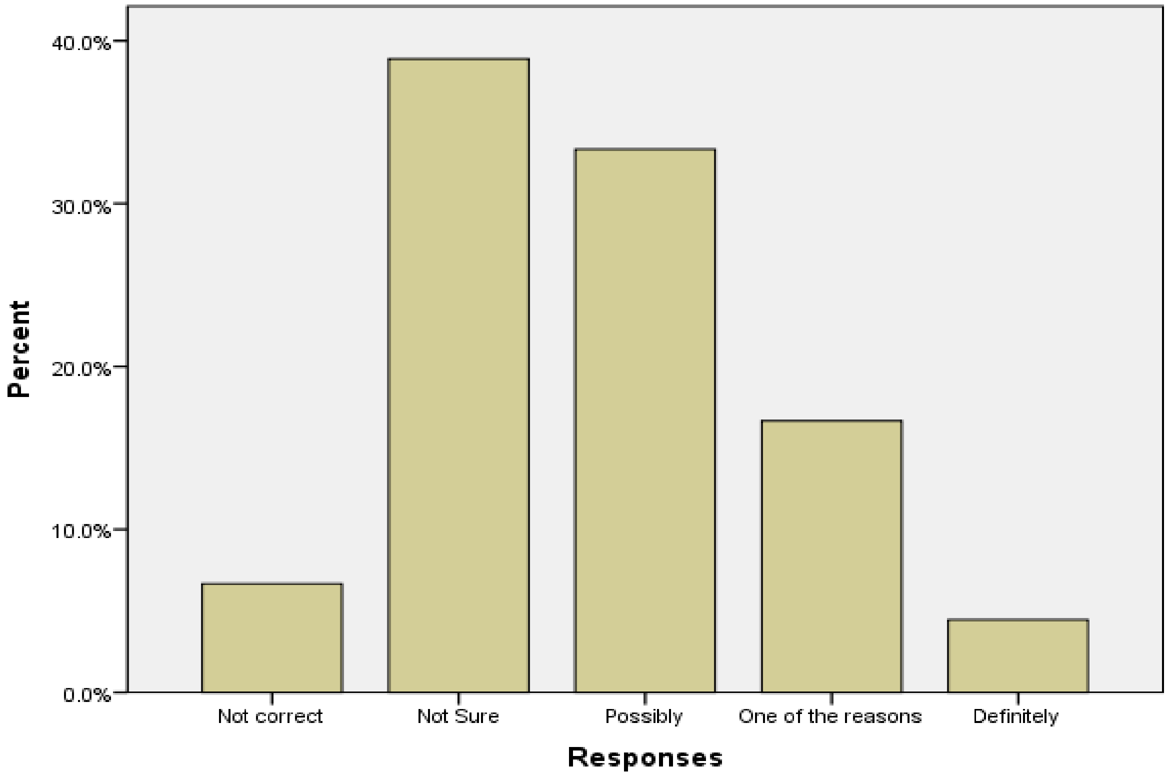


Figure. 32: Distribution of 5-point scale responses for the Item 5 (The training received on using the system was adequate) of RFID Tagging as a potential solution in easing ED Overcrowding

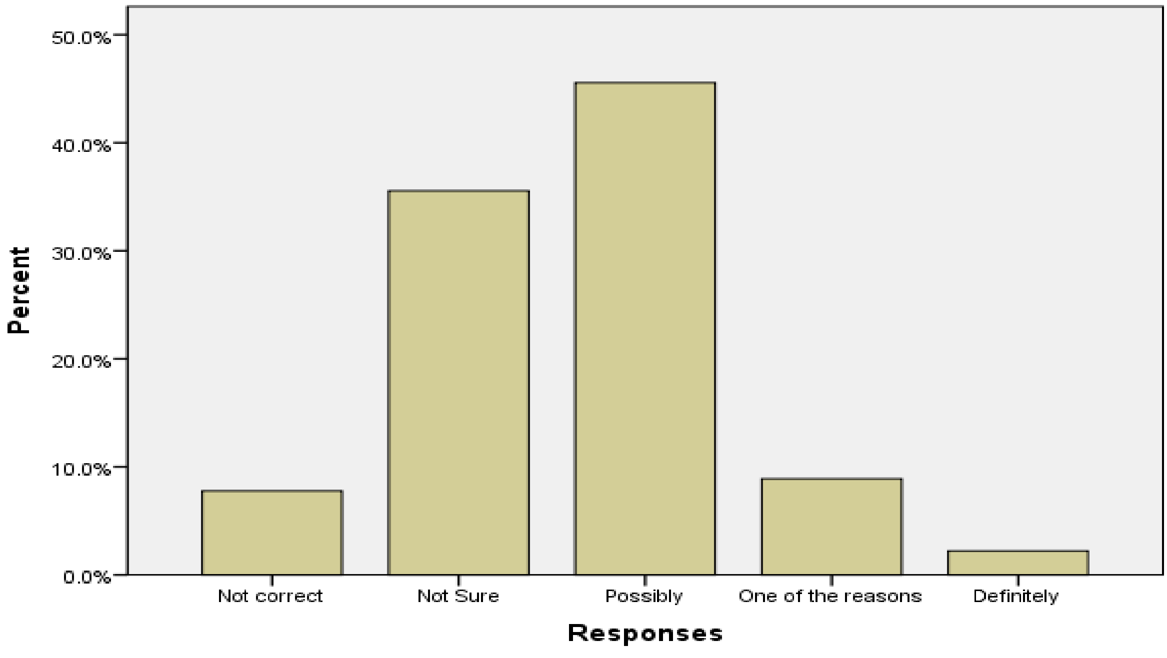


Figure. 33: Distribution of 5-point scale responses for the Item 6 (The technical support received/ continue to receive was adequate) of RFID Tagging as a potential solution in easing ED Overcrowding

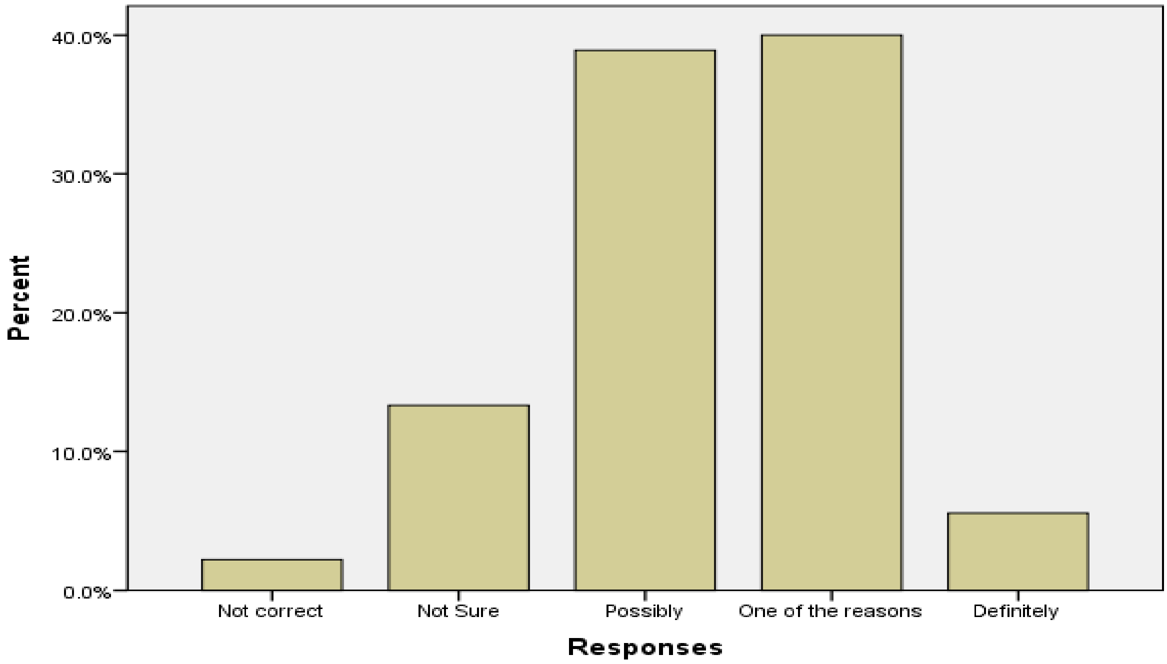


Figure. 34: Distribution of 5-point scale responses for the Item 7 (The ED patients did not like wearing the RFID tags) of RFID Tagging as a potential solution in easing ED Overcrowding

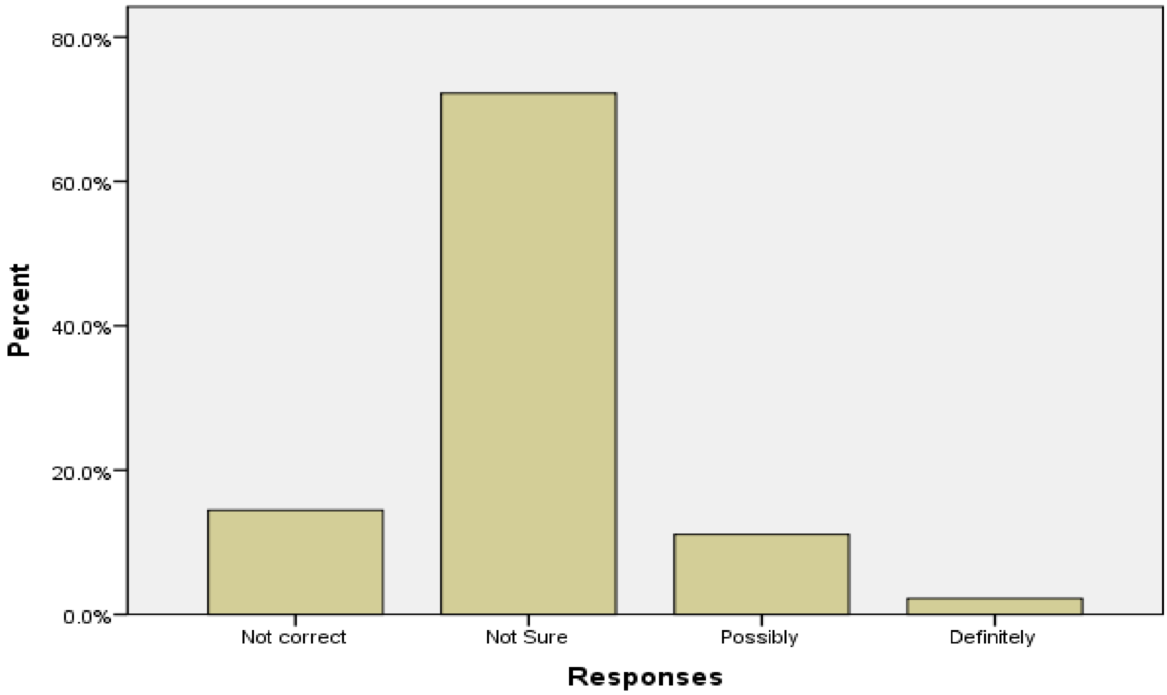


Figure. 35: Distribution of 5-point scale responses for the Item 8 (The RFID should be extended throughout the whole hospital system) of RFID Tagging as a potential solution in easing ED Overcrowding

Table 27: Testing of responses of subjects for each item of RFID tagging as a potential solution in easing ED Overcrowding

Factor 5	Observed N	Expected N	Residual	X^2 value	P value
Item 1					
1-Not correct	17	18.0	-1.0	70.444	<0.0001
2-Not sure	47	18.0	29.0		
3-possibly	19	18.0	1.0		
4-one of the reasons	5	18.0	-13.0		
5-definitely	2	18.0	-16.0		
Item 2					
1-Not correct	14	22.5	-8.5	22.622	<0.0001
2-Not sure	36	22.5	13.5		
3-possibly	31	22.5	8.5		
4-one of the reasons	9	22.5	-13.5		
Item 3					
2-Not sure	6	22.5	-16.5	44.933	<0.0001
3-possibly	28	22.5	5.5		
4-one of the reasons	46	22.5	23.5		
5-definitely	10	22.5	-12.5		
Item 4					
1-Not correct	5	18.0	-13.0	61.222	<0.0001
2-Not sure	10	18.0	-8.0		
3-possibly	41	18.0	23.0		
4-one of the reasons	30	18.0	12.0		
5-definitely	4	18.0	-14.0		
Item 5					
1-Not correct	6	18.0	-12.0	43.444	<0.0001
2-Not sure	35	18.0	17.0		
3-possibly	30	18.0	12.0		
4-one of the reasons	15	18.0	-3.0		
5-definitely	4	18.0	-14.0		
Item 6					
1-Not correct	7	18.0	-11.0	66.778	<0.0001
2-Not sure	32	18.0	14.0		
3-possibly	41	18.0	23.0		
4-one of the reasons	8	18.0	-10.0		
5-definitely	2	18.0	-16.0		
Item 7					
1-Not correct	2	18.0	-16.0	59.667	<0.0001
2-Not sure	12	18.0	-6.0		
3-possibly	35	18.0	17.0		
4-one of the reasons	36	18.0	18.0		
5-definitely	5	18.0	-13.0		
Item 8					
1-Not correct	13	22.5	-9.5	1.099E2	<0.0001
2-Not sure	65	22.5	42.5		
3-possibly	10	22.5	-12.5		
5-definitely	2	22.5	-20.5		

4.2.6 Conclusions:

The confirmatory factor analysis shows the construct validity of an instrument used in this study is having good validity. Regarding the reliability, the internal consistency of each of the items of 5 factors, shows significant level of cronbach's α for all the 5 factors (Reason for ED overcoming, Effect of ED overcoming on patients**,** Managing ED overcoming, Applied and implemented solutions to ED overcoming, and Radio Frequency identification (RFID) tagging) indicates that the study subjects have responded appropriately to all the items of an instrument.

The study subjects' responses to the 29 items under the 5 factors of the study instrument and their implications will be discussed in Chapter VI.

Chapter V

FMEA Sheet Application

5.1 Introduction

Failure Mode and Effects Analysis (FMEA) is a proactive risk assessment tool used to identify potential vulnerabilities in complex, high-risk processes and to generate remedial actions before the processes result in adverse events. FMEA is increasingly used to proactively assess and improve the safety of complex health care processes such as drug administration and blood transfusion. A central feature of FMEA is that, it is undertaken by a multidisciplinary team, and because it entails numerous analytical steps, it takes a series of several meetings. Composing a team of busy health care professionals with the appropriate knowledge, skill mix, and logistical availability for regular meetings is, however, a serious challenge (Ashley 2010). The medical imperative is clear: To make health care safe we need to redesign our systems to make errors difficult to commit, and create a culture in which the existence of risk is acknowledged and injury prevention is recognized as everyone's responsibility (Leape et al 1998)

The analysis of the data obtained from the 90 participants in the online survey, highlighted a number problems with using RFID in a clinical setting, namely the emergency department from the perspective of the various users. Equally, it highlighted a number of benefits. These problems can be viewed as potential failures that are capable of undermining the application of a technology that has the potential along others to ease ED overcrowding. These failures can render RFID as well as any other such solutions somewhat obsolete.

In this chapter the author will highlight results obtained from analyzing the survey data, and convert them to failure modes. These will be analyzed and added to the FMEA sheet, which has been discussed above. Potential solutions are then suggested within the sheet. Further discussion of these solutions will follow in the last chapter of this thesis.

A reminder of how process FMEA works could be useful at this juncture of the work. This is to help the reader follow this chapter without the need to refer to chapter three where P-FMEA and D-FMEA have been discussed.

1. Identify failure mode. This is the manner in which a component, subsystem, system, process, etc. could potentially fail to meet the design intent.

2. Describe the effects of the failure mode. For each failure mode identified the designers of the systems should determine what the ultimate effect will be?

3. Establish a numerical ranking for the severity of the effect on a scale that uses 1 to represent no effect and 10 to indicate very severe effect. This enables prioritizing the failures and address the real big issues first.

4. Identify the causes for each failure mode. A failure cause is defined and documented as a design weakness that may result in a failure.

5. Establish a probability factor. A numerical weight should be assigned to each cause that indicates how likely that cause is (probability of the cause occurring). A common industry standard scale uses 1 to represent not likely and 10 to indicate inevitable.

6. Identify Current Controls. The mechanism that prevent the cause of the failure mode from occurring or which detect the failure before it reaches the end user.

7. Determine the likelihood of Detection. An assessment of the likelihood that the Current Controls will detect the cause of the Failure Mode or the Failure Mode itself.

8. Determine Recommended Action(s) to address potential failures, these could include specific inspection, testing or quality procedures; selection of different components or materials.

9. Assign Responsibility and a Target Completion Date for these actions. This makes responsibility clear-cut and facilitates tracking.

10. Indicate Actions Taken. Re-assess the severity, probability and detection and review the revised actions.

11. Update the FMEA Sheet as the design or process changes, the assessment changes or new information becomes known.

5.2 RFID Failure Mode

The author has been able to identify a number of potential failure modes as a result of analysis of the data derived from the online survey. These failures could be responsible for reducing the ability of RFID to achieve its full potential as a technological solution to help dealing with ED overcrowding. The failures above have been eluded for mostly in under the heading of RFID tagging as a potential solution in easing ED Overcrowding. Given the qualitative nature of this work, other failure modes that lead to ED overcrowding have been identified under the other headings explored in the survey.

5.2.1 Failure mode in causes of ED overcrowding

It has been statistically concluded that, the reasons for ED overcrowding were due to deficiencies in infrastructure, lack of manpower, inappropriate management of skills and partly due to inappropriate visits by patients who do not require emergency care. As the analysis of data related the causes of ED overcrowding; respondents responded with "possibly" to inappropriate patients visits to ED at 33%, lack of appropriate staffing skills at 10%, access block at 45.6%, and poorly designed facilities at 41.1%. From this, we can infer that, access block appears to be the highest rated reason for ED overcrowding. Therefore, it has been chosen as one of the most likely failure modes and, could potentially be eased via the use of

RFID tagging. This allows for monitoring of patients flow through the ED and forecasting of potential bottlenecks that could lead to overcrowding. Added to this, and as mentioned earlier in the work, extending to the tagging system throughout a given healthcare facility will likely allow for more seamless patient flow from ED to the point of admission.

5.2.2 Failure mode in management of ED overcrowding

Management of ED overcrowding is multifactorial and requires the availability of many elements for successful outcome. Data obtained from the online survey highlighted a number of issues related to management of ED overcrowding and provided a number of potential failures in the system that can be anticipated, prevented or at least modified to stop minimize the impact of ED overcrowding on the ED and the rest of the healthcare facility in which it exists.

In their responses, the respondents generally rated the importance of management as very significant compared to the rest of the survey. For instance, 44.4% thought that public and patient education about proper use of ED helps reduce overcrowding. Whereas 35.6% thought better management of paperwork and forms improves the situation. However, 50% considered the use technology such as RFID could have a positive impact on improving overcrowding. As mentioned above, management of overcrowding is multifactorial and the survey reflects this view because, although technology was chosen as the highest impact factor, other factors were of statistical significance as well

5.2.3 Failure mode in the use of RFID Tagging

Data obtained from the survey highlighted a number of interesting issues with regards to the use of RFID tagging of patients in ED at the Riyadh Military Hospital. The study subjects were not “definite” in their views, because all the 8 items, under this factor were related to the knowledge application, and utility of RFID in managing ED overcrowding. Closer look at the data provides explanation to that statement. For instance, 52.5% were not sure if RFID it too complicated to use, but 51.1% thought it made the department less crowded. Furthermore, only 38.9 felt they received or continue to receive adequate training and support on the use of RFID. One of the unexpected outcomes was that, 72.2% were not sure about if RFID should be extended to the rest of the healthcare facility. This is despite the fact that it very likely to lead to a positive impact on patient flow and reducing the likelihood of ED overcrowding. The author could infer that this is a failure mode in itself, one that could be rectified improvement of the

RFID tagging system, better training and staff support who use the system and demonstrating the integrated picture of improved patient flow throughout the entire healthcare facility rather than viewing ED overcrowding as an isolated ED issue. It is, of course, very important not to ignore the 45.6% rate of responses stating that patients did not like wearing RFID tags. This is yet another potential failure of the system that relies on the compliance of patients in order to function smoothly. It is expected that further work would look into this particular issue of patients not wishing to wear the RFID tags.

5.3 Applying Failure Mode to FMEA Sheet

After surveying users of the RFID system at the ED at the RMH, the author identified a number of issues that could be applied to the FMEA sheet presented in chapter III (research methodology). The author will use the elements contained in the said FMEA sheet and applied the potential failure modes discussed above. The risk priority number (the standard scale of 0 to 10) will be replaced by the percentage of responses given in the survey. No actual entry of data into the sheet was attempted to due to space restrictions.

5.3.1 Failure mode

<u>1. Causes of overcrowding: </u>As stated above, access block is a highly rated failure mode (RPN 45.6). As such the potential for failure and impact on ED overcrowding is significant. Potential causes for such failure is lack of beds or destinations to which ED patients can be disposed of. Poor coordination and communication between various hospital departments is another reason for such failure. The frequency of such failure is highly likely given the state of patient flow in most hospitals. The exact degree of detectability of such failure is difficult to predict in the absence of unified systems (RFID throughout the hospital), lack of good and effective coordination between ED and different departments.

The logical recommendations in order to reduce the likelihood of such failure and its impact on ED overcrowding are: extending RFID to be hospital-wide, setup alert systems to predict issues with patient flow, regular and effective communication and coordination systems between ED and other hospital departments.

2. Management of ED overcrowding: The use of technology has been rated the highest, this means that its failure is likely to represent the highest impact (RPN 50). However, this point will be discussed below.

Lack of public awareness of the proper and effective use of ED resources is very likely to lead unnecessary or even inappropriate visits. Thus, overcrowding becomes very likely. The impact of such failure is clear and has been discussed on a number of occasions throughout the work. Such failure is frequent and is predictable (RPN 44). A number of actions can be advised to minimize the likelihood of this failure and its impact. These include: public awareness campaigns (TV and radio ads and billboards etc., opportunistic education of patients of visit ED inappropriately, the use of retrospective audits to identify inappropriate visits and communicate the outcomes with the appropriate parties such as primary care and public health sector.

3. RFID Tagging: As discussed above, given the technological nature of RFID systems they are subject to a number of failures. However, functional failure is not the only one of interest here. As the survey showed, a large number of respondents were not sure if RFID should be extended to the entire hospital. It would seem logical that the system becomes hospital-wide given the clear benefits to the patients flow from the ED to the point of destination. However, the responses do not reflect this. Such failure is predictable due inability (of the management) to demonstrate the overall benefit to the staff on how it could reduce ED overcrowding.

Another failure that was realized from the survey is the low number of respondents (38.9%) who felt they received or continue to receive adequate support while using the RFID system. This represents a huge potential of failure with significant impact on the overall performance of the system, its users (patients and staff) and will likely lead to poor management of ED overcrowding. Potential causes of such low rate of support could include: poor documentations included with the system, slow response from the technical support team, short periods of initial training that leads to high rate of error or poor design of the actual RFID system. Failure of the RFID system due to whatever reason will, likely, lead to severe disruption of ED processes, patient flow and management and worsening overcrowding. Therefore, suitable length of staff training periods, good availability and quick response time of technical support are crucial to alleviate RFID failure. This, in addition to good design of the RFID system itself in order to satisfy the need of users both staff and patients.

Chapter VI

Discussion

ED overcrowding is a global issue that is featured almost everywhere in the world and the Kingdom of Saudi Arabia is no exclusion.

The FMEA tool which was used in the survey has provided good internal consistency with average measure of Cronbach's α value of all the 29 items is 0.805 and having good validity as all the 29 items fall under the 5 constructs (Factors). From the responses of the study subjects on a 5-point Likert scale towards the on-line survey, the author discussed the following points:

As depicted in Table 19, six potential causes of ED overcrowding in RMH are identified.. The first reason relates to the inappropriate visits made by patients who do not need ED services, was responded by 33.3% as possible and 17.8% as definitely. This particular cause appears to be universal among almost all EDs. In fact, none of the respondent surveyed disagreed with this observation, while almost half of them agreed either completely with it as a basis for overcrowding in ED. A third (30%)of them cited this as one the reason as possible while only about one fifth (18.9%) of the respondents were not sure.

The same situation can be seen in almost all EDs in the city and probably around the country. In most cases, this is explained by the fact that, it difficult to obtain timely appointments with primary care and other specialty physicians. Hence, many patients use the ED as a quick short route to access the healthcare system and perhaps attain a referral to an outpatient department. Another benefit of attending ED, as perceived by the patients, is the much needed and additional reassurance offered by emergency care physicians.

A similar pattern of response is noted in 2nd reason that states overcrowding is believed to be due a shortage of skilled staffing in the ED. This question was responded by 53.3% of subjects as "possibly" which seems to be a global and chronic issue. It is especially true in Saudi Arabia. Where it is believed the country needs to surmount several obstacles to achieve self-sufficiency with medical staffing. This is true of entire range of medical staffing compliment. The second reason - could be simply attributed to a tremendously high number of patients attending the ED with an inadequate number of resources to meet such demand which is another commonly encountered and a chronic issue at the RMH ED as well as most other large and inner cities.

Lack of beds in the departments of destination in the hospital follows a similar pattern as in the case with the first three reasons and still carries significant weight with almost two fifth of subject citing that as one of the reason.

The issue of over complicated management policies and care pathways ranks second as a cause of overcrowding in the surveyed study subjects. Again, a vast majority of these subjects cited this as partially or totally the reason for overcrowding in the ED. While only less than 10% of respondents were not sure, but none disagreed with the statement. The author attributes these responses to the general complexity of policies and procedures and, on occasions, the poor communication style and efforts of management at the RMH. This impedes an effective flow of communication. Another, but less significant, factor as noted by the participants is that a number of patients do not need to be seen at ED but they are permitted to do so by management due to favoritism and other similar factors.

None of the respondents disagree with the statement of this question, however almost half of subjects consider it as a possible reason, possibly because evidence of such response lies in the hands of another section in the ED or in the admission office hands. The last two in this question as depicted in table reason follows a pattern that very much mimics those in the proceeding reasons.

In summing up results of this question, it is obvious that the vast majority of the study subjects consider each of the six reasons as a possible; the reason or definite reason for the overcrowding at the ED is the RMH. While a relatively very small rate of subjects were not sure of these reasons as cause almost none of the subjects disagreed with these reason as causes of overcrowding. The author tends to believe that these reasons individually and collectively can be considered as valid and true reason for overcrowding at the ED.

Table 21 illustrates the reason listed by the study questionnaire as main reasons that effect of ED overcrowding on patients. Reason 1 that states ED overcrowding causes extended pain and suffering, only 6.7% of subjects disagreed with this statement and the vast majority 45.6% considering the statement as possible one of the reasons, or definitely a reason for extended pain and suffering. In fact this sort of response follows normal expectations. For the second reason (I believe ED overcrowding is a risk for poor outcomes), 55.6% had responded as “possibly”, for the third reason (I believe ED overcrowding causes actual poor outcomes), 57.8% had responded as “possibly”, for the fourth reason (I believe ED overcrowding causes dangerous delayed diagnosis and treatment), 48.9% as “possibly”, whereas for the fifth reason (I believe ED overcrowding causes significant patient dissatisfaction), 52.2% as “one of the reasons”.

However, the rest of the respondents stated it was possible and agreed totally with it as a reason for more pain and suffering in patients attending ED at the RMH. Pain and suffering can be seen as having a direct relationship with ED.

Overcrowding with them comes the insecurity and uncertainty that patient and their families experience while waiting to be seen and diagnosed and a prognosis is provided by healthcare professional at ED can be a serious suffering to this population and may represent continuous pressure on the healthcare team as they become pressed by questions and attempts to get them to attend to these patients, while they are busy treating other cases. Reason #2 that states ED overcrowdings is a risk for unfortunate outcomes and can be seen as a natural continuity to reason #4 with a pattern of agreement that spans over two thirds of subject only2 (2.2%) subject disagreed with it is as a reason but a good 31% were not sure whether it is a good reason or not. It can be seen that when ED overcrowding is a reason for extended pain and suffering, it follows that it can hinder proper diagnosis, medical interference and treatment outcome. In many situations direct and instant decisions and measures are required to be taken and implemented to stop ailment and prevent complications or even mortality.

Overcrowding can delay this process and patients can experience severe consequences’ as a result for such delay in ED. Majority of study respondents believed ED overcrowdings is a basis of actual poor out comes and causes significant patient dissatisfaction.

In fact, dissatisfaction is an associated and result of overcrowding and is a vital measure for quality cure delivery but client dissatisfaction has been cited in large number of studies across all industries, is a significant criteria for quality service. The researcher strongly believes that this question (F2) has yielded a consistent agreement with its 5 items as effect of overcrowdings in ED. The problem can be magnified in special circumstances or crisis where massive groups of patients are brought to the ED in a short period of time. The problem however does not only include patients and their families, but can add pressure on healthcare professionals and deter them from utilizing their full capacities and efficiency as the problem turn out to be chronic and acknowledged as a fail.

Towards the management of ED overcrowding (as shown in Table 23), and for the first item (I believe ED overcrowding can be reduced when the issue is viewed with the context of overall pressure on the entire healthcare system), 34.4% had responded as “possibly”, for the second item (I believe ED overcrowding can be reduced by increasing the number and expertise of ED staff), 35.6% had responded as “possibly”, for third item (I believe ED overcrowding can be reduced by better design of the way patients flow through the department (forms and paper work), 38.9% had responded as “possibly”, for fourth item (I believe ED overcrowding can be reduced by educating the public about the proper use of ED resources), 44.4% as “possibly”, whereas for fifth item (I believe ED overcrowding can be reduced by applying/implementing technological solutions), 50% as “one of the reasons”.

For the factor of “Management of ED overcrowding” the study subjects had responded in higher proportion as “possibly” to the 4 ways (items) and as “one of reason” to the fifth method (item) of managing overcrowding of ED. Here, the study subjects were not “definite” in their views, because 4 out of 5 items, under this factor were related to administrative feasibility of managing ED overcrowding. The responses to the first 4 reasons (as one of the reason) because these 4 reasons (items) are completely related to the administrative measures towards the management of ED overcrowding. Whereas the 5th reason (I believe ED overcrowding can be reduced by applying/ implementing technological solutions), the study subjects has responded as definite. This indicates that the study subjects were willing to adopt technological solutions in the management of ED overcrowding.

For the factor of “applied and implemented solutions to ED overcrowding” and its 5 reasons responses by the study subjects as given in Table 25, for the For the first reason (I believe ED overcrowding can be solved by having a dedicated bed-management team to tackle the issue of Access Block), 47.8% had responded as “possibly”, for the second reason (Consultant or Senior

ED nurse lead triage could help making an impact an ED overcrowding), 40% had responded as “possibly”, for the third reason (Diverting some of the emergency calls to advice help lines enabling paramedics to assess and discharge at the scene could help reduce ED visits), 37.8% had responded as “possibly”, for the fourth reason (An early warning system that could alert to the development of overcrowding could help management prepare and apply resources to prevent overcrowding), 40% as “possibly”, whereas for the fifth reason (I believe ED overcrowding can be solved by implementing technological innovations such as Radio Frequency Identification of patients and assets), 70% as “one of the reasons”.

For this, factor of “Applied and implemented solutions to ED overcrowding” the study subjects had responded in higher proportion as “possibly” to the four solutions (items) and as “one of the reason” to the fifth solution (item) of Applied and implemented solutions to ED overcrowding. Here, the study subjects were not “definite” in their views, because all the 5 items, under this factor were related to hospital management system, which includes adequate infrastructure, administrative feasibility, and availability of appropriate manpower with efficient management skills. The feasibility of implementing technological innovations particularly, Radio frequency identification of patients, could be considered as a possible solution to ED overcrowding because 70% of the study subjects was responded “ as one of the reasons”.

In the analysis of responses for the 5^{th} factor (RFID Tagging as a potential solution in easing ED overcrowding) of an instrument which is given in Table 27, in which for the first reason (I believe the RFID is too complicated to use), 52.5% had responded as “Not sure”, for the second reason (The RFID system does not always function the way it is supposed to), 40% had responded as “Not sure”, for the third reason (The RFID system made our department less crowded than before we started using it), 51.1% had responded as “one of the reasons”, for the fourth reason (The RFID system should not be relied upon as the only solution to ED overcrowding), 45.6% as “possibly”, for the fifth reason (The training I received on using the system was adequate), 38.9% as “one of the reasons” for the sixth reason (The technical support I received/continue to receive was adequate), 45.6 % as “possibly” for the seventh reason (The ED patient did not like wearing/using the RFID tags), 40% as “one of the reason” and for the eighth item (The RFID should be extended throughout the whole hospital system), 72.2 % as “ Not sure”.

For this, factor of “Radio frequency identification (RFID) tagging” the study subjects had responded in higher proportion as “Not sure” to the 4 reasons, as “one of the reason” to 2 reasons and as “possibly” to the remaining 2 reasons. Here, the study subjects were not “definite” in their views, because all the 8 reasons, under this factor were related to the knowledge application, and utility of RFID in managing ED overcrowding.

Chapter VII

Conclusions & Recommendations

7.1 Conclusions

ED overcrowding is a negative phenomenon of healthcare that has been described abundantly globally. Factors that have been found to be associated with it range from the nature of the healthcare systems themselves, demographic reasons, lack of suitable technological infrastructure and similarly suitably equipped and trained clinical manpower.

The impact of overcrowding can be serious and have been shown to be an important factor in raising deaths and suffering. This study aimed to investigate the use of technology in health care, especially RFID supplemented by FMEA, as a tool for tracking and management in Emergency department overcrowding. The author proposed the potential use of FMEA as an assessment tool to help identify the impact of technology, namely RFID, in dealing, improving and, on in the long term, preventing ED overcrowding. The author utilized a survey questionnaire to study the following areas:

- Causes of ED overcrowding
- Effects of ED overcrowding on patients
- Management of ED overcrowding
- Applied and implemented solutions to ED overcrowding
- RFID as a solution to ED overcrowding

It was obvious from the results of this survey that the common reasons for overcrowding in ED that are globally known, do exist in the population of this study. Inappropriate visits made by patients who do not require emergency care, as one of the causes of ED overcrowding was viewed by our study subjects. On the other hand the survey subjects have also showed that there is a limited or short availability of skilled staff at the ED. It is not really known how much are these two reasons related because increased numbers of patients who do not require emergency care can result in an overflow of ED patients where it becomes very difficult by current ED staff to meet their needs and overcrowding in ED occurs as a natural process.

It can also be that access block which may be defined as a situation where hospital beds are not available, due to high occupancy rate as compared to a high number of ED patients who are obliged to wait in the ED for long periods. Outcomes of access block can be very serious especially in the cases of elderly, pediatrics, acute and chronic illnesses. Access block alone can lead to overcrowding in ED. It is clear, at the Riyadh Military Hospital, that the number of beds available, despite expansions in this capacity does not commensurate with the rate of increase in the number of ED visits, which indicates it as a major reason for overcrowding in ED. Expansion of the ED alone without considering other bottle necks will not resolve the issue and would only show up the ED as a non-efficient poorly designed facility as concluded by study subjects when they were surveyed about design of ED as a cause factor of overcrowding.

On the other hand, this study has shown that ED overcrowding can cause extended pain and suffering, in fact many studies around the world has documented similar results. Because of the importance of timely diagnosis and treatment initiation, ED overcrowding can delay medical care. Intravenous injections that provide the most direct route for delivery of medications can be delayed due to ED overcrowding. Diagnosis itself can be delayed due to delay in patient referral to diagnostic services and laboratory. Hence prompt treatment and pain management are hampered of which consequences are extended pain and suffering. It can be concluded from this study that, while the ED is a fast way to handle patients, stabilize their condition and start them on treatment that prepare them to be admitted to the hospital or transferred to the ICU, ED overcrowding can become a major obstacle to achieve these results and can significantly add or extend patients pain and suffering, In fact this may explain increased death rates in such populations as a result of overcrowding as reported in many studies. This suffering is not only limited to the ED population but can extend to patients already admitted to hospitals as some of them is prematurely discharged to allow for availability of beds to ED patients which may result in serious complications and possible re-admission through the ED which in turn creates a condition similar to a vicious circle.

The third factor of the survey instrument in this study focused on questions that explored the multi-factor approach to managing of ED overcrowding. It is obvious and has been documented by responses of study subjects, as is the case in many other research works around the world that efforts for management of overcrowding in the ED should focus on various aspects that contributes to ED overcrowding. This can start by creating a more effective patient flow, which covers every aspect of this process including micro activities like forms and paper works. It also includes educating patients themselves in regards to proper use of ED services and making better use of personnel working at the ED in regards to delegating them certain decisive responsibilities the utilization of technological advance also play an important role in management efforts to reduce overcrowding in the ED, in addition to proper management of hospital beds. It can be concluded that management of overcrowding in the ED is an issue that should be shared by all stakeholders and is a multi-disciplinary hospital wide process. This section have shown that every step at the overcrowding process once mapped and studied can form a crucial aspect of improvement efforts aimed at reducing overcrowding in ED.

It is also concluded that working at one step without consideration of others, which are closely interlaced into it, can be a failure and can lead to deterioration of the whole process. The section on utilization of RFID technology to tag patients as a potential solution in easing ED overcrowding yielded some insight into its use. It may be concluded that, although the use of RFID system in the ED did help reduce overcrowding, but it seems that besides its technical difficulties and complexity, does not alone solve the problem of overcrowding. RFID can be utilized as a means of better patient logistical management but cannot provide solutions to lack of beds in the hospital nor to reductions of unnecessary visits to the ED.

As discussed above, FMEA as a risk assessment technology has been in use for over fifty years. It has been utilized in large of commercial and industrial sectors and all too often provided valuable input in design, manufacturing and usage of modern day product. The author concluded that, FMEA can be applied to assess the risk of potential failures in health in general. However, it can play a very valuable role in the case of assessing potential failures relevant to the use of technology, in this case RFID, managing, reducing and perhaps preventing ED overcrowding. As noted below, there is now a new term has been coined to describe the use of FMEA in healthcare. It is known as Healthcare Failure Mode and Effects Analysis (HFMEA) (McNally et al. 1997).

It would be logical to apply the concept of process FMEA to the subject of using RTLS technology to manage ED overcrowding. This is because the movement of patients through ED is viewed as a process and P-FMEA would be able to monitor the steps that RFID monitoring goes through and identify potential failures. When these are identified, then solutions can be developed and applied. The cycle of P-FMEA is repeated to observe the impact of those solutions and the overall goal of dealing with ED overcrowding.

7.2 Recommendations

The author of this research recommends that a true and thorough investment in the ED physical setting and manpower resources at RMH is urgently studied and implemented. It is hoped that such initiatives can create changes in the culture of the ED, improve communication among organization members, develop and implement training and education programs and improve staff morale. Eventually such effort can improve patient flow and maintain efficiency in patient's management and care provided to ED patients. It also can reduce those patients' stay at the ED. The RMH top management is highly encouraged to get involved in such efforts to show their support and provide guidance towards creative and innovative ways of implementing them their involvement can also make the funding process more understandable and feasible special efforts are also recommended to process patients with special needs like those in severe pain, critical condition, new born and children as well as elderly. These groups can benefit from a standalone fast track to handle them promptly, stabilize their condition and alleviate their pain and suffering.

Technological innovation and solutions should be invested in. RFID is one such technology, as identified in this work. It has a solid place in helping to ease and better manage overcrowding. Naturally, other similar technologies are being invented and develop in tandem with RFID. These include WiFi with various bandwidths (900 MHz, 2.4 GHz and 5.0 GHz.), and the recent developments in Bluetooth technology.

In the case of access block it is highly recommended that special task force is established at the RMH which includes members of different medical and non-medical division, to study the mechanics of bed management and better utilization of beds. Such force can find way to prevent abuse of beds by certain patients who for certain geographic reasons prefer to extend their stay at the hospital instead of being discharged and become obliged to stay in a hotel. The RMH is encouraged to provide special long stay facilities that require minimal care and minimal staff outside the hospital facility. Long stay housing areas can also be operated by the private sector; they definitely will decrease the number of occupied beds and increase availability for new admissions from the ED.

On the other hand it is recommended to work also on the other end of the process: where only eligible patients are allowed or accepted in the ED. It has been shown that creating filters within process does not really make much difference but a thorough and efficient intermediate screening section in the ED can be beneficial in screening, assessing and quickly assigning those cases that are the source of in appropriate visits to the ED and referring them to regular clinic specialties. This may help in reducing the input of unnecessary visits to the ED. Naturally, with new technologies and innovations there is more potential for risk for failures and subsequent risks to the subjects using these technologies. As demonstrated in this work, FMEA can be applied to identify, study the root causes of these failures and provide potential solutions to minimize those risks and prevent their occurrence in the first place where possible.

The author recognizes that, this work is not exhaustive with regards to exploring the full potentials of either RFID or FMEA. Much needed work remains to be done in both fields. Ideally, follow up research should be conducted to advance the stages of this work. This could take the form of repeating the FMEA cycle set out here and identify whether the initial work and the proposed changes made an impact on the issue of ED overcrowding. If so, then how can this be improved further? Furthermore, impetus can be given on the positive influence of technology, namely RFID, on helping day-to-day healthcare problems such as ED overcrowding.

As described in above, FMEA has its origin in the industrial sector and it took a while before it was used in other sectors such as healthcare. As a result and as expected the term Healthcare Failure Mode and Effects Analysis (HFMEA) is being coined and most likely will be widely used. In the past, medicine used a human error approach, which identified the individual as the cause of the adverse event. We now recognize that errors are caused by system or process failures (McNally et al. 1997). FMEA focuses on the system within an environment and uses a multidisciplinary team to evaluate a process from a quality improvement perspective. The Joint Commission for Accreditation of Healthcare Organizations (JCAHO) in the US has recommended that healthcare institutions conduct proactive risk management activities that identify and predict system weaknesses and adopt changes to minimize patient harm (Adachi et al. 2001).

In 2001 the Veteran's Administration (VA) National Centre for Patient Safety (NCPS) specifically designed the HFMEA tool for risk assessment in the healthcare field. The HFMEA tool was formed by combining industry's FMEA model with the U.S. Food and Drug Administration's Hazard Analysis and Critical Control Point (HACCP) tool together with components from the VA's root cause analysis (RCA) process. HACCP was developed to protect food from chemical and biological contamination and physical hazards. The HACCP system uses seven steps: (1) conduct a hazard analysis, (2) identify critical control points, (3) establish critical limits, (4) establish monitoring procedures, (5) establish corrective actions, (6) establish verification procedures, and (7) establish record-keeping and documentation procedures. It uses questions to probe for food system vulnerabilities as well as a decision tree to identify critical control points. The decision tree concept was adapted by the VA for the HFMEA tool. The HFMEA tool has been subsequently recognized in the White Paper prepared by the American Society for Healthcare Risk Management (ASHRM). In an effort to globally share the merits of this process, a video, instructional CD and worksheets on the use and application of HFMEA has been sent to every hospital CEO in the US to be shared with individuals and risk managers responsible for patient safety (American Society for Health Risk Management 2002).

With the above in mind, the author advises that the discussed future work would then adopt some of the steps taken and apply HFMEA principles to the RFID and/or other technologies in order to advance healthcare safety and efficiency in general and contribute to solving as many problems as possible within healthcare including ED overcrowding. And the use of technology is highly recommended to be utilized at the RMH ED due to its ability to ease processes, identify physical location of patients and assist in their parallel treatments at other departments like radiography and laboratory. It also can ease communication with them which can finally create a better flow of patients setting up technological applications in the ED can prepare this department for future upgrades and newer version of technical applications that are witnessed and expected to appear regularly which can improve patient management at the ED.

As a final closing statement, the contribution of the work has been clarified as identifying the impact of RFID as RTLS technology in ED in the RMH for managing and controling overcrowding. This research also identified potential failure modes of this technology in ED overcrowding using FMEA analysis. Therefore, the outcomes of this work would provide an important contribution to the limited body of literature, outlined in the literature review chapter of this thesis, on the technological solutions of overcrowding in ED. Most of the search carried out by the author identified large variation in approaches to dealing with the issue of ED overcrowding. Those ranged from applying more human resources to altering the pathways of managing patient's journey through healthcare system to applying more intermediate layers of management to ease the pressure off of the EDs. Other approaches included some aspects of technology such as development of early warning systems that have not been widely adopted and remained as isolated efforts.

Appendix

Survey Question Design

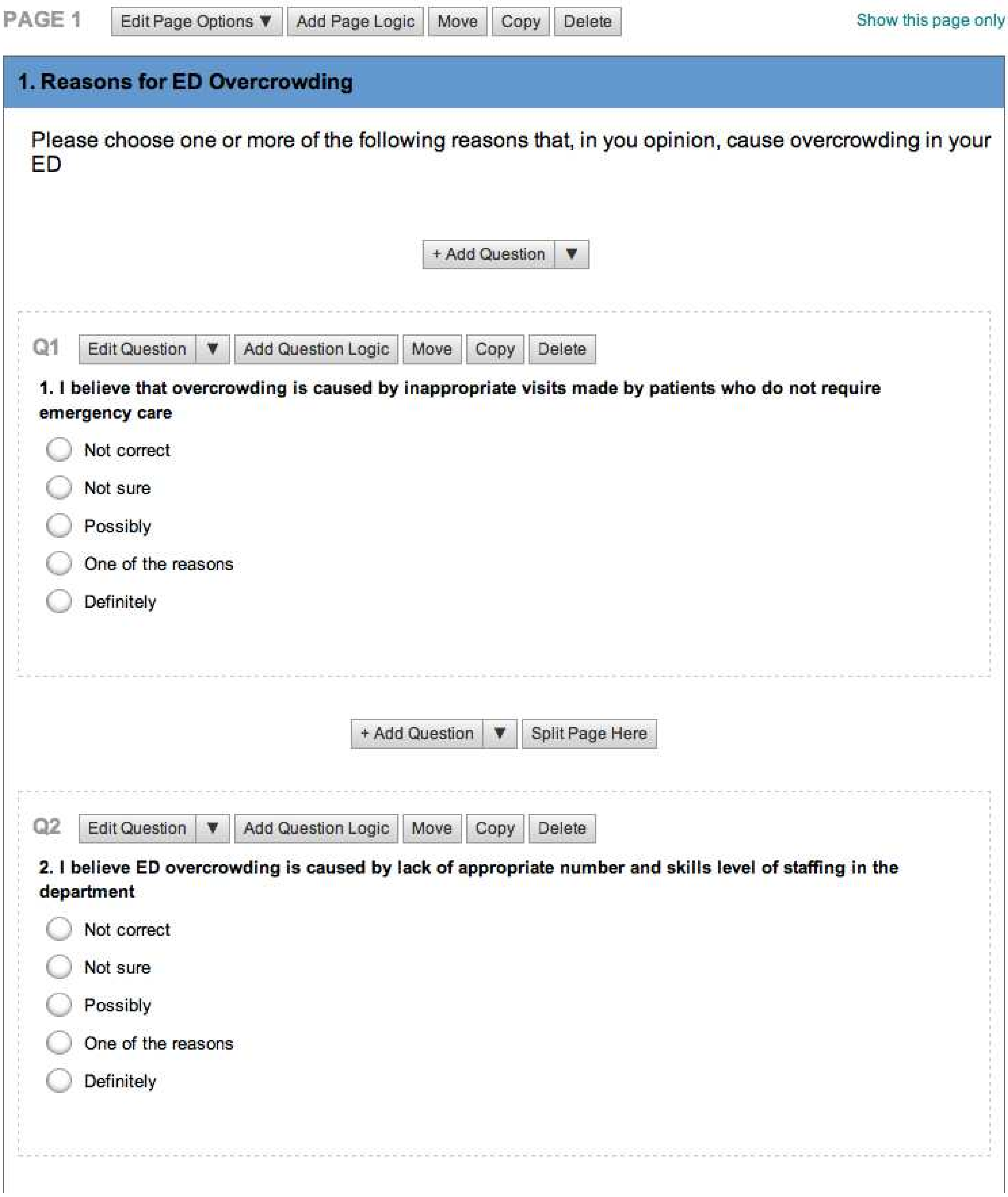
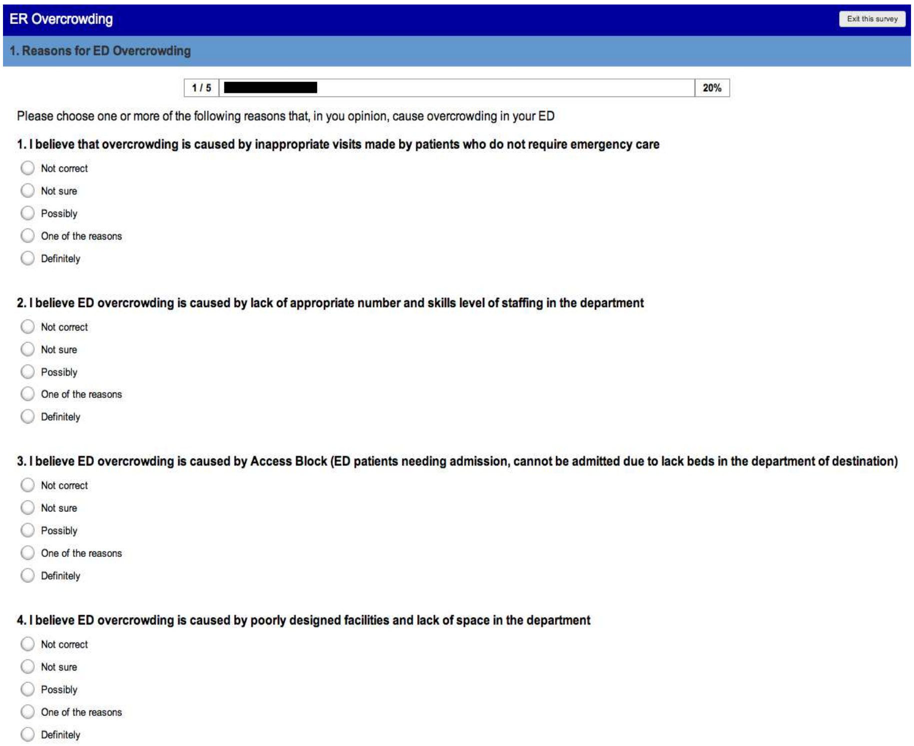


Figure 36 Online survey design

Survey Responses



ER Overcrowding

Exit this survey

1. Reasons for ED Overcrowding

1 / 5 20%

Please choose one or more of the following reasons that, in you opinion, cause overcrowding in your ED

1. I believe that overcrowding is caused by inappropriate visits made by patients who do not require emergency care

- Not correct
- Not sure
- Possibly
- One of the reasons
- Definitely

2. I believe ED overcrowding is caused by lack of appropriate number and skills level of staffing in the department

- Not correct
- Not sure
- Possibly
- One of the reasons
- Definitely

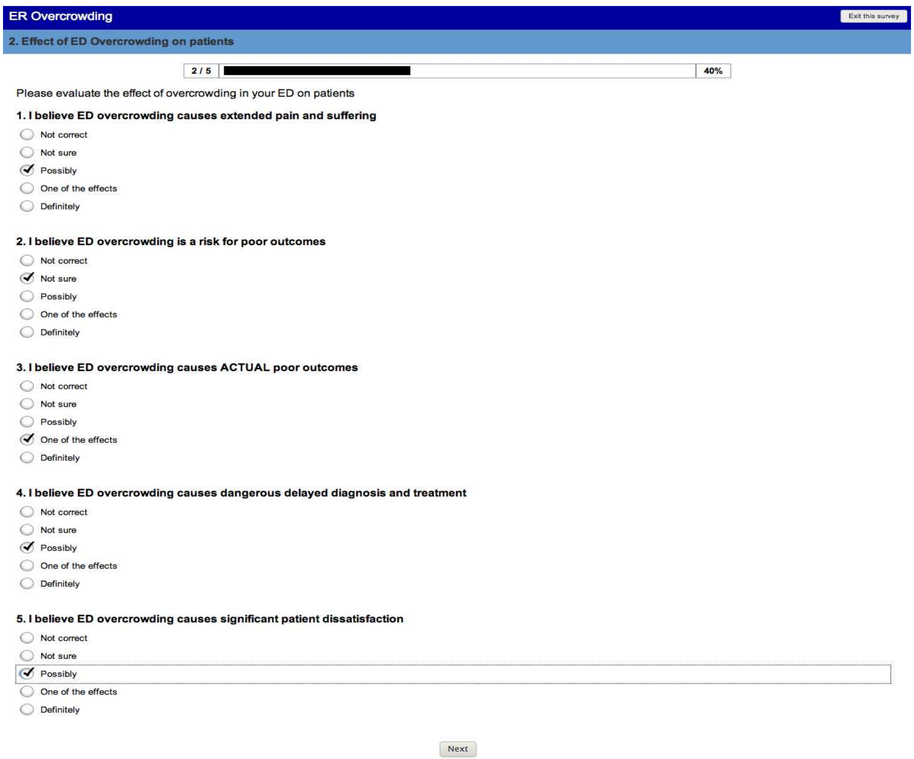
3. I believe ED overcrowding is caused by Access Block (ED patients needing admission, cannot be admitted due to lack beds in the department of destination)

- Not correct
- Not sure
- Possibly
- One of the reasons
- Definitely

4. I believe ED overcrowding is caused by poorly designed facilities and lack of space in the department

- Not correct
- Not sure
- Possibly
- One of the reasons
- Definitely

Figure 37 Factor 1 responses (Causes of ED Overcrowding)



ER Overcrowding

Exit this survey

2. Effect of ED Overcrowding on patients

2 / 5 40%

Please evaluate the effect of overcrowding in your ED on patients

1. I believe ED overcrowding causes extended pain and suffering

- Not correct
- Not sure
- Possibly ✓
- One of the effects
- Definitely

2. I believe ED overcrowding is a risk for poor outcomes

- Not correct
- Not sure ✓
- Possibly
- One of the effects
- Definitely

3. I believe ED overcrowding causes ACTUAL poor outcomes

- Not correct
- Not sure
- Possibly
- One of the effects ✓
- Definitely

4. I believe ED overcrowding causes dangerous delayed diagnosis and treatment

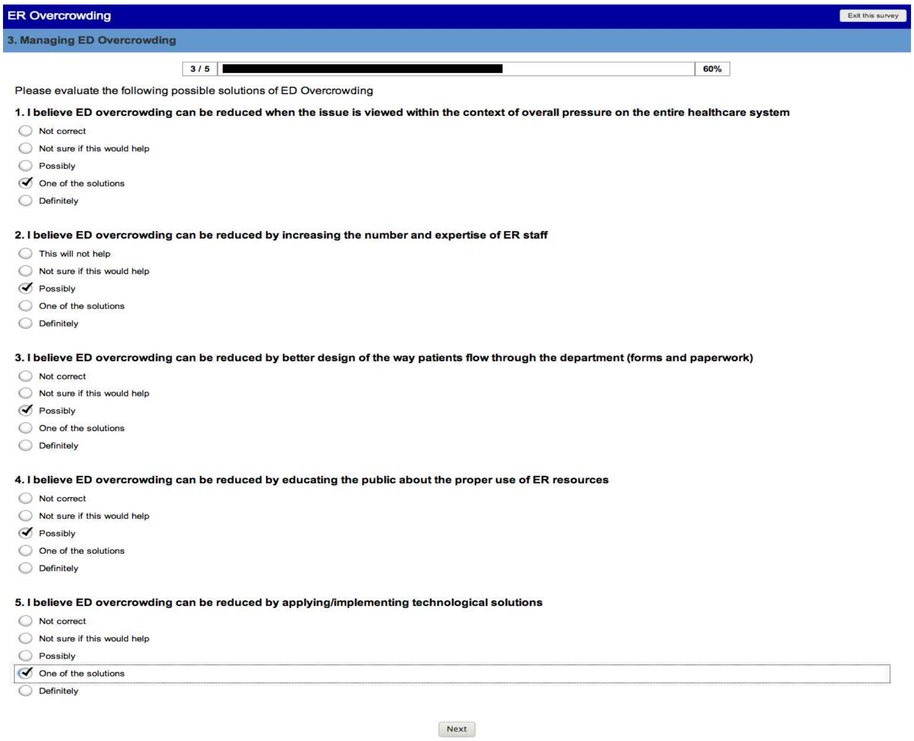
- Not correct
- Not sure
- Possibly ✓
- One of the effects
- Definitely

5. I believe ED overcrowding causes significant patient dissatisfaction

- Not correct
- Not sure
- Possibly ✓
- One of the effects
- Definitely

Next

Figure 38 Factor 2 responses (Effects of ED Overcrowding on Patients)



ER Overcrowding — Exit this survey

3. Managing ED Overcrowding

3 / 5 — 60%

Please evaluate the following possible solutions of ED Overcrowding

1. I believe ED overcrowding can be reduced when the issue is viewed within the context of overall pressure on the entire healthcare system

- [ ] Not correct
- [ ] Not sure if this would help
- [ ] Possibly
- [x] One of the solutions
- [ ] Definitely

2. I believe ED overcrowding can be reduced by increasing the number and expertise of ER staff

- [ ] This will not help
- [ ] Not sure if this would help
- [x] Possibly
- [ ] One of the solutions
- [ ] Definitely

3. I believe ED overcrowding can be reduced by better design of the way patients flow through the department (forms and paperwork)

- [ ] Not correct
- [ ] Not sure if this would help
- [x] Possibly
- [ ] One of the solutions
- [ ] Definitely

4. I believe ED overcrowding can be reduced by educating the public about the proper use of ER resources

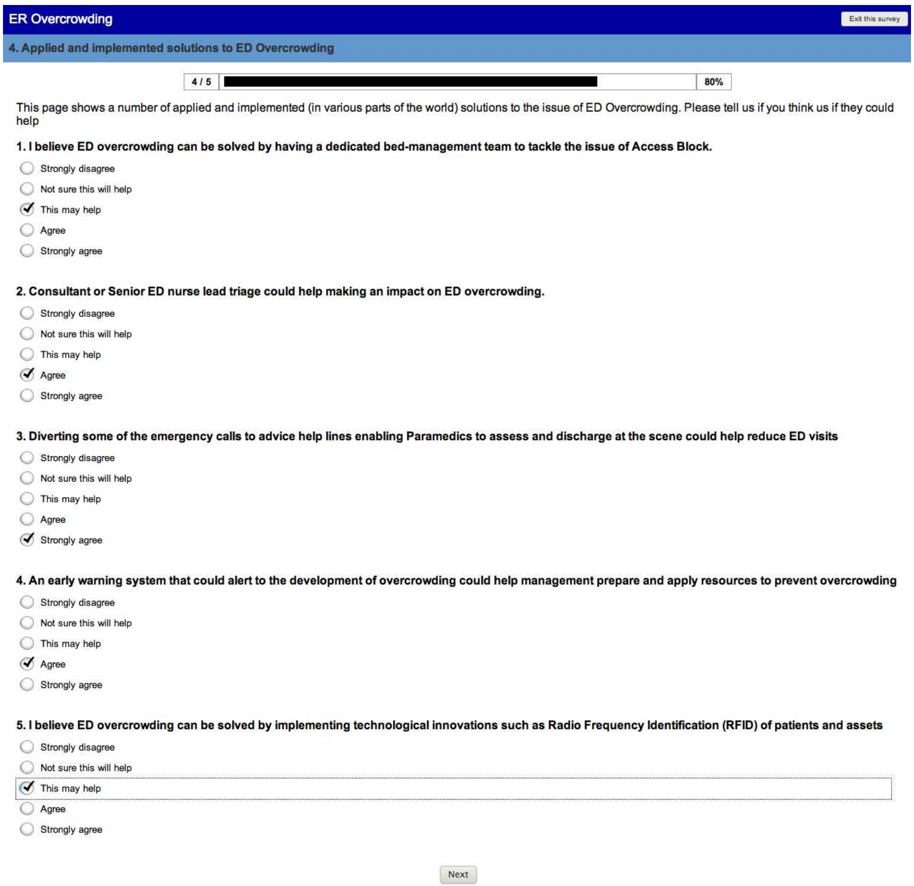
- [ ] Not correct
- [ ] Not sure if this would help
- [x] Possibly
- [ ] One of the solutions
- [ ] Definitely

5. I believe ED overcrowding can be reduced by applying/implementing technological solutions

- [ ] Not correct
- [ ] Not sure if this would help
- [ ] Possibly
- [x] One of the solutions
- [ ] Definitely

Next

Figure 39 Factor 3 responses (Management of ED Overcrowding)



ER Overcrowding — Exit this survey

4. Applied and implemented solutions to ED Overcrowding

4 / 5 — 80%

This page shows a number of applied and implemented (in various parts of the world) solutions to the issue of ED Overcrowding. Please tell us if you think us if they could help

1. I believe ED overcrowding can be solved by having a dedicated bed-management team to tackle the issue of Access Block.

- [ ] Strongly disagree
- [ ] Not sure this will help
- [x] This may help
- [ ] Agree
- [ ] Strongly agree

2. Consultant or Senior ED nurse lead triage could help making an impact on ED overcrowding.

- [ ] Strongly disagree
- [ ] Not sure this will help
- [ ] This may help
- [x] Agree
- [ ] Strongly agree

3. Diverting some of the emergency calls to advice help lines enabling Paramedics to assess and discharge at the scene could help reduce ED visits

- [ ] Strongly disagree
- [ ] Not sure this will help
- [ ] This may help
- [ ] Agree
- [x] Strongly agree

4. An early warning system that could alert to the development of overcrowding could help management prepare and apply resources to prevent overcrowding

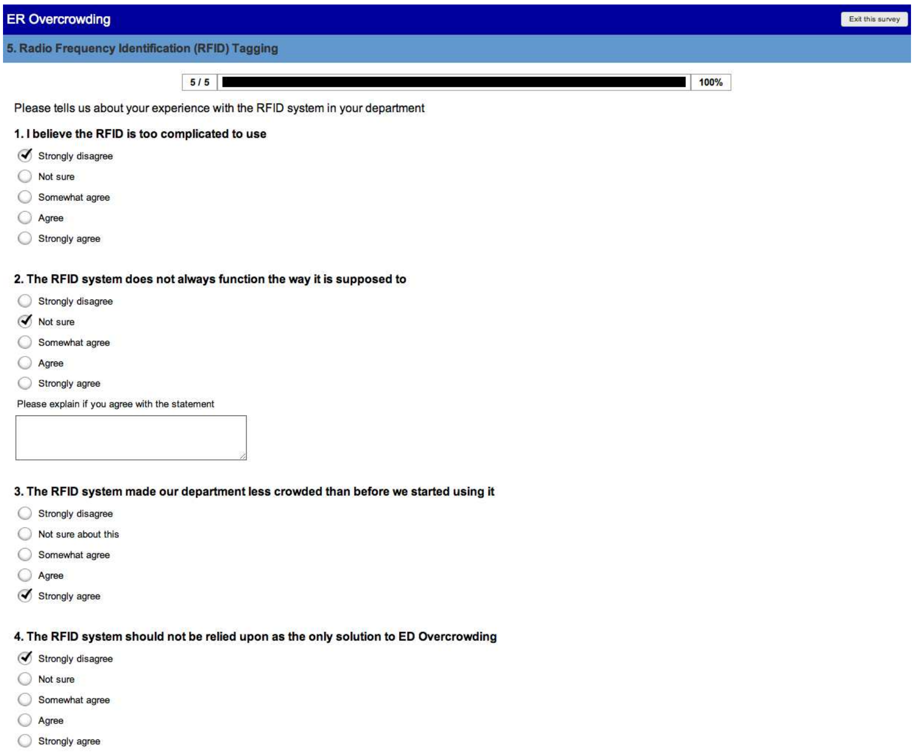
- [ ] Strongly disagree
- [ ] Not sure this will help
- [ ] This may help
- [x] Agree
- [ ] Strongly agree

5. I believe ED overcrowding can be solved by implementing technological innovations such as Radio Frequency Identification (RFID) of patients and assets

- [ ] Strongly disagree
- [ ] Not sure this will help
- [x] This may help
- [ ] Agree
- [ ] Strongly agree

Next

Figure 40 Factor 4 responses (Applied and implemented solutions to ED overcrowding)



ER Overcrowding

Exit this survey

5. Radio Frequency Identification (RFID) Tagging

5 / 5 100%

Please tells us about your experience with the RFID system in your department

1. I believe the RFID is too complicated to use

- [x] Strongly disagree
- [ ] Not sure
- [ ] Somewhat agree
- [ ] Agree
- [ ] Strongly agree

2. The RFID system does not always function the way it is supposed to

- [ ] Strongly disagree
- [x] Not sure
- [ ] Somewhat agree
- [ ] Agree
- [ ] Strongly agree

Please explain if you agree with the statement

3. The RFID system made our department less crowded than before we started using it

- [ ] Strongly disagree
- [ ] Not sure about this
- [ ] Somewhat agree
- [ ] Agree
- [x] Strongly agree

4. The RFID system should not be relied upon as the only solution to ED Overcrowding

- [x] Strongly disagree
- [ ] Not sure
- [ ] Somewhat agree
- [ ] Agree
- [ ] Strongly agree

Figure 41 Factor 5 responses (RFID Tagging as a potential solution in easing ED Overcrowding)

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