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Summarizing the Theoretical Foundation for Hospital Communication Research: A Scoping Review of Interdisciplinary Literature

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ABSTRACT

Hospitals are complex socio-technical systems where health professionals from varied backgrounds interact with each other and technology for the wellbeing of patients. Effective communication among the members of the care team is vital for optimal care; poor communication can result in suboptimal care and in many cases, lead to adverse events (AEs) and even death. More than a decade after the US Institute of Medicine report which catalyzed patient safety improvement measures, patient safety remains a major concern. Two-thirds of AEs in hospitals are still linked to communication errors. Hospitals are trying to improve communication by introducing new communication devices like smart phones and tablet computers for professional use. However, they are being deployed without adequate study of the mechanics of communication in hospitals or their use affects inter-professional communication. High risk organizations such as nuclear power plants, aviation and the military have achieved better safety records than healthcare. This is likely because they have studied their communication challenges and based their assessments on a firm theoretical foundation before implementing customized solutions. This approach in healthcare is lacking. Therefore a scoping review was conducted to collect communication theories, models, frameworks, and methods applicable to new information and communication technology used in hospitals. Literature from basic and applied science domains such as cognitive psychology, human factors engineering, organizational behavior, sociology, communication sciences and from high risk organizations like aviation, nuclear power generation and defense was reviewed. 14 theories, 12 models and 12 communication analysis methods were identified. One of the selected methods was employed to conduct a case study of a case of faulty communication reported in the Agency for Healthcare Research & Quality (AHRQ) web morbidity and mortality (M&M). It is not known how well those theories, models and analysis methods can be adapted to medicine. Future research may be able to address the issue and adopt theories and models to hospital communication research, modifying existing theories and models to suit the unique requirements of hospitals or by developing a strategy to design them de-novo.

Keywords: Communication, health facility, medical informatics, hospital communication systems, high risk organizations, inter-professional communication

INTRODUCTION

Raging Fires to Medical Errors

An "accident" is a disastrous and inadvertent event resulting in significant damages to people, objects or processes[1]. The history of humans is dotted with accidents of varying scale and magnitude. From airplane crashes, forest fires, mine explosions, pandemics and train derailments to raging fires that engulfed whole cities, large scale accidents have produced lasting effects on human life since time immemorial. Not all accidents are as spectacular as an airplane crash; thousands of mishaps of smaller scale also occur virtually every moment – a man gets run over by an automobile, a maintenance worker is electrocuted while servicing a power line, a beach surfer drowns because he did not heed the warning signals, a family falls ill due to food poisoning caused by consuming contaminated pizza, the list is virtually unending.

Large or small, the origins of many of these accidents can be traced back to seemingly trivial incidents. The London fire of 1666 was started at the bakery of Thomas Farriner (or Farynor) on Pudding Lane, shortly after midnight on Sunday, September 2, 1666[2]. Apparently, the baker had forgotten to extinguish the ovens completely (a fact which he eventually denied). Movement of American soldiers in large numbers during the latter phase of World War I acted as a force multiplier in quickly transforming an isolated viral mutation in Haskell County, Kansas, into a pandemic. This Spanish influenza, as it was later named, is believed to have affected 8% of all young adults worldwide[3].

Disasters, big and small, often cannot be attributed to any one single cause; they generally have complex multi-factorial etiologies. However, failure to communicate, assert and initiate corrective action has been invariably identified as a common feature amongst many of them. Better communication, effective coordination and overall better preparedness can make a remarkable reduction in loss of life and property among disasters of apparently comparable magnitudes. Contrasting the aftermaths of the Indian Ocean tsunami that struck East Asian nations on the December 26, 2004 and the Japanese tsunami of 2011 is an example of how big a difference better ‘accident-preparedness’ can make. In retrospect, the magnitudes of the earthquakes that triggered both the tsunamis were somewhat similar (9.0 and 9.1) but the loss of human life in Japan was only a fraction of that in the Indian Ocean rim nations[4]. Although factors such as quake resistant building construction in Japan (quake resistant construction prevents the collapse of buildings and hence minimize damage, injury and loss of life) were vital in preventing injury and minimizing loss of human lives, timely early warnings and coordinated communication between authorities and the general public might have markedly reduced the magnitude of destruction in Japan, a densely populated island nation. Admittedly, some disasters (such as a tsunami) cannot be prevented, only the resultant damage can be reduced. However, that is not always the case; several accident inducing errors can be prevented by adhering to rules and regulations and being watchful. In the case of large organizations, such as a nuclear power plants, errors and accidents cannot be totally avoided. According to Charles Perrow, increased

levels of tight coupling and interactive complexity in an organization are associated with a higher probability of errors and accidents[i]. He coined the term "normal accidents" to represent such inevitable incidents which happen due to the inherent complexity of a system. Hospitals are places where sick people go to get cured. But these very hospitals inadvertently cause preventable damage to life and even deaths of a surprisingly large number of people. Adverse effects of these incidents typically do not create large societal impact because they usually affect one individual at a time. In recent times data that quantifies such hospital incidents has emerged. The first large scale reports on medical errors were presented in the pair of classic papers titled 'Incidence of adverse events and negligence in hospitalized patients: results of the Harvard Medical Practice Study'[5]. The first article in the series, in 1984 reported that "there is a substantial amount of injury to patients from medical management". This study reviewed 30,121 randomly selected medical records from 51 randomly selected acute care, non-psychiatric hospitals in New York State in 1984 and found that "adverse events occurred in 3.7% of the hospitalizations"[6]. That translated to 98,609 adverse events (AEs) among the 2,671,863 patients discharged from New York hospitals[5]. In the second part of the study, 1133 patients, (3.7% of the original hospital patients in the initial study), were identified and two physician-reviewers independently identified any AEs and evaluated them with respect to negligence, errors in management and the extent of the resulting disability. More than half of the AEs were found to be attributable to "errors in management"[5]. Another AE study, done in Utah and Colorado in 1992 replicated these methods and found comparable results[5]. In the Colorado and Utah hospitals, 6.6% of the AEs led to death, as compared with 13.6% in the New York hospitals. In both of these studies, over half of the AEs resulted from preventable medical errors. Extrapolation of this data to the over 33.6 million admissions to U.S. hospitals in 1997, the results of the studies in Colorado and Utah implied that at least 44,000 Americans die each year as a result of medical errors. The results of the New York Study on the other hand suggest that the number may be as high as approximately 98,000[7]. To place the figure in to perspective, these numbers are said to be higher than the deaths due to motor accidents, breast cancer or AIDS in the USA[8].

The first Canadian study of AEs was conducted in 2004. It reported that these events occurred in 7.5% of all hospital admissions[9]. The authors estimated that 36% of the errors were preventable. These findings mean that "of the almost 2.5 million annual hospital admissions in Canada similar to the type studied, about 185,000 are associated with an adverse event and close to 70,000 of these are potentially preventable"[9]. The authors estimated that "9,250 to 23,750 deaths from AEs

[i]A single, specific, isolated failure is referred to as a "discrete" failure. A system in which two or more discrete failures can interact in unexpected ways is described as "interactivity complex''. A tightly coupled system is one with subcomponents which affect each other in a prompt and major manner. In contrast, in a loosely coupled system, when something happens in one part of the system this event will not have much impact on another part of the system or the impact will happen very slowly.

could have been prevented"[9]. More specifically, 1 in 9 Canadians received wrong treatments. In addition, 1 in 9 adults and 1 in 11 children contracted an infection during their hospital stay[10].

The Institute of Medicine (IOM) report commended that "Healthcare in United States is not as safe as it should be and can be"[7].This report pushed patient safety and medical errors in to the center stage of public debate in U.S. and elsewhere, including Canada. Since then medical errors have received an unprecedented volume of public attention and this attention has remained high ever since[11,12]. More than a decade later, the IOM report is referred to as a landmark, heavily-cited, report in both the scientific literature and lay press.

Communication and Patient Safety

A faulty pre surgical briefing resulting in a wrong site surgery, a new bar-coding system erroneously triggering the administration of a fatal dose of insulin in response to another patient's reported hyperglycemia, a monitoring error in anesthesia eventually costing the patient's life are examples of medical errors that abound. Diagnostic errors, transfusion errors, hand off errors, medication errors and identification errors are just a few of the types of errors that can and do occur in the process of healthcare. Each one of these errors can add to a large pool of health related errors. While many errors are reported, many more go unrecognized and or unreported[13-15]. These errors can be fatal or 'near misses' and can ultimately result in substantial damage. Comprehending the cumulative damage caused by these incidents requires high levels of awareness, vigil and good reporting practices.

Good communication between the members of the care team plays a vital role in ensuring the safety and wellbeing of the patient. The U.S. Joint Commission on Accreditations of Healthcare Organizations (JCAHO) sums up their views on issues related to communication in healthcare: "Communication among clinicians in providing health care is a highly complex but important component in the delivery of health care. In fact, clinician communication is consistently the most frequent contributor to sentinel events reported to the Joint Commission. Sentinel events are the most serious and harmful of patient safety events and are a high priority for intervention and improvement"[16]. Problems with processes and systems designed for clinician communication have been associated with patient safety risks for children as well as for adults. In 1993, an Australian study of AEs reported that 70% to 80% of medical errors were related to faulty communication[17]. Another Australian study linked communication failures to 25% to 41% of sentinel events from 2004 to 2005[18].

The Canadian study of AEs did not report the root cause of the events. However, they listed communication issues under 'systemic causes' that accounted for substantial numbers of events. In a retrospective review of 14,000 in-hospital deaths in Australia, communication errors were found to be the lead cause, twice as frequent as errors related to inadequate clinical skill. Furthermore, nearly half of all the AEs in a study of primary care physicians were linked to communication issues[19]. Other studies have shown that faulty communication was a contributing

factor in as many as 43% of incidents in surgeries[20]. The JCAHO report titled "Sentinel Event Data Root Causes by Event Type: 2004-Fourth Quarter 2010" states that over two-thirds of serious and unexpected events may be traced back to communication failures[21]. This means a tremendous scope exists for improvement in communication inside our hospitals.

Faulty Communication and Medication Errors

Medication management is a multistep process which involves ordering or prescribing, transferring the order to the pharmacy, dispensing the medication by the pharmacy, administration of the medication and monitoring the medication - a typical tightly coupled interactive process. The process involves several professionals with physicians, pharmacists and nurses being the major players in the hospital setting. An error at any stage in medication management can be carried over to the subsequent phases of medication management potentially creating damaging consequences for the patient. Clear and assertive communication, teamwork and vigil are the keys in preventing errors in the medication management process. A study investigating medication errors found that approximately 20% of errors were attributed to faulty recording or transmission of information22. Physician's illegible handwriting has been historically regarded as the weakest link in the medication management chain[23,24].

Some evidence exists to suggest that lack of coordination amongst the varied professionals involved in the process also is contributory to errors. A 2007 Time magazine article titled "Sloppy Doctors" reported that poor handwriting was associated with more than 7,000 people each year and that electronic prescribing or e-prescription is a solution to the problem[25].

A few years later, we now know that e-prescription by itself can reduce some traditional errors but at the same time, create new types of errors which may be equally or even more difficult to control. Some of the recent patient safety reports in the Web M&M (Morbidity and Mortality Rounds on the Web) maintained by the U.S. Agency for Healthcare Research and Quality (AHRQ) cites instances of those 'revenge effects of technology'[ii]: A short outline of three representative incidents follow: "After entering an electronic prescription for the wrong patient, the clinic nurse deleted it, assuming that would cancel the order at the pharmacy. However, the prescription went through to the pharmacy, and the patient received it"[26]. "While entering an order via Smartphone to discontinue anticoagulation on a patient, a resident received a text message from a friend and never completed the order. The patient continued to receive warfarin and had spontaneous bleeding into the pericardium that required emergency open heart surgery"[26]; "Antibiotics administration for an elderly man hospitalized for acute infection is delayed by more than 24 hours due to a mix-up and override in the computerized provider order entry system. However, none of the clinicians on the floor questioned the delay"[26]. In these

[ii] This phrase was coined by the writer and academic Edward Tenner. The first use of the term was in an article titled "Revenge Theory" that he wrote for Harvard Magazine's March-April 1991 issue.

cases, new information technology produced previously unknown communication and coordination issues.

Faulty Communication and Discharge, Hand over Processes

One of the reasons modern healthcare has been extremely effective is that it has efficiently utilized the concept of specialization and teamwork. Collectively, these concepts entail forming groups of professionals with high levels of expertise in one area of medicine to work intensively on a particular problem. Alternately, specialization and the resultant compartmentalization of care have potential for some less favorable outcomes – having to transfer a patient from one group to another is one of those. The higher the accuracy and completeness of information exchanged during the transfer, the better will be the continuity of care and patient safety. Unfortunately, as Sunil Kripalani rightly pointed out in the patient safety perspective section of AHRQ (Agency for Healthcare Quality and Safety) M&M (morbidity and mortality) section, the transfer process has several challenges. According to him discharge summaries are often found to be lacking vital information needed to continue patient care at home or a long term nursing facility. For example, 21 % of the discharge summaries in his study did not contain medication information and 65% did not have pending laboratory tests. A smaller, yet significant number (14%) of summaries did not contain follow up care instructions nor reasons for changing medications at the time of discharge[27].

Destructive or faulty communication patterns have clearly been identified as a major problem in the patient transfer process involved in trauma care[28]. JCAHO's 2007 report on American hospitals pointed out that inadequate communication between care providers or between care providers and patients and families is consistently the main root cause of sentinel events. They also noted that only 17.7% of hospitals assessed maintained high standards in discharge communications even after five years of tracking, the rate being similar to the 2002 statistics.

Shared information during the nursing handover includes clinical information, functional changes in clinical status and amended plans of care as well as psychological and social issues. Nursing handover has also been shown to be vital in building good team morale and facilitating cohesiveness of the nursing unit[29].

A study of critical incidents found that in many instances the giver and receiver do not meet face to face and communicate about the patient's condition at the time of hand over[27]. Such deficiencies in the handover process can cause "near misses (potential mistakes that were caught before implementation), avoidable escalations in care (e.g., transfer to the intensive care unit), inefficiencies in care and delays in diagnosis or treatment"[27].

Other research demonstrates that periods of cross-coverage by a physician who is less familiar with the patient represent vulnerable points in hospital care. In a study of hospitalized adults, cross-coverage was a strong independent predictor of preventable AEs. In another study, 59% of

medical and surgical house staff reported that one or more patients had been harmed in their most recent rotation due to handover-related problems[27].

The most common methods for the handover process are verbal, written and computerized or a combination or any of those. It is increasingly becoming recognized that despite the long-standing routine practice of handover, not enough attention and research has been directed at improving communication to promote patient safety. Lardner identified key points in the promotion of effective shift handover communication: (1) presenting information in multiple media (e.g. verbal and written); (2) two-way communication with feedback to increase accuracy of communication; (3) verbal face-to-face handover wherever possible; (4) as successful communication is facilitated by shared mental model, it can be expected that handover between experienced staff will take as much time as necessary to ensure adequate communication and (5) present only key information with the exclusion of irrelevant information[30].

Cheung and colleagues studied the problems in handoffs and stated that standardization of the process is the key[31]. According to them handovers may be divided into four phases: (1) "Preparation – when the handover giver updates and organizes information; (2) Engagement – the giver and receiver stop other tasks to conduct the handover; (3) Dialogue – giver and receiver exchange information; and (4) Post-handover – the receiver integrates the new information and assumes care of patient. In addition, handovers often involve three distinct components: (i) verbal exchange, (ii) written communication, and (iii) transfer of professional responsibility",[27].

In a systematic review on handovers conducted for the Society of Hospital Medicine Handoffs Taskforce, Arora and colleagues recommended the best practices for a verbal handover. According to them, the spoken dialogue during handoff should be well structured and standardized and should be performed at a pre-assigned venue at a specific time. Greater importance should be given for patients who are extremely sick. Finally, the team members should pay special attention towards obtaining anticipatory guidance. Anticipatory guidance entails advance mental preparation for an anticipated event[32].

In summation it can be concluded that handover process is extremely information intensive and are vulnerable to mistakes which could result inpatient harm.

Faulty Communication in the Operation Theatre and Peri Operative Period

Unprecedented improvements in techniques, materials and devices have made surgical procedures more predictable, safer and faster than before. Haller has noted that these advances have not created a major improvement in the field of teamwork, communication and coordination among members of surgical teams. This implies that technology alone cannot improve patient safety. Recently, a major shift can be noticed in the type of medical errors. The lack of focus on the crucial factors of teamwork, communication and coordination has created a situation in which, unlike in the past when most of the AEs could be traced back to deficiencies

in techniques or technology, today "21% to 65% of accidents and errors in patient management during the perioperative period are related to communication problems"[33].

Response of the Medical Profession

The medical profession was quick to acknowledge the importance of the findings from IOM report and initiated several measures to prevent medical errors. Hospitals today devote considerable time and resources towards improving their patient safety records[iii]. Improving communication and team work constitutes an important component of their patient safety framework. Generally, efforts in health care to improve communication can be viewed as a two-pronged approach in which training for personnel is coupled with introduction of sophisticated technology. Established team training methods such as six sigma and Crew Resource Management (CRM) have been employed in training healthcare personnel.

In their quest to improve communication among care team members, hospitals introduced cell phones, PDAs (Personal Digital Assistants) and advanced paging systems. Presently, hospitals are in the midst of another technological wave in which tablet computers and smart phones are being deployed in large numbers. More and more hospitals are becoming virtually paperless with the large scale adoption of electronic medical record systems. It has been predicted that the pace of technology introduction in medicine is here to stay. More information and communication technology (ICT) will likely be introduced into medicine in the next ten years than in its entire previous history[34].

In addition to ICT and team training, several hospitals have increased the level of automation to reduce human errors. Robotic surgery is becoming more and more common. Emergency rooms (ER), operation theatres (OTs) and intensive care units (ICUs) are using state of the art equipment. These steps of adding ICTs directed towards better safety have not always produced the desired outcome. For example, a case study of robot-assisted cholecystectomy procedure revealed "teamwork disruption and an increase in the complexity of information flow and communication in the operating room as a result of the novel technology"[35].

Why Healthcare May Benefit From Other Industries in Improving Safety?

Are accidents inevitable? The simple truth is that "any system, and especially any system that is complex and interdependent, will eventually fail"[36]. We can either accept this inevitability and wait for those 'normal accidents' to happen or "take proactive measures that allow them to put off the day of reckoning as long as possible"[36]. A careful examination of any high impact accident will tell us that practitioners and managers can "delay or prevent major organizational catastrophes that can harm them and their employees (e.g., Barings Bank and the Russian

[iii] Several federal bodies in the US including JCAHO and Agency for Health Research and Quality publishes their annual and periodic reports. Comparison of the JCAHO records shows that overall patient safety scores are improving. Investments in ICT by healthcare sector is increasing fast.

submarine Kursk) or harm an unknowing public (e.g., Chernobyl, Bhopal, and the U.S. Navy submarine Greeneville)"[36].

Ultimately, the first questions healthcare managers and indeed practitioners need to ask are 'Must accidents happen?' and 'How can we minimize errors?'. Experience of the medical profession is that answering the first question is easier than the second. As mentioned elsewhere in this document, despite substantial efforts and huge investments healthcare's progress in improving communication and teamwork can be described as patchy at best.

Healthcare is only one of many fields where error prevention and safety is of prime importance. Errors in nuclear power generation, the military and commercial aviation industries also are costly in terms of potential loss of human life. Safety lapses in these three information-critical and high risk organizations (HROs) also entail high financial expenditure. All of these industries rely heavily on accurate and timely communication to ensure safety. Each of these information-critical professions is safer today, compared to the past, because they have carefully studied their communication challenges basing their work on a firm scientific and theoretical foundation. With this informational foundation, these industries implemented customized solutions unique to the needs of the situation and setting. Some limited evidence shows that communication methods from nuclear power, aviation and the military have been integrated with communication methods in hospitals[37]. However, this integration is not common, nor is it based on a theoretical foundation.

To ensure that health care organizations emulate the success of other high risk industries in dealing with their communication challenges, we need to firmly anchor hospital communication research to a solid theoretical foundation. Health care must consider that the mere introduction of state-of-the-art communication devices will not likely solve the problem in a lasting manner. Even substantial efforts have yielded only marginal improvements. Therefore those in the healthcare industry may need to devote more attention towards improving its communication effectiveness. To achieve the best possible solutions the medical profession needs to work in synergy with technologists and researchers in the design and implementation of hospital communication systems.

In addition to understanding the implications of technology, understanding and working within the culture of the organization is also vital to improving communication. For example, if the organization approaches errors and error reporting based on the 'name, shame, and blame' dynamic (i.e., find the person responsible for the mistake and punish them) errors will go unreported and become buried. A cultural shift from this shame and blame to one of prevention is vital: Find the mistakes that could happen and fix the system before AEs happen and if an AE does occur, acknowledge it and then fix the system in a cyclical process of improvement. Transfer of the Six Sigma strategy, which espouses this cycling of small improvements based on identified errors, from the industry is one way that hospitals have used to address adverse events and communication problems. The health care industry and health care professionals must be

willing to treat faulty communication as a true malady and apply methodological rigor in studying it before moving to make improvements.

To start the process of improving communication in hospitals we need a basic understanding of what clinical communication is and its goals. Horwitz and Detsky provide our chosen working definition: "The fundamental purpose of clinical communication is to generate a shared mental model of a patient and to transfer responsibility for some aspect of care from the communicator to the recipient"[38]. Better methods to improve communication may be available from other safety critical industries and basic and applied sciences. But we need to analyze the evidence from these industries carefully before making recommendations to move their successes into the health care processes.

Experience of aviation and other HROs[iv] illustrate that mere introduction of technology will not improve communication. They achieved satisfactory levels of safety because they studied the effects of each new device or change in work practices on communication and safety based on theories and models. Healthcare also needs to follow their path.

This review compiles communication theories, frameworks and models used by HROs outside healthcare to study and resolve workplace communication issues. The theories and models identified in this review will likely cover a broad range of basic and applied sciences such as psychology, human factors engineering, organizational behavior, nueroergonomics and cognitive psychology among others. To our knowledge, such a review has not been performed. Our initial literature search could not locate any peer reviewed scientific reviews covering our focus area of the theory, models or frameworks on health professional communication using ICTs. In this review the term ICT denotes mobile phones, smart phones, pagers, electronic medical record systems (EMRs) (when used as a means to transfer information), tablet computers and any other devices and means used as modes of communication inside hospitals. We also believe no knowledge synthesis reviews the problems or makes recommendations for health professional communicating with new ICTs that integrates the theoretical aspects of communication and perspectives from other safety-conscious industries.

[iv] High Risk Organizations (HRO) are "enterprises [that] have catastrophic potential, the ability to take the lives of hundreds of people in one blow, or to shorten or cripple the lives of thousands or millions more" [36]. Conversely, those organizations which exhibit high level of safety over long periods of time are termed as High Reliability Organizations

They share some characteristic like

1. "Prioritization of both safety and performance and shared goals
2. A "culture" of reliability
3. A learning organization that uses "trail-and-error" learning to change to the better
4. A strategy of redundancy beyond technology but in behaviors such as one person stepping in when a task needs completion"[39].

RATIONALE

Several compelling reasons exist for undertaking this proposed research into the theoretical basis of communication using ICTs. They are:

1. Substantial improvement in hospital communication between members of healthcare teams has not occurred despite concerted efforts in the past decade.
2. Considerable changes have occurred in communication patterns and devices within hospitals in recent times.
3. High cost (human, economic) of communication errors and related adverse events in hospitals.

Lack of Progress in Past Decade

Addressing the communication problem is the most compelling motivation behind undertaking this research. Communication breakdown is a crucial factor contributing to most instances of patient harm, and this harm continues to occur at unacceptable levels[40]. In recent years substantial efforts and resources have been expended to improve patient safety in our hospitals; several improvements have been achieved especially in the case of protocol adherence and checklists[21]. However, progress in communication can at the best be described as patchy, as can be inferred from the 2010 JCAHO report. Some reports even suggest hospitals have even become more dangerous[40]. Therefore a clear scope exists for improvement in this vital area. Studying methods and practices from other HROs can provide pointers for future research.

Change in Communication Patterns

The transformation from a physician centered, acute illness focused, and comparatively smaller-scale practice model into a patient centric, accountable, sophisticated team work focused on complex chronic illnesses and wellness has changed the communication requirements of hospitals[41]. Today's hospitals bring together professionals from related, yet highly evolved and distinct fields. These professionals have had unique education and educational cultures. To be successful they must undertake collaborative and distributed tasks[42]. Communication in these transformed settings and potential for errors are distinct from smaller, relatively homogenous and less sophisticated groups characterized by earlier hospitals. In complex multidisciplinary teams, tasks are distributed among the team members. Undoubtedly, delegation and shared responsibility of patient care has positive effects. For example the added expertise of a team member may help in formulating an effective treatment plan. At the same time, the unique expertise or specialization might make communication and coordination between team members more difficult.

Teams also face other impediments to good communication. These impediments could be at the level of the system or the individual. Structurally present impediments are those which are built in to the system such as overcrowding in ERs and the interruptive nature of the work impede

communication at system level. Memory failure or failures to follow established procedures are examples of impediments to effective team work in an individual level[43].

These changes in communication patterns induced by the evolving nature of medical practice and dynamics within our hospitals need to be studied with suitable methods to design better communication systems. Use of ethnographic observations and interviews can provide contextual information but are limited in their ability to capture all perspectives of the process[44]. Our approach to address the issue of finding means to improve hospital communication entails distilling the existing research methods of studying communication and reinforcing those methods with techniques and frameworks from other domains and complex team-based HROs.

Aviation and nuclear power industries have improved their safety records because they moved from 'technical era' (1950s) to 'human era' (1970s) to an organizational era (2000s). Refer Figure 1[45,46]. We hope to provide researchers and administrators with a compact view of available methods and theories to base planning for better communication.

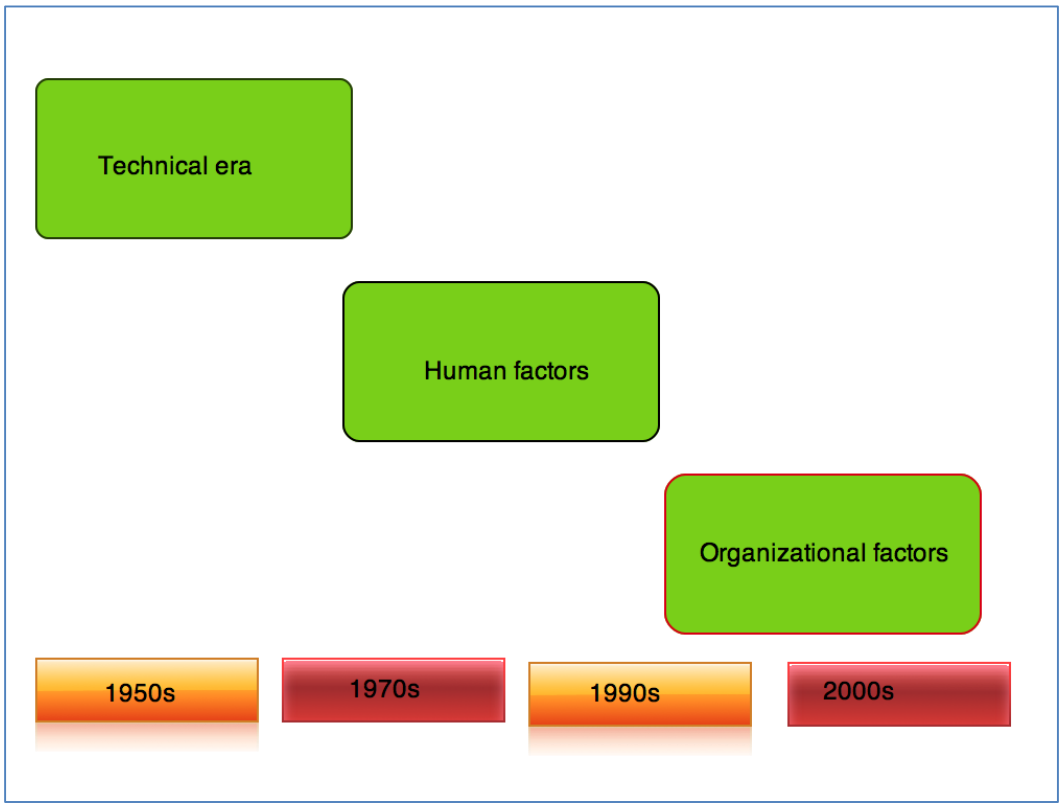

Figure 1: Evolution of Safety Thinking in Aviation

Figure adapted from: International Civil Aviation Organization (2009), Safety Management Manual (SMM)

Economic Cost of Communication Errors

Compared with the volume of peer-reviewed literature available, the human cost of medical errors, economic analysis of the errors is sparse. The IOM, extrapolating from state data, projected that preventable adverse events cost between $8 and $29 billion annually[7,10]. Bosand

Van Den in 2008 used actuarial methods and reported that medical errors resulted in extra expenditure of 17.1 billion dollars in 2008. Estimated costs of AEs per hospital range from $1 million in a smaller hospital[47] to $5.6 million US in 2 larger hospitals[48]. Hug, Balthasar and others conducted a study to calculate the economic impact of adverse drug events (ADEs) in which they found that "ADEs were associated with an increased adjusted cost of $3,420 and an adjusted increase in length of stay (LOS) of 3.15 days. For preventable ADEs, the respective figures were +$3,511 and +3.37 days. The severity of the ADE was also associated with higher costs—the costs were +$2,852 for significant ADEs (LOS +2.77 days), + $3,650 for serious ADEs (LOS +3.47 days), and + $8,116 for life-threatening ADEs (LOS +5.54 days, all $p < .001$)"[49]. Zhan and colleagues found up to 10.9 days of excess hospital stay related to AEs and these contributed to additional expenses of $57,727; infections related to medical errors were associated with 9.6 extra days and $38,656 in excess charges. In Canada, 1.1 million added hospital days and $750 million in extra health-care spending may be attributable to medical errors[50]. DC Suh and colleagues in a study of clinical and economic impact of ADEs found that "Length of hospital stay and total hospitalization costs were significantly higher for patients experiencing ADEs than those who did not experience ADE"[51].

These data are not direct estimates for communication errors. However, they may be seen as providing some idea about the costs involved. In a recent analysis, Hug and colleagues reported that ADEs in community hospitals cost more than 3,000 dollars each on average[49]. Kaushal and colleagues report that errors costs per patient was 3,961 dollars in ICU and 3,857 dollars in cardiac ICU52. Burton and colleagues reported that an error in ambulatory care resulted in an average of 926 dollars[53].

AIMS AND OBJECTIVES

This review has 4 objectives. They are:

1. Collect and compare communication theories, models, frameworks that have been used in basic science and applied science domains such as cognitive psychology, human factors engineering, organizational behavior, sociology, and communication sciences as well as others applicable to inter-professional communication in hospitals with the use of new ICTs.

2. Collect and compare communication theories, models, frameworks, and methods used in other highly safety-conscious fields (aviation, nuclear power generation and defense) that have applicability to new ICTs.

3. Summarize the knowledge determined in the first 2 objectives and make suggestions for future research in inter professional hospital communication using ICTs.

4. To conduct a case study of a reported instance of faulty communication in a hospital in the light of the theories and models contained in this review.

METHODS

Justification of Selected Technique

Few studies of hospital communication are built on theory, models or frameworks regardless of the domain. This is consistent with other informatics/e-Health projects as the domain is new and lacks a theoretical basis[54]. Therefore, this project is ideal for a scoping review. Scoping reviews are most effective when a highly specific body of literature does not exist[55]. Scoping reviews rely on rigor to identify, collect, extract and analyze data as do other systematic reviews. However, the coverage of the literature in scoping reviews is often sparse, broadly based, and comprised of studies of varying research methods. Scoping reviews identify strengths and gaps in the evidential base and summarize them.

The scoping review framework originally proposed by Arksey and O'Malley and later modified by Levac, Colquhoun and O'Brien was used in this review. Wherever the unique nature of the project warranted a different approach to the prescribed methods, they were fine-tuned accordingly.

Because some of the information on the theories and models was included in the body of articles standard searching methods based on indexing terms and notation in titles and abstracts were not likely going to be effective for article identification and therefore we proposed a substantial amount of hand searching. Theoretical material is difficult to search for as it is often embedded within the methods, results, and discussion sections and not the abstracts or titles. Only abstracts are easily searched electronically in most databases. Screening was also complex and required review of many full text articles in print and electronic format.

Inclusion/Exclusion Criteria

Our project has four basic concepts: location of the communication (e.g., hospitals or nuclear power plants); theories, models or frameworks related to communication; the communication itself; and the use of new ICTs. To be included in this review the article must discuss one or more theories, models and frameworks. These must have been applied to communication systems, used to propose either a new or modified communication system, or if the authors have proposed or used a theory, model or framework to evaluate communication issues in any domain of interest (health care, nuclear power, military, or aviation).

Our searching sought to capture three groups of studies or articles. The first category describes communication theories, models and frameworks that have been applied to inter professional communication in any of our settings of interest. These articles are more theoretical and often do not have study data. The second group consists of articles that contain descriptions of methods of communication error analysis in our settings of interest using the new ICTs and use or mention a theory, model or framework in the article. From our initial review of the literature we found that the theories, models and frameworks we sought were often embedded within individual studies

of communication. The third group consists of stand-alone articles (not experimental studies) that concentrated on describing these theories, models and frameworks. Hypothetical, abstract and purely academic theories, models, or frameworks as well as those pertaining solely to interpersonnel communication without use of ICTs were not included.

Search Strategy

The healthcare databases searched included Medline, CINAHL, EMBASE, and PsycInfo. In addition, we searched engineering and science literature to include articles in the fields of information sciences, computer sciences, nuclear power generation, aviation, the military and other domains such as sociology that address the science and theory of communication. Comprehensive searching was also done in the communication studies literature. We also reviewed conference proceedings and grey literature[v]. We also conducted citation tracking and bibliography checks. Our searching was iterative in nature and each database and domain needed tailored searching strategies.

The search terms and strings used for systematic searching are listed in the appendix.

Article Screening and Data Extraction

Article screening was done in several steps. Titles and abstracts were reviewed in the first round of screening and full texts in the second. For the second screen we read and scanned the full text. Screening and data extraction were done in duplicate. A second eHealth candidate performed the duplicate screening.

Data extraction was done on theories, models and frameworks of interest; the communication processes studied; professionals involved in the communication; study type; ICT technologies used; publication year; and outcomes, name and any synonyms of the theory, model or framework; its relation to other theories (e.g., if the new theory is developed from a previous theory); subject domain; attributes and how it is applied to communication using new ICTs.

RESULTS

The literature search for this project was organized in two separate yet confluent sections - a systematic search of peer reviewed literature from relevant databases and an extensive hand search (electronic and manual). Systematic searches were conducted in the following databases:

[v] Definition: “Information produced on all levels of government, academics, business and industry in electronic and print formats not controlled by commercial publishing" ie. where publishing is not the primary activity of the producing body." .Source:http://hlwiki.slais.ubc.ca/index.php/Grey_literature

Table 1: List of Databases Systematically Searched

Ovid MEDLINE (1948-2011 Oct)	EMBASE	Psycarticles (1806- Oct 2011)
OVID Health and Psychosocial Instruments	IEEE	Engineering Village
CINAHL	Business Source Complete	Military and Intelligence database

Electronic hand searching was conducted in following sources and databases.

Table 2: List of Databases and Sources Hand Searched

Scholar's Portal	Business Source Complete	The International Journal of Aviation Psychology
Google Scholar	Proquest	International Journal of Human-Computer Interaction
Tayler and Francis	Science Direct	OVID Health and Psychosocial Instruments
Cognitive Systems Research	Leadership in Health Services	ACM Special interest group - HCI
Computer Supported Cooperative Work	Cognition, Technology & Work	Journal of Loss Prevention
Computers in Human Behavior	Social Science & Medicine	Human Resource Management Review
International Emergency Nursing	Nursing Times Research	Journal of Communication Management
International Journal of Nursing Studies	Internet Research	Campus-Wide Information Systems
Journal of Managerial Psychology	Wilson Web	Corporate Communications: An International Journal
Journal of Clinical Psychology in Medical Settings	Multicultural Education & Technology Journal	International Journal of Operations & Production Management
		Business Process Management Journal

It is difficult to identify all relevant literature by electronic searching[56]. The term electronic hand searching is used here to denote the electronic equivalent of power browsing, footnote chasing and pearl growing. Pearl growing denotes the process of using the characteristics of a relevant and authoritative article, called a pearl, to search for other relevant and authoritative materials[57].

In addition, manual searching was conducted in the library to locate relevant textbooks and monographs. The reference sections of identified papers were also searched to locate relevant cross-references. We have used the following methodology to synthesize the results of the review.

Most of the fundamental concepts pertaining to communication have their roots in the domain of cognitive psychology. Therefore, certain key concepts from cognitive psychology are outlined first. This is followed by the section on theories and models. This section contains a short introduction to theories and models in general before proceeding on to description of individual theories and models. The next section contains an overview of traditional methods used by communication researchers to analyze errors in communication following which some of the newer methods used in HROs such as nuclear power, defense and aviation.

Our initial systematic search yielded 15,365 articles. Hand searching and searching back references resulted in a set of 181 articles. One hundred and forty one full text articles were read and forthy of them were selected to be included in the review. The screening process is represented in Figure 2.

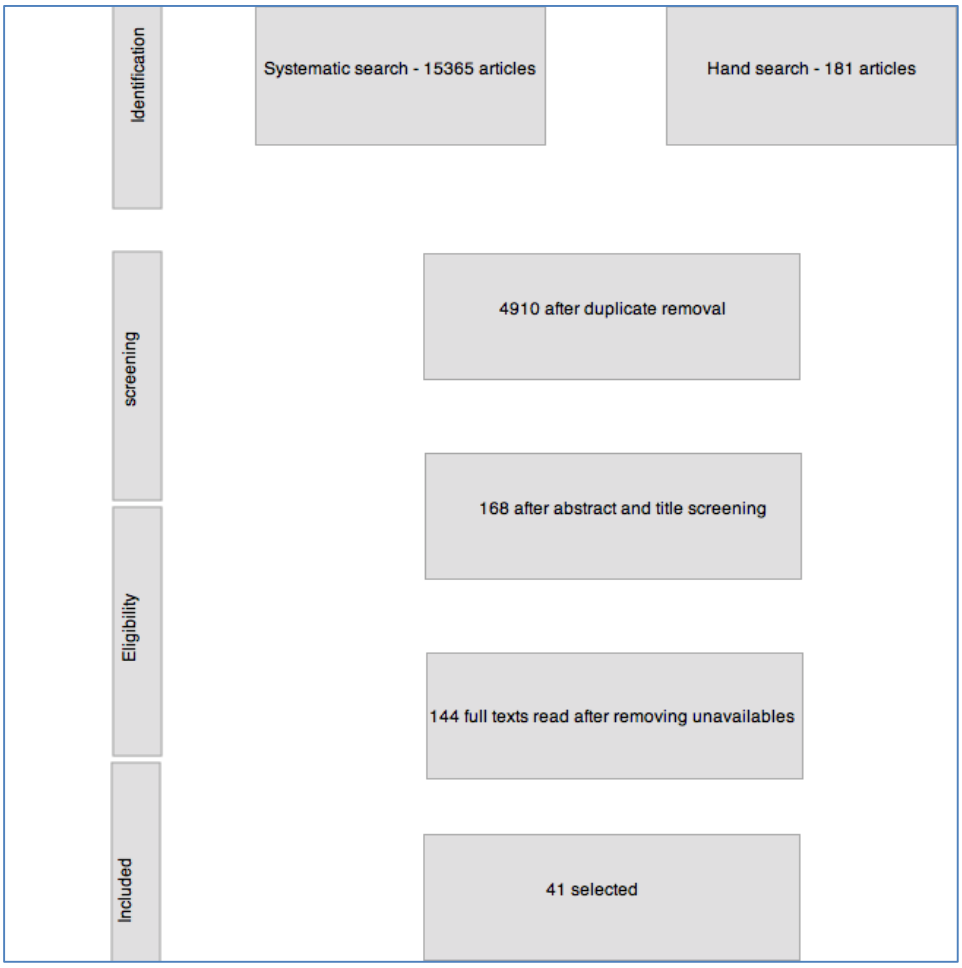

Figure 2 Diagrammatic Representation of the Search and Selection Process

Eighteen articles were published in psychology journals or as books. A total of ten articles were from the domain of computer science and three were from aviation. Two articles were from the domain of military / defense and 1 was sourced from a medical domain.

We were able to identify fourteen theories and twelve models which could be applied in hospital communication research. They are listed in Tables 3 and 4 respectively.

We were able to identify nine methods which could be adapted for analyzing errors in hospital communication. They are listed in Table 5.

Table 3 List of Theories Identified in the Review

No	Theory
1	Information theory
2	Systems theory
3	Socio-technical theory
4	Taylor's theory of organizational communication
5	Humanistic communication theory
6	Communication accommodation theory
7	Convergence theory
8	Network theory
9	Likert's four system's theory
10	Uncertainty reduction theory
11	Wicked problems theory
12	Task artifact cycle
13	Chaos theory
14	Risk communication theory

Table 4 List of Models Identified in the Review

No.	Model
1	Limited capacity model
2	Wicken's staged model
3	Socio-technical theory
4	Shannon – Weaver's model
5	Linear model
6	Mechanical model
7	Psychological model
8	Interactional and Transactional model
9	Systemic interaction model
10	Uncertainty reduction theory
11	Schein's cultural model
12	Andersch, Staats and Bostom model

Analysis Methods

Table 5 List of Methods for Communication Analysis Identified in the Review

No.	Analysis method
1	Cognitive work analysis
2	Computer-based linguistic method of text analysis
3	Sentence completeness analysis method
4	Social network analysis
5	Communication And Teamwork Skills Assessment
6	C3TRACE (Command, Control, and Communication Techniques for Reliable Assessment
7	Case based reasoning (CBR)
8	Cognitive archeology
9	CREAM-based communication error analysis method (CEAM) communication

Cognitive Psychology Concepts

Cognitive psychology is the science that studies how the human brain processes information. Communication is the process by which information is exchanged. Therefore, we need describe some cognitive psychology concepts before progressing to communication theories and models. This section contains a brief description of some very important concepts.

Communication is Cognition at Work

The term cognition simply refers to mental activities. Whether we are talking with people, planning a task or trying to remember the name of an old friend, we are engaging in cognitive activities. In short, everything we do is cognition[58]. Indeed, "the domain of mental activities is obviously very broad, encompassing everything that transpires from the initial perception of a stimulus to invocation of thoughts and emotions, and even production of overt responses"[59]. Thus, all communication is cognition. Cognitive science is a broad, interdisciplinary domain that draws from numerous intellectual traditions: philosophy, sociology, psychology, linguistics, artificial intelligence and communication[60]. Cognitive theories describe the mental systems that give rise to various phenomena of interest.

The descriptions of three cognitive psychology concepts are given below.

Cognitive Subsystems

One of the key concepts of cognitive science is that mind is comprised of a series of subsystems, each one involved in carrying out specific operations. One of the basic approaches to classify these systems is to group them based on three major information processing stages - input processing, memory and response generation.

The input processing system entails the mechanisms responsible for attention, perception and comprehension. It is the system that allows us to recognize letters and words on a printed page, identify facial expressions of emotion, hear auditory stimuli such as music, and follow the plot of the movie and so on. The response generation system is responsible for the production of both covert (i.e., mental) and overt (i.e., behavioral) outputs. The activities of this system include processes such as goal setting, response planning, behavioral monitoring and motor control. The memory system is the repository of information acquired through activities of the input processing and response generation systems. As such, the memory system holds both declarative information (i.e., factual knowledge) and procedural information that is the knowledge that underlies the ability to perform skilled activities such as driving a car or pronouncing words of one's native language[60].

Working Memory

Hebb, in 1949, was the first to suggest a distinction between long-term and short-term memory. In his classic book, The Organization of Behavior, Hebb (1949) suggested a distinction between long-term memory (LTM), which involved durable changes in the nervous system, and short-term memory (STM), which he attributed to temporary electrical activity. Some ten years later, empirical research by Brown (1958) in Cambridge and the Petersons in Indiana (Peterson & Peterson, 1959) reported the results of their empirical research in which they presented evidence to suggest that if a person is not allowed to rehearse some text material which is presented, he/she will be unable to reproduce the majority of it even after only a few seconds. Both studies attributed their results to a temporary STM system which they contrasted with LTM. In other words rapidly presented material seemed to be first lodged in a temporary storage system before being sent to long term storage. It is similar to cache or random access memory (RAM) in computers[61].

In the 1960s Atkinson proposed a two stage model of memory in which information was first stored temporarily before it moves into long-term storage. Until then, STM was thought to be working memory. It was Baddeley and Hitch who, based on a wide range of experimental data, proposed to divide STM in to "into three separable components, which were assumed to work together as part of a unified working memory system that served the function of facilitating the performance of a range of complex tasks"[61]. The STM system comprises of three subsystems:

1. A temporary verbal–acoustic storage system which is assumed to be necessary, for example, for the immediate retention of sequences of digits.
2. A parallel visual subsystem for storage and manipulation was proposed, and was termed the visuospatial sketchpad.
3. A limited capacity attentional system, the central executive which controls the behavior.

Working memory is “a limited capacity cognitive system that is used to temporarily store, update, prioritize, integrate and mentally manipulate information[62]. The Baddley and Hitch model of working memory that includes a central executive and two subsystems: a visuospatial sketchpad and a phonological loop. The central executive is a limited-capacity supervisory mechanism that allocates resources to the phonological and visuospatial subsystems. The visuospatial sketchpad is assumed to consist of a passive “visual cache” for the temporary storage of visual objects and an “inner scribe” used to rehearse and maintain spatial information in working memory. The phonological loop consists of a temporary phonological store and an articulatory rehearsal mechanism that retrieves and refreshes memory traces held in the phonological store. The fact that working memory is a finite cognitive resource that can be used up or become overloaded by too much information, might have implications on communication in an information-rich interruptive environment.

Working Spheres

The concept of "working spheres" was introduced as a proposal to understand the way in which people organize and execute their work activities. A working sphere has been defined as "a set of interrelated tasks, which share a common motive, involve the interaction with a particular constellation of people, use ensembles of resources and have their own individual time framework"[63]. As a concept, a working sphere refers to a particular way to abstract human work from the perspective of those executing it and, more important, as a way to represent those efforts that transcend mere actions, for example, when an ER staff makes a telephone call to the attending physician, the call by itself is but one of many interrelated tasks whose ultimate purpose is to summon the physician and to attend to the patient in the best possible manner. From the clerk’s perspective, making the telephone call itself may be seen as a large component of his or her work but the task itself fits in to the working sphere of ER activities. From a system perspective, a working sphere could be supported by implementing a repository where the resources and the applications concerning each sphere can be stored and easily recovered whenever necessary. Consider the telephone example again – from the perspective of the hospital (system) efficiency of ER work (working sphere) may be improved by introducing a set of protocols, procedures and resources (a readily accessible file of telephone numbers of doctors maybe) to follow in case of an emergency . The components of the ER working sphere could be used to improve the efficiency of other spheres in the hospital system (for example, in disaster response).

All Medical Work is Cognitive - Micro and Macro Cognition

Hollangel and Woods argued that every activity in health care is cognitive, from diagnosis to consultation to complex surgeries. They also say that the distinction between “mental, physical, social and behavioral aspects of performance is useful, but artificial, because all four aspects require cognitive processes”[64].

There are several ways to comprehend cognitive performance. It can be perceived from the perspective of a micro cognitive or macro cognitive process. From the micro cognitive perspective, cognition consists of a number of repeating tasks which involve processing of available information from sensations like touch. A micro cognitive lens depicts cognitive performance as consisting of a repeating series of information processing steps such as "sensation, perception, central processing and execution, and narrower constituent processes such as verbal working memory, switching attention between tasks and the planning and execution of eye movements"[64]. How these are integrated while carrying out complex tasks is seldom clear. However, "individual micro cognitive processes are well studied (e.g., studies show that proactive interference (interference) is the chief cause of errors in verbal working memory)"[64].

In contrast, from a macro cognitive perspective cognition is a set of rather broad processes such as "situation assessment, problem detection, planning and decision making"[64]. Such a view it can be seen that cognition is not the result of one single person's mental activity but the result of collaborative work involving many. For example, although a single physician may be responsible for an individual patient, he or she utilizes the collective wisdom of all members of the team. The physician relies on prior history entered in to the EMR by other physicians or nurse's reports[64].

Theories and Models

Until now the focus was on introducing certain key concepts in cognitive psychology. Before starting to discuss the theories and models, it would be advantageous to review what exactly they are and what purposes they serve.

What is a Theory?

There are different viewpoints to what constitutes a theory. According to Bacharach a theory may be viewed as a "system of constructs and variables in which the constructs are related to each other by propositions and the variables are related to each other by hypotheses"[65]. He also states that "The primary goal of a theory is to answer the questions of how, when or where, and why unlike the goal of description, which is to answer the question of what or who"[65]. Poole and Van de Ven opine that ''A good theory is, by definition, a limited and fairly precise picture''[66]. One way to define theory is to establish a set of stipulated standards by which that theory can be distinguished (stipulative approach). Another approach to defining what has been denoted as theory in the past has been called the reparative approach which advocates the gradual development of theory from initial to fully developed stage[67]. Both these approaches have their disadvantages. Comparing an evolving theory against a set of standards may be restrictive as only those potential theories which compare favorably with the standard will become accepted as a theory. This approach might limit the scope for advancement of knowledge. The second approach (reparative) may also be erroneous in that anything that compares with a theory in the

past will qualify as a new theory. Yet another approach to theory building is the deductive approach whereby abstract theories are developed and subjected to empirical confirmations.

According to Fred Casimir, theories do not develop in a social, intellectual or cultural vacuum. "They are necessarily the results of or products of specific times, insights, and mindsets. Theories dealing with the process of communication, or communicating are tied with social cultural value systems and historic factors which influence individuals in ways often inadequately understood by those who use the theory"[67].

What Does a Theory Do?

According to Larry Lauden a theory should essentially sort out or explain an empirical or conceptual problem[68]. Cohen later added that a theory should also solve practical problems[67]. A theoretical basis for a discipline or domain is vitally important to researchers and developers. Theories guide research, development and implementation by providing an understanding of processes and products and allow hypotheses-driven research enriching phenomena important to the domain, and as Kuhn says, provide legitimacy that the domain is mature, stable, and viable[69].

What Makes a Good Theory?

Six criteria are commonly used to test a theory: appropriateness, validity, scope, heuristic value, parsimony and consistent worldview[60]. Appropriateness means that a given theory is developed and used to deal with a specific set of circumstances. Validity is a closely related concept which means that the theory must explain what it sets out to explain. Scope entails how specific or general a theory can be. A theory which stimulates further thought or developments or insights is said to have good heuristic value. Parsimony indicates that out of the possible explanations of a phenomenon the most appropriate is the simplest and most direct –without sacrificing the other criteria for a good theory. World view is a more complex concept, and it is comprised of two types. In the first variety more importance is given to analytical processes while the second is social and constructivist in nature or in other words, process oriented[60].

What is a Model?

A model has been described in several ways. For this thesis we are going to use the definition Mortensen provided in 1972. He states that "In the broadest sense, a model is a systematic representation of an object or event in idealized and abstract form. Models are somewhat arbitrary by their nature. The act of abstracting eliminates certain details to focus on essential factors. The key to the usefulness of a model is the degree to which it conforms--in point-by-point correspondence to the underlying determinants of communicative behavior"[70]. Yet another way of understanding what a model is to think of them as metaphors; they allow us to see and understand one thing in terms of another.

What Does a Model do?

A good model allows us to ask questions. Mortensen provides a concise summary of this question asking ability: "A good model is useful, then, in providing both general perspective and particular vantage points from which to ask questions and to interpret the raw stuff of observation. The more complex the subject matter—the more amorphous and elusive the natural boundaries—the greater are the potential rewards of model building"[70].

Good models should clarify complexity. Models also clarify the structure of complex events. They do this by reducing complexity to simpler, more familiar terms[71]. Thus, the aim of a model is not to ignore complexity or to explain it away, but rather to give the situation or phenomena order and coherence.

Good models should also lead us to new discoveries. Ideally, any model, even when studied casually, should offer new insights and culminate in what can only be described as an "Aha!" experience[70].

Theories, Models and e-Health

As recently as 2009 Friedman stated that "the field of biomedical informatics continues to struggle to define itself. Those in the field refer often to large numbers of people in health care and biomedical research who "don't get it" with regard to informatics" 54. A sound theoretical basis for e-Health/informatics tools in almost all areas is lacking and the domain of communication is not an exception. Many other researchers, educators, developers and implementers agree that informatics lacks a strong theoretical background[72-74].

A medical informatics saying is that before we can informate or automate a task, we must first model it[75]. To illustrate the point Berg focuses on EMR systems. Early in their implementation, EMR systems were designated to be data repositories, a role in which they were often superior to paper. However, many changes have taken place in the subsequent years (integrated care, Evidence Based Medicine, to name just a few) and the once repository-based EMR system is now regarded as a 'process-oriented' enterprise tool. Some researchers feel that this process role for EMR systems has not been tested adequately. Berg makes the case for detailed modeling of ('business') processes as the primary step we need to complete before we can hope to design a process-oriented EMR system, or to acquire or tailor such a system[75]. Communication device usage in hospitals also might benefit from a similar thinking: moving from data conveyors to being part of the health care process. Early pagers and telephones were intended merely as the means to transfer messages between personnel or departments. With the changes in care patterns, however, these new communication devices have been used to facilitate decision making, care coordination and teamwork. Considering the example of EMR systems, we need to model the processes involved and the expected and unexpected outcomes before we adapt an existing device, make changes or design a new system for communication.

Communication Theories

The domain of communication studies comprises of several sub domains, each dealing with various aspects of communication processes in diverse settings as for example, organizational communication, interpersonal communication, media communication. Each of these domains has its own set of unique theories and models, although some of them find applicability across several subdomains. This literature search was able to identify a large body of literature containing references to numerous communication theories and models. Since our focus was on finding theories and models of communication which may find applicability in a hospital setting we chose to avoid theories which were deemed as purely academic in nature. We also avoided theories and models which dealt solely with interpersonal communication. In all, twelve theories were identified and included in this section. An equal number of models also were identified. For purpose of presentation, the following order is used: First human communication theories are listed followed by organizational theories and then the technological theories. Each has been explained in the subsequent section. Most of the theories and models have their origins in organizational communication. It is the collaborative nature of the major part of hospital work that made those theories and models a better fit for application in healthcare setting. For the same reason, a number of theories and models having their foundation in a systems approach also have been included. We have only attempted to provide a brief overview of the basic tenets of the selected theories and models. Exhaustive information and analysis on each of them could not be included due to the broad scope of this review.

Uncertainty Reduction Theory

Uncertainty reduction theory was proposed by Charles Berger and Richard Calabrese in 1975. It generally concentrates on the reduction of the high level of cognitive uncertainty present in an initial interaction. It also distinguishes between a predictive component (e.g., we are uncertain about what a person will do) and an explanatory component (e.g., we are certain about why a certain person did something). In formulating their uncertainty reduction theory Berger and Calabrese attempted to model the processes through which communication is used to reduce uncertainty in an initial interaction between strangers. This theory has been developed as an axiomatic theory. Axioms were formulated first and then used to derive theorems. The axioms are listed in Table 6. Basically the axioms and theorems of uncertainty reduction consider the causal relationships between uncertainty and seven other key theoretical variables: verbal communication, nonverbal affiliate behavior, information seeking, intimacy level, reciprocity, similarity and liking. These relationships are linear and causal in nature. For example, axiom three proposes a positive or direct relationship between uncertainty and information seeking. Axiom seven proposes a negative or inverse relationship between uncertainty and liking. By logically relating all axioms to each other, twenty-one theorems were derived.

This uncertainty reduction theory has been mostly used to analyze uncertainty in continuing relationships and in intercultural relationships. Recently this theory has been applied in the area

of organizational communication. The most important observation in this regard is made by Michael Krammer who stated that the theory has implications for exploring communication as a means of resolving incompatibilities among cognitive structures, experiences and behaviors in various settings[58].

Table 6: Axioms in Uncertainty Reduction Theory

Axiom Number	Axiom
1	Given the high level of uncertainty present at the onset of the entry phase, as the amount of communication between strangers' increases, the level of uncertainty for each interactant in the relationship will decrease. Subsequently, the amount of verbal communication will increase.
2	As nonverbal affinitive expressiveness increases, uncertainty levels will decrease in an initial interaction situation. In addition, decreases in uncertainty level will cause increases in nonverbal affinitive expressiveness.
3	High levels of uncertainty cause increases in information-seeking behavior. As uncertainty decline, information-seeking behavior decreases.
4	High levels of uncertainty in a relationship cause decreases in the intimacy level of communication content. Low levels of uncertainty produce high levels of intimacy.
5	High levels of uncertainty produce high rates of reciprocity. Low levels of uncertainty produce low levels of reciprocity.
6	Similarities between persons reduce uncertainty, while dissimilarities produce increases in uncertainty.
7	Increases in uncertainty level produce decreases in liking; decreases in uncertainty produce increases in liking.
8	Shared communication networks reduce uncertainty, while lack of shared networks increases uncertainty

Adapted from Berger CR, Calabrese RJ. Some explorations in initial interaction and beyond: Toward a developmental theory of interpersonal communication. Human Communication Research. 1975;1(2):99-112.pg.99

Communication between members of healthcare teams can be regarded in terms of the level of uncertainty regarding a particular piece of information which is needed to care for the patient. The higher the level of cognitive uncertainty, the greater will be the amount of communication required for coordination of each member's activity. The amount of communication required between members of well-functioning teams will be far less than what is needed even if a single member of the team is new and unfamiliar with the protocol and patient's details. From that point of view the theory has a 'human' perspective and an element of teamwork on inter personnel interactions. To illustrate the point, imagine a patient who is admitted in to the hospital for multi system failure. Such a patient's care will involve virtually large number, in some cases more than hundred people, directly or indirectly. To achieve optimum and timely care hospitals need to facilitate rapid reduction of uncertainty in the teams. ICT enabled devices and EMRs can

help create a shared mental model even before direct patient contact so that the volume of required communication is kept low while improving teamwork.

Humanistic Communication Theory

Humanistic communication theory was proposed by Duldt and Giffin in 1985. Its application has been primarily in nursing. Based on the symbolic interactionist model and a paradigm of Bubeis "I-Thou," the theory defines person as "a living being capable of symbolizing, perceiving the negative, transcending his/her environment by his inventions, ordering his environment, making choices, and self-reflecting". Dehumanizing communication, which ignores the unique human characterization, occurs when one speaks to people as if they were "things" rather than human beings; people are devalued. The continuum of humanizing/dehumanizing sets of attitudes portrays the value one holds for human beings[76].

Humanistic communication theory cautions against dehumanizing communication. Electronic communication is more mechanical and is devoid of real contact between the providers and hence does not provide context and situational awareness. Consequences of dehumanized communication are illustrated with the following case: An elderly man was admitted in hospital for a surgery. The surgery was scheduled for the next day and the surgeon ordered intravenous antibiotics to be given every 6 hours. The first dose was to be started at 8:00 pm. The computer system automatically adjusted the time of the first dose to 12:00, as the 'logical time of administration'. A pharmacist noted the error and changed the time to 9:00pm. But instead of 9:00 pm the same night he accidently changed it to the next night. The nurses for two shifts did not notice the anomaly. Only when the surgeon came back the next day the error was noticed[26]. Had there been a conversation between the pharmacist and nurses the error could have been prevented.

Communication Accommodation Theory

When we think about our interactions with others we can undoubtedly think of many instances when we change our style of talking or the words we use based on the person with whom we are conversing. A kindergarten teacher, for instance, will adjust vocabulary to the level of his or her students. The study of these behaviors in communication based on one's audience led to the development of communication accommodation theory. Three different concepts in the theory are convergence, divergence and maintenance. The most frequently studied concept in this theory is convergence. Convergence occurs when individuals adapt to each other's speech by means of a wide range of linguistic features, including speech rates and utterance length, pronunciations and several other factors. In more recent versions of the theory, convergence was expanded beyond just patterns of speech to include a wide range of communicative behavior. Examples of convergence include a student dressing in a professional way to be liked in an interview or an individual talking in a softer manner than usual with the quiet professional partner.

The second key concept in the communication accommodation theory is divergence. Divergence occurs when people try to accentuate communicative differences between themselves and others in the interaction. For example, someone from England might accentuate his or her accent to make a point about national allegiance. The third concept, maintenance, occurs when an individual's communicative patterns remained stable throughout the interaction.

Convergence can be either upward (i.e., towards a socially accepted form of communication or speech) or downward (i.e., away from a socially sanctioned form of communication). Convergence can occur to varying extents. It can be full, (i.e., the individual actually matches the communicative behavior of the other), partial or even hyper or crossover (i.e., the individual goes beyond the behavior of another on a part or a particular dimension). Convergence can be unimodel as for example, converging on the dimension of vocabulary but not on the dimensions of accent or speech rate. Convergence can also be multimodal as for example, converging on several dimensions of communicative behavior. Convergence can be symmetrical where both parties and the interaction attempt to converge towards each other or asymmetric where only one party in the interaction attempts to converge. Convergence can be based on objective communicative behavior such as the actual speech rate, accent vocabulary or it can be perceptual (the perceived speech rate or category) or it can be psychological. An example of psychological convergence is a speaker who believes that the speech rate, accent or vocabulary of the other is of a particular category[77].

That nurses tend to communicate among themselves more than with physicians and vice versa can be considered an expression of convergence theory in action inside a hospital. Convergence and divergence of communication need to be considered when a new communication device is provided for care team members. This is because of a tendency to believe that the mere provision of these devices will improve the teamwork occurs. It is worth investigating hospital communications to understand the effect of introduction of new devices on extent interprofessional (doctor - nurse, nurse - pharmacist etc.) communication.

Taylor's Theory of Organizational Communication

This theory was proposed by Fredrick Taylor in 1911.Taylor’s theory is based upon two concepts - text and conversation. Text is the content of an interaction. Conversation is the interaction between two or more individuals. According to Taylor the interaction between text and conversation is more complex than that. To understand the complexity we need to introduce two types of translations. The first is the translation of text into conversation and the second one, the translation of conversation back into text. These two translations happen almost at the same time. Mere translation of text and conversation to each other does not guarantee that the intent and context are conveyed. Often the same text may be translated by the sender and receiver in contrasting ways. In such instances, Taylor says, that a gap appears between the intentions of the people involved in a conversation. This gap, dispensation, is explained in terms of degrees of separation.

Taylor's theory supports the concept of six degrees of separation. If the separation is of the first degree, then the speaker's intention is accurately translated and embedded in the conversation. That is what occurs in a face to face conversation. In the case of second degree the conversational events are narrated in such a way that the meaning is understood as for example when a news reporter narrates the exchange of ideas between two leaders. In the third degree of separation, the text is transcribed onto a medium; the minutes of a meeting, transcript of an interview are examples of the third degree of separation. When the speaker and the listener converse in a specialized language that is particular to their activity the separation is of the fourth degree. For example when two lawyers argue in a court they will use language developed for legal activities. In the fifth degree the text and conversation are converted to physical objects or materials, e.g.,an organizational chart. When text and conversation are standardized and diffused through media for general consumption a sixth degree of separation is said to have taken place. Examples of sixth degree are television news or a public leaflet.

Taylor's theory has been mainly used to study organizational communication, especially the personal interactions inside an organization, which according to him, shape an organization. Concepts of text, conversation, intent, context, dispensation and degree of separation provide a framework to analyze communication[60]. Communications in hospital can be viewed in terms of degree of separation. Face to face consultation between doctors and nurses is an example of first-degree separation. It is the best mode of communication because efficient translation of text (content) and conversational interaction. In hospitals it is a common practice for the senior member of the team, usually the consultant to be briefed by one of the team members. Second degree of separation occurs in such cases. In the case of transcription of physician's case notes by a transcription professional separation is of the third degree. Professional communication between physicians is an instance of separation if fourth degree. Introduction of ICT enabled devices change the communication patterns and organizational culture in a hospital. Conversely, organizational change can be achieved by changing the communication pattern.

Chaos Theory

Chaos theory has its origins in mathematics and physics. It was originally propounded by Edward Lorenz while working on prediction of weather patterns. CT provides a framework to understand organizational communication, especially during crises[78]. It is defined as a set of "loosely related principles regarding the behavior of complex and dynamic systems"[79]. The theory emphasizes the "lack of predictability in system behavior, unexpected and non-linear interactions between components, radical departures from established normal system operations, and, ultimately, the re-emergence of order through natural self-organizing processes". This means that although all organizations have a general order in their functioning, even minor things can potentially produce a major impact. According to CT, this point is known as bifurcation, "the flashpoint of disruption and change at which a system's direction, character, and/or structure is fundamentally altered,"[79]. Any organization can experience bifurcation at any time. From this perspective the theory represents "broad conceptualization of both organization

and crisis that moves beyond the traditional crisis communication and public relations frameworks"[78]."Sensitive dependence on initial conditions"[78] is the most basic feature of chaos. This feature is also known as butterfly effect. "The flapping of a single buttery's wings," Stewart argued "produces a tiny change in the state of the atmosphere"[78]. This small change in the atmosphere can produce, over a period of time, "a tornado that would have devastated the Indonesian coast doesn't happen. Or maybe one that wasn't going to happen, does"[78].

Self-organization or anti chaos is another major concept of CT. It is described as the natural "process whereby order re-emerges out of the chaotic state brought on through bifurcation"[78]. Naturally occurring self-repeating patterns in a complex system are termed as 'fractals'. Those features or components of a system which maintain order are called 'attractors'.

Minor failures in communication processes such as failures to transmit or receive warnings, improper interpretation and misreporting of messages can trigger major crises. This aspect of CT is applicable to hospitals also. Failure to report or acknowledge critical information can endanger patient's lives. CT also serves as a means to explain the complexity of healthcare services[80,81].

Risk Communication Theory

Risk communication theory is a subset of communication theory which aids in understanding how risks and crises can change the customary rules of communication[82]. This theory addresses the problems raised in the "exchange of information about the nature, magnitude, significance, control, and management of risks"[82]. It also deals with determining the strength of channels through which information about the risk is transmitted. Risk communication is based on four theoretical models - risk perception, mental noise, negative dominance, trust determination. The risk perception model explains how risk is perceived and which factors influence that perception. Mental noise model is concerned with how individuals assimilate information and the effect any change in the mode of information processing can have on communication. Negative dominance model outlines how individual process negative information when faced with a risk. The trust determination model helps in ascertaining the level of trust which is associated with a communication strategy. It helps to choose which category of individuals can create trust in a given crisis situation.

Risk communication theory involves a wide variety of personnel from administration, government, hospitals, public health agencies and public. The theory is not limited to inter professional communication. Timothy L. Sellnow and colleagues have outlined a set of best practices for risk communication. They include: 1) Infuse risk communication into policy decisions; 2) Treat risk communication as a process, account for the uncertainty inherent in risk; 3) Design risk messages to be culturally sensitive; 4) Acknowledge diverse levels of risk tolerance[83]. Caron Chess describes the evolution of risk communication as a series of communication strategies and is closely related to organizational communication[84]. Little agreement exists regarding the best method to transmit communications regarding risk. Basically

the method is chosen based on the recipient. Emails, paging and text messages are some of the strategies used by hospitals for informing healthcare professionals about a potential nosocomial infection. Lack of information regarding context is one potential pitfall of electronic transmission. According to Baruch Fischhoff no single best technology is available to employ in risk communication; all technologies have their own shortcomings and advantages. Each of them also has negative consequences for some segments of population[85]. It is advisable to weigh the benefits and risks for a given situation before choosing one communication method over another.

Task Artifact Cycle

Carroll and Campbell have described the 'task-artifact cycle', as a process by which technological artifacts are designed to support existing tasks[86]. These tasks in turn are modified by the new technology, resulting in the need for redesigned artifacts. Multiple cycles of this can happen in communication[87].

The crux of this theory is that tasks and artifacts co-evolve. For example, to accomplish a task, a set of artifacts may need to be designed. These artifacts may in turn change the way the tasks are performed in that the artifact opens up new possibilities or constraints. Thus the artifact may end up changing the task. It does not stop there. The process can continue in a cyclical fashion endlessly. In simpler terms, introduction of a tool to facilitate a task will change the way the task is performed. This in turn will create new needs and necessitate changes in the tool. This mutual modification of tasks and tools can continue in an endless loop. In terms of communication, this cycling can mean that communication process improvements and device designs will continue in an endless spiral of versioning in which processes and devices influence each other and modify mutually. This happens because requirements never stabilize and the introduction of the device into the process changes the process itself which in turn necessitates device refinement.

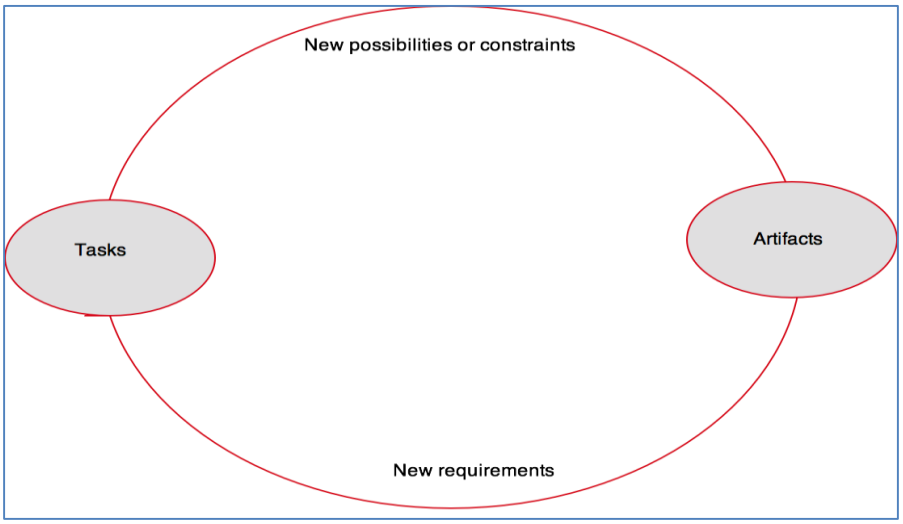

Figure 3: Task Artifact cycle

Adapted from: http://www.interaction design.org/encyclopedia/task_artifact_cycle.html

Human organizations are continuously evolving in response to ever changing circumstances. These changes are reflected in the form of work processes, meanings and identities. As easy as this principle is to understand from a social science point of view, it poses considerable challenges to information systems design. That is because computers and software can respond to finite predefined situations only. This places information systems in a position of disadvantage when it comes to keeping up with the ever changing human requirements. The rule based behavior of systems is just not sufficient to deal with human and evolving situations[88].

The primary aim of introducing ICT enable communication devices and EMRs is to improve communication and thereby coordination between healthcare providers. According to the task artifact theory, these tools change the way patient care is delivered. For example, after EMR implementation physicians and nurses find that a large portion of their time otherwise spent in direct patient contact is taken up by record keeping. It is increasingly common to hear a physician complaining about this unexpected demand. One way to reduce the time needed for updating electronic records is by improving its usability. Usability requirements will then change the EMR software presentation. This, according to the task artifact theory, is bound to be a virtually never ending spiral.

Systems Theory

Systems theory is the term used to denote a group of theoretical concepts originated from systems thinking which has a wide variety of interpretations and adaptations in various fields. For the sake of simplicity only the basic concepts of systems theory are presented here. In fact, many of the theories discussed elsewhere are also systems theories in their broad approach.

In systems theory a system is considered to be a set of objects or entities that interrelate with one another to form a whole. Systems can be closed or open. A closed system is one that has no interchange with its environment. An open system is one that accepts matter and energy from, and send it to its environment. Basically, a system is made up of four components. Systems consist of objects, their attributes, internal relationships and environment. Objects are the basic building block of any system. They can be physical like people and machinery or abstract like art and culture. In many cases a system may be composed of both abstract and physical objects. Attributes are the qualities or properties of the objects in a system. They can range from physical attributes like height, weight, color to behavior. Interaction between the objects is the most vital dynamic of a system. Finally, in system parlance environment means the surroundings in which the system exists[58].

In this theory a system has a property called hierarchy. Systems tend to be embedded within one another. In other words, one system is a part of the entire system (e.g., an ER is a system by itself but is embedded with the larger system of hospital). Every complex system consists of a number of subsystems. Any system therefore is embedded within a series of levels of increasing complexity.

The system's activities are controlled by its aims and the system regulates this behavior to achieve those aims. Systems are said to have inputs and outputs. These inputs and outputs follow logically from the ideas of hierarchy and cybernetics. System also processes balance. Balance is also known as homeostasis. A successful system must be adaptable. Cybernetics is the study of regulation and control of systems, which emphasizes on feedback. Cybernetics deals with the ways systems, along with their subsystems, modulate their affect and make necessary adjustments[58].

Many of the departments in a large hospital are so diverse in the scope of their objectives, operative procedures and team composition that each of them may be considered semi-autonomous units, as in example, an ER and the operating room complex in a large hospital. Ever increasing levels of specialization sometimes ensures that those units are often studied in relative isolation. From the systems theory perspective every unit constitutes a set of objects that interrelate with one another to form a whole, the hospital itself. Admittedly each unit has its own set of attributes, but patient safety research addressing communication issues may be better served by careful study of internal relationships of the various 'subsystems' inside the larger hospital system.

Information Theory

Information theory is important in the study of electronic communication. It focuses on measurement of information. This theory deals with the quantitative study of information in messages and flow of information between senders and receivers. According to this theory, information can mean several things. Information is the level of entropy, the unpredictableness in a system. Higher levels of entropy are associated with more information, and vice versa (negantropy). Information can also be viewed as the number of messages needed to completely reduce the uncertainty in a situation. For example, flipping a coin is an uncertain situation and the uncertainty can be reduced by knowing beforehand if the coin is fixed as for example if the coin had two heads and no tails. If uncertainty goes away, no information exists.

Another way of defining information is the number of choices or alternatives available to a person in predicting the outcome of a situation. The higher the complexity of the situation, the higher the number of alternatives will be and vice versa. Another concept in information theory is redundancy. Redundancy is a measure of the predictability of information. For example if we receive a letter in which the following phrase is written "how.....you?" we can probably guess that the sender meant a "how are you". A certain amount of redundancy is necessary for complete understanding and for systems that are self-checking and even more for self-correcting[58].

The theory can be seen in action when information about a patient is exchanged between members of a care team. When the patient is a new admission entropy exists and the messages must contain larger amounts of information. As the team members coordinate progressively and

form a shared mental model of the patient and his or her situation the amount of information in messages goes down. Yet another instance of information theory tenets being applicable in hospitals is when redundancy exists in messages. According to information theory, some amount of redundancy is good, but the limit is not known. It follows that messages between hospital care teams must contain the right amount of information to convey the intended message. Incomplete or highly redundant messages might result in patient harm.

Another reported case provides an illustration of how important is the amount of information available to medical team members: Towards the end of his working day an emergency physician received a call from a referring doctor. The physician had to get off the phone before they were through with the hand off because he was called urgently by the nurse to see a critically ill patient who had just arrived. The physician rushed in to the ER and stabilized the patient. Paramedics who brought the patient had left without passing on any paper work or speaking with the physician. Therefore the physician had trouble getting prior medical history or information about medications the patient was on; the physician had to proceed with emergency treatment without full information. Later only he came to know that the referring doctor was trying to hand over this patient[26].

The scenario faced by this emergency physician is all too common—because of lapses in communication, he was forced to make crucial medical decisions with little information. In this case, communication failures occurred between the nursing home and the ER as well as between emergency medical services personnel and the emergency department. This case provides an opportunity to explore these critical transitions in care.

Network Theory

Network theory was propounded by Richard Farace, Peter Monge and Hamish Russell. The theory has its foundation in the systems concept. According to network theory an organization is defined as a system of at least two people, with interdependence, input, throughput and output. This group communicates and incorporates the results of the communications to produce some end product by using energy, information and materials from the environment.

Two types of information can be present in an organization - absolute and distributed. Absolute information is the sum total of all the information in the organization while distributed information is that which has been spread. Questions of absolute information deal with what is known, questions of distributed information deal with who knows it. It is important to know who knows what because the mere presence of information does not guarantee that it is available to all who need to know it. Practically, leaders of an organization need to know who needs to know what. They also need to establish how these people get their information. Failure to do these two things will result in either information not reaching the intended personnel or the information is rendered redundant by the time it reaches them.

A network is considered to have three main parts – scope, function and structure. "The level of analysis is scope. Function is the information collected, dispersed and exchanged. The third, structure, illustrates how the information flows through the organization"[60]. 'Load' and 'overload' are terms used to describe the volume of work at a given time in an organization. The set of rules by which an organization functions is called dyads. The level at which persons communicate is termed as 'symmetry', the frequency of which is called 'strength'. The level at which persons in an organization communicate with each other is called 'reciprocity'. 'Mode' denotes how the communication occurs for example, on telephone or in a direct face to face manner.

By applying network theory it is possible to discover and study complex networks existing in an organization. Essentially a network is a representation of how information is created and flows through in an organization. In many organizations, we can observe that communication does not take place in the manner it should. How information flows through an organization is very much connected to how personal relationships develop.

Network theory has three traditions - positional, relational and cultural. Positional tradition basically refers to the structure and hierarchy in an organization. Relational tradition is based on how relationships initiate change while the cultural tradition deals with the manner in which the experiences, perception and tasks of its members will come to define an organization.

Network researchers define a group by four criteria: "(1) More than half of the members' communication is within the group; (2) each person must be linked with all others in the group; (3) the group will not break apart with the exit of one person or the destruction of one link; and (4) the group must have at least three members"[60]. The member of the group who forms relations with another group is termed as a 'bridge' while a 'liaison' is the person who communicates with two groups but not a member of either of them. Finally an 'isolate' is the group member who practically does not communicate with others. Networks in an organization are characterized by their size, centrality and density. Centrality denotes how much access each network has with other networks while density is the difference between the number of actual and possible links [60].

While a system theory perspective may be useful in studying hospital communication from a high level network theory can be used to evaluate communication dynamics within each subsystem. One of the prime objectives of using modern communication devices for communication inside a hospital is to dissipate distributed information. Absolute information can be found embedded in to the system as procedure protocols, automated alerts or others. However, distributed information is more loosely held by the personnel as it needs to be delivered to whoever needs such information. Many a time information may be present in the system but will be made redundant because of faulty distribution. Network theory provides the basis for evaluation of the various information networks inside the hospital. Often channeling critical information to the right personnel will be the difference between life and death of a patient.

Socio-Technical Theory

Social network theory was formulated by Trist and Bamforth based on their study of coal miner's behavior in response to change in their work flow and pattern - introduction of long wall mining to replace short wall mining. The authors argued that "technical work processes as well as social systems need to be considered and optimized to improve organizational performance". For these early theorists, the social system comprised elements such as the workers, (e.g., employees, managers and contractors); their practices, (e.g., their behaviors, activities and skills); their mental constructs, (e.g., their attitudes and beliefs) and their interactions (e.g., their relationships, coalitions, and the political milieu). The tools, devices, materials and techniques by which work was performed make up the technical system. The theory holds that a balance is needed to be found between technical and social systems. Context influences the behavior of individuals in an organization. According to socio technical theory, technology is an important determinant of organizational context. Changes in technical systems will create changes in the social system. Many such changes may solve several existing problems but may bring about new kinds of errors. It is essential to study how each subsystem is influenced by context and the effect of those changes on other subsystems[89].

Social system inside a hospital consists of workers (doctors, nurses, pharmacists, other professionals and employees) their work practices (behaviors, activities, skills, etc.), their mental constructs (attitude, organizational and professional culture) and their interactions. The technical system, on the other hand, consists of artifacts such as the instruments and devices used by the employees. In the case of communication, artifacts will be the communication devices such as pagers, cell phones, medical records. According to socio technical theory the interaction between the technical system and the social system is pivotal in achieving organizational goals. Designing systems, processes, practices and protocols without considering this crucial relationship can be counterproductive.

Translated in to the context of hospital communications, the theory implies that before introducing new devices and practices it is important to study their impact on the system as a whole. This is a very important point because a large number of hospitals are in the process of upgrading their communication systems by introducing new devices such as Black Berry, iPads and iPhones. The usage of these devices can effect changes in the sociotechnical system of the hospital which in turn will affect the hospital's safety performance. These new devices change the way team members communicate with each other. Therefore the communication practices need to be fine-tuned to accommodate the changes.

A simple illustration of the point can be found in this AHRQ M&M case report: While entering an order via a smartphone to discontinue anticoagulation on a patient, a resident received a text message from a friend and never completed the order. The patient continued to receive warfarin and had spontaneous bleeding into the pericardium that required emergency open heart surgery.

The mishap could have been prevented if the effect of Smartphone use on care delivery workflow was studied and appropriate policies were in place[26].

Likert Four Systems Theory

Likert proposed four subsystems to characterize an organization. According to him, these subsystems are a continuum and an organization can be at any point along it. The exploitative authoritative system is one in which all the decisions are made by administrators without considering feedback from employees. In the benevolent authoritative system, the administration is sensitive to the needs of the employees but only when they notice it and make decisions. Little feedback occurs in the benevolent authoritative system also. In a consultative system, administration makes decisions after consulting with the employees. The last subsystem is participation management system. In such a system managers and employees are fully involved in decision making[60].

Communication plays a vital role in Likert's theory. Communication functions as the intervening variable. Little communication happens in an authoritative system; communication channels are used only to inform the workers of a decision. In other words all communication is 'upline'. Likert believed that the participatory management system was the best among the four as it encourages the formation of cohesive teams. Both 'upline' and 'downline' communication are present in such a system. Effective and appropriate communication in an organization elicits cooperation and higher productivity on the part of the employees[60].

Wicked Problems Theory

Wicked problems are those that are "ill-defined, ambiguous and associated with strong moral, political and professional issues"[89]. These problems are characterized by their dynamic nature. They exist in a complex interactive environment and are difficult to solve. Typically it is also difficult to know when a solution has been reached in these problems[89]. The theory of wicked problems is not connected directly with communication. It is being introduced as it provides a unique perspective in looking at the problem of hospital communication using new technologies.

Considerable efforts directed towards improving patient safety hospitals have succeeded in improving protocol adherence and reducing procedural lapses and information gaps. However, as noted in the 2010 JACHO report, improvements in communication and teamwork have been slow and unsatisfactory. Technical improvements alone have failed to produce the desired results of improved care processes and patient outcomes[21]. In other words, communication remains a vitally important, unsolved problem. Therefore, one may view hospital communication as a wicked problem. Wicked problems are better dealt with from socio-technical angle because this provides a complex framework in which to accommodate the multiple facets of the problem. It may be argued that the problems of hospital communication do not possess all the features of a typical wicked problem. But a case can be built up for its consideration as one if the sociotechnical angle of the problem is considered. For a communication system to achieve its

intended efficiency it is important to consider the professional barriers and organizational climate.

Communication Models

As previously mentioned, models help us understand a phenomenon by providing an abstract and simplified representation which contains essential elements. This section contains brief descriptions of the twelve communication models identified in the literature search.

Wicken's Staged Model

Christopher Wicken's 2002 article entitled "Multiple resources and performance prediction" begins by asking this question: "Driving along a crowded highway on a rainy evening, while trying to glance at the map and search the road sign for the right turnoff, the driver's cellular phone suddenly rings. The driver feels compelled to answer it and engage in conversation with the caller. Will the driver be successful? What is the likelihood that this added demand will seriously impair safety? Could a different interface on the phone make a difference? Suppose the map was presented in a head up location? Will the benefits of not having to look downward be offset by the clutter costs of trying to see two overlapping images?"[90]. His article continues as he describes his multiple resource model (MRM) which he feels can be applied to find answers to those questions he posed.

Wicken's Multiple Resource Theory (see Figure 4) proposes that the "human operator does not have one single information processing source that can be tapped, but several different pools of resources that can be tapped simultaneously"[90]. His MRM is the practical application of the theory. The theory originates from the concept of 'single channel bottleneck' (Craik, Broadbent and Welford) and the `limited capacity central processor' (Moray) as well as the attention model proposed by Daniel Kahneman.

The work of Craik, Broadbent and Welford and Moray essentially concluded that the more demanding a task is, the more it will interfere with a concurrent task. Rasumussen in 1986 proposed a continuum of resource - task related terms: Tasks that require little or no resources are said to be `automated'. Tasks that require large amounts of resources to obtain optimum results are said to be fully `resource limited'. Tasks which can be performed optimally by allocating a portion of resources are said to be `data limited'.

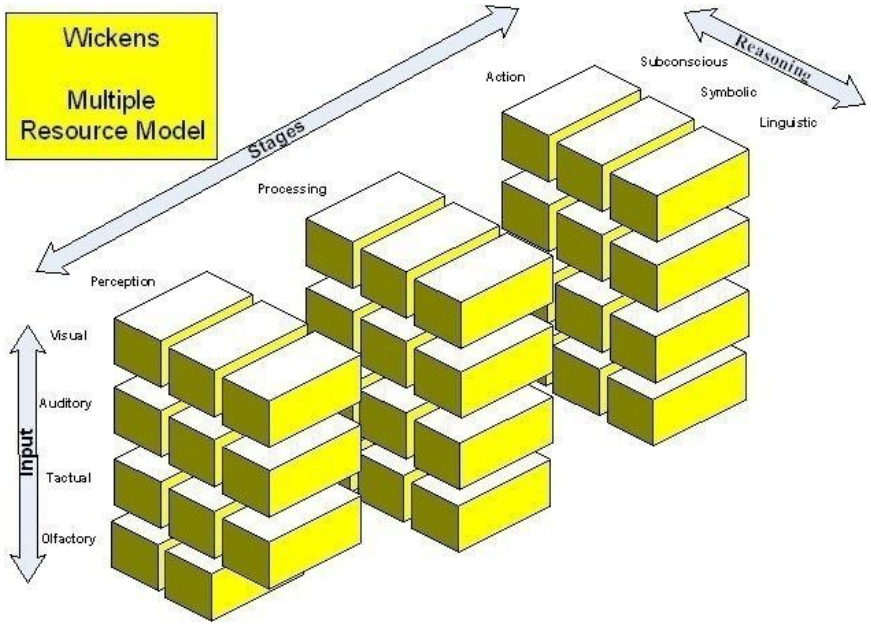

Figure 4: Multiple Resource Model

Figure source: "Multiple resources and performance prediction", Christopher.D. Wickens, Theor. Issues In Ergon. Sci., 2002, Vol. 3, No. 2, 159-17

Wicken expanded his thinking by suggesting that difficulties in multitasking are not just a quantitative (not having enough resources) or a resource allocation policy problem. Wicken and colleagues expand the scope of their model by making a structural distinction between auditory and visual processing. According to him, "Time-sharing between two tasks was more efficient if the two utilized separate structures than if they utilized common structures"[90]. In the case of the driving example quoted earlier, "the vehicle driver will have more success (at driving and comprehension) while listening to a set of instructions than while reading the same set (Parkes and Coleman 1990). That is, the eyes and ears behave as if they use multiple processing structures or resources"[90].

MRM proposes four categorical and dichotomous dimensions that influence the variations in time sharing performance (multitasking). Each dimension has two levels. This is described as follows "All other things being equal (i.e., equal resource demand or single task difficulty), two tasks that both demand one level of a given dimension (e.g. two tasks demanding visual perception) will interfere with each other more than two tasks that demand separate levels on the dimension (e.g. one visual, one auditory task)"[90]. In the context of this model, 'multiple' connotes "parallel, separate or relatively independent processing" and 'resources' connotes "something that is both limited and allocatable (i.e., can be distributed between tasks)".

The stages of the processing dimension indicate that perceptual and cognitive (e.g., working memory) tasks use different resources from those underlying the selection and execution of action. The codes of processing dimension indicate that spatial activity uses different resources than does verbal/linguistic activity, a dichotomy expressed in perception, working memory. The

modalities dimension (nested within perception and not manifest within cognition or response) indicates that auditory perception uses different resources than does visual perception[91]. Wicken proposed four dimensions for his model: processing stages, perceptual modalities, visual channels and processing codes.

Stages of the Wickens Multiple Resource Model

According to MRM, perceptual and cognitive activities do not interfere with the performance of a concurrent task whose demands are primarily response-related. In other words, resources used in cognitive or perceptual tasks are different from those needed to execute response based tasks. Wickens uses a practical example that can be used to explain this dichotomy: "the added requirement for an air traffic controller to acknowledge vocally or manually each change in aircraft state (a response demand) would not disrupt his or her ability to maintain an accurate mental picture of the airspace (a perceptual cognitive demand)"[90]. The stage dichotomy of MRM also predicts substantial interference between resource-demanding perceptual tasks and cognitive tasks involving working memory to store or transform information.

Perceptual Modalities in Wicken's Multiple Resource Model

The second concept in the model is a difference in perceptual modalities. It is easy to divide attention between ear and eye rather between two tasks whose demands are totally auditory or visual. That is, as Wickens states: "cross-modal time-sharing is better than intra-modal time-sharing"[90](auditory-visual time sharing is better than audio-audio or visual-visual time share). For example, route guidance given to a driver using audio will be more effective and safe for the driver than if presented visually because hearing and seeing utilizes two different structures and hence allow time sharing. Furthermore, if two visual modalities are far apart from each other, a person must scan between them and this movement between them will affect performance. Similarly, two or more auditory modalities which overlap each other will create confusion and thereby may lead to error and or drop in performance.

Visual Channels in Wicken Multiple Resource Model

The third concept in MRM divides visual processing in to two types: focal and ambient. Focal vision (details) uses a separate set of resources from ambient (peripheral). Therefore time sharing can occur between them. This is what makes it possible to walk properly even when one is reading a book. Reading is the focal visioning action while walking uses ambient processing.

Processing Codes in the Wicken Multiple Resource Model

The fourth concept, processing codes, is used by Wickens to state that spatial/analogue processes require a different set of resources than categorical or symbolic (i.e., linguistic, verbal) codes. Continuous manual tracking and a discrete verbal task are time-shared more efficiently when the discrete task employs vocal as opposed to manual response mechanisms. Also consistent is the

finding that "discrete manual responses using the non-tracking hand appear to interrupt the continuous flow of the manual tracking response, whereas discrete vocal responses leave this flow untouched"[90]. A very important practical implication of the concept of processing codes is that these codes help to decide which type of control or messaging is to be used in a given situation. Manual control will disrupt a task that is spatial in nature while verbal control will disrupt tasks which have heavy verbal loads. That is why texting and driving is a dangerous combination and also why pagers and cell phones are a major disruptive force in chaotic multitasking environments.

In the applied context, "the value of such models lies in their ability to predict operationally meaningful differences in performance in a multi-task setting, that results from changes (in the operator or in the task design) that can be easily coded by the analyst and the designer" as for example, the automobile driver in heavy traffic, the aircraft pilot while landing or the secretary in a busy office.

MRM can be used to predict the level of performance of two or more time shared tasks (e.g., predict the level of disruption or interference between two tasks when they must be time-shared). MRM can also be used to answer questions such as when is it better to use voice control than manual control, to use auditory rather than visual displays or to use spatial graphic, rather than verbal material.

Cognitive overload is a concept that follows closely from the concepts presented in the MRM and theory. According to Esgate and Groome, the term cognitive overload refers to "organizationally induced and constrained limited capacity processing inherent in the way improvised discourse practices, and annotative devices or artifacts (such as written notes or some related strategy). It has been reported to affect communication by contributing to the noise"[59].

In a modern hospital, personnel are subjected to a virtual bombardment of information by means of a variety of displays including tablet devices and smart phones in addition to other audio visual means. Applying the limited capacity model to hospitals provide us with several communication situations- if encoding is low (absence of an orienting response) storage will be high and the event or message will be remembered by the recipient but he or she will be missing details. In some other situations, encoding is high but storage is low - this results in instances of good recognition memory but very poor cued or free recall. Encoding allows high attention and poor memory of all types, which can result, for example, when multiple structural features engage the automatic allocation systems at a very high level, but the system is overloaded. A perfect example of such a condition is television broadcast news where encoding is fast but memory is poor. The analogous situation in a hospital could be the case when multiple, poorly targeted messages are sent to doctors and nurses. These messages lead to cognitive overload and may be a factor in inducing an error.

Work inside a hospital is characterized by its chaotic nature; multitasking is very common. In psychological terms, multitasking is described as time sharing of internal resources between various modes of cognition such as visual, auditory, and spatial. In addition to multitasking, healthcare professionals receive messages in multiple formats - visual, verbal, auditory or a combination of those. Wicken's MRM can be applied to evaluate healthcare workflows and workload. According to Wicken "All other things being equal (i.e., equal resource demand or single task difficulty), two tasks that both demand one level of a given dimension (e.g., two tasks demanding visual perception) will interfere with each other more than two tasks that demand separate cognitive resources (e.g. one visual, one auditory task)"[90]. According to the Wicken's model, cross modal time sharing is better than intra modal time sharing. The Wicken model can find application in deciding which mode of communication is better in a particular situation.

In a busy chaotic work environment such as an ER, it is not an uncommon occurrence that a doctor reading a patient's history is interrupted by the beeping of his/her pager. The doctor will have to divide attention between the pager and the record. This is just one instance where the Wicken's staged model concepts are applicable in hospitals.

Shannon-Weaver Model of Communication

The Shannon-Weaver model is one of the earliest models of communication. Shannon was an engineer at the Bell Telecom company; his interest was solely in the technical aspect of communication. He proposed the mathematical theory of signal transmission to improve signal transfer in telephone lines[92]. Weaver applied this model to interpersonal communication. Since then the model has been known as the Shannon -Weaver Model of Communication. In this model, the term communication has a broader meaning than usual: "... all of the procedures by which one mind can affect another"[93].

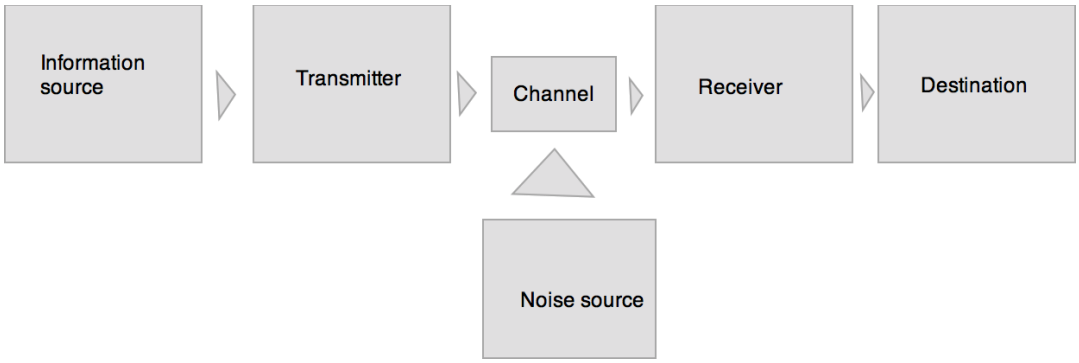

Figure 5: Shannon Weaver Model of Communication

Figure adapted from: Isaac A, Shorrock ST, Kirwan B. Human error in European air traffic management: the HERA project. Reliability Engineering & System Safety. 2002;75(2):257-272.

The original model consisted of five elements:

1. An information source - Anything that creates a message can be called as an information source.
2. A transmitter, which encodes the message into signals.
3. A channel - The information passes from the source to the receiver through the channel. Depending on the channel that is used, a signal may have to be adapted to the channel.
4. A receiver-The encoded messages are reconstructed by the receiver.
5. A destination is where the message finally arrives.

A sixth element, noise, was a later addition to the model. Whatever blocks or negatively affects the passage of the message through its channel is deemed to be a noise.

The model has been regarded as the precursor of all subsequent models of interpersonal communication. That is the main reason for including it in this manuscript even though it does not have any real application in hospital communication. The model has several disadvantages. Apart from its obvious technological bias, the model is linear. The model looked at communication as a one-way process. This flaw was later corrected by adding a feedback process, as can be seen in the next model discussed.

Circular Model of Communication

Osgood and Schramm (1954) further developed Shannon and Weaver's (1949) Model to account for the role of feedback and created a circular model of communication as shown in Figure 6[94].

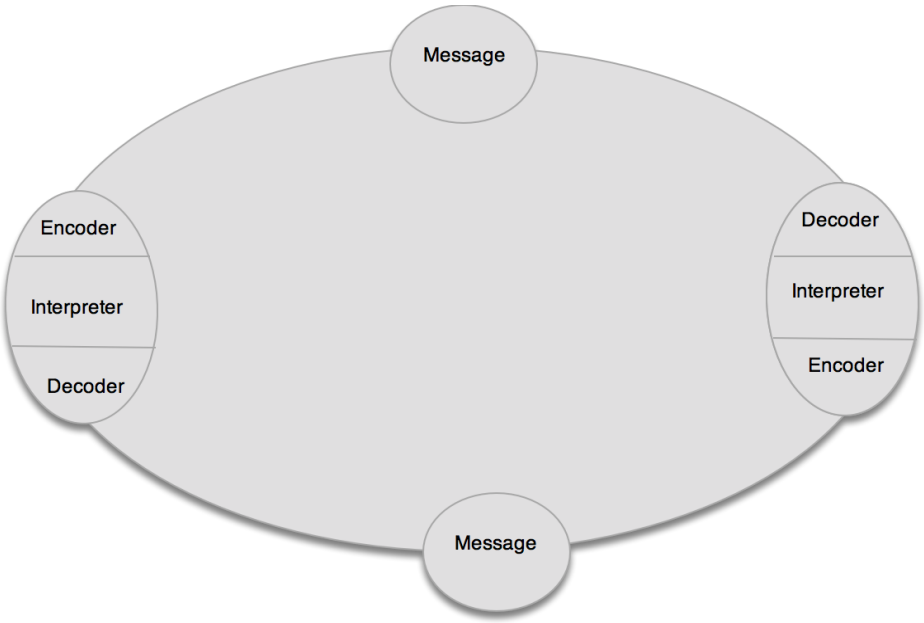

Figure 6: Circular Model of Communication
Organization ICA. Safety Management Manual (SMM) 2009

Similar to the Shannon Weaver model, the Schramm model is also of largely academic and historic interest.

Helical Model of Communication

Dance's (1967) Helical Model is actually a metaphor, which combines aspects of the early linear models of communication and the later circular models of communication to form a helix. Linear models omit the role of feedback in communication and circular models are flawed in that they suggest communication comes full circle to the same point from which it started. The helix implies that while communication is moving forward, it is also coming back upon itself and is being affected by its past behavior. For instance, what is communicated now will influence the structure and content of communication later on. The helix suggests that different aspects of the communication process change over time. The shape of the helix can differ according to the situation - with prior knowledge of a topic the helix widens quickly. With little or no prior knowledge, such as in new situations, the helix widens more slowly[94].

The helical model is likely more representative of hospital communication than the previous two linear and circular models. This is because the helical model overcomes certain disadvantages of the other two and suggests that the communication exchange is not a linear one way process or a complete circle but a transactional two way process.

Westrum's Categories of Organizational Communications

Westrum (1995) has proposed a categorization of communication types within organizational practices. This approach captures the problems of a sociological nature that have an important influence on the safety health of aviation organizations. Westrum's model is a broader approach towards representing communication.

Three types of communication styles produce different organizational climates. Westrum describes these as pathological, bureaucratic and generative. These varying organizational climates handle safety information quite differently and are summarized in Table 7.

Table 7: Westrum's Communication Model

Adapted from Technical Review of Human Performance Models and Taxonomies of Human Error in ATM (HERA), European Air Traffic Management Programme

	Generative	**Bureaucratic**	**Pathologic**
Information	Actively sought	May not be found	Not wanted
Messenger	Trained	Listened if arrived	Shot
Responsibility	Divided	Shared	Avoided
New ideas	Welcomed	Problematic	Discouraged

The generative culture is obviously the type of approach that should be the goal in a safety-critical organization. In groups with a generative culture hidden failures are actively sought and if possible, removed. However, generative culture can only be successful if the management not only encourages people at all levels to communicate but also urges all personnel to critically evaluate all levels of operation. These organizations that follow generative methods also develop effective ways of reporting problems and deal positively with errors; the system learns through its mistakes rather than punishing those that are involved in the error chain. Generative organizations use these error events to improve the safety of the group. This way of handling errors can have a influential effect on the beliefs and operating practices of staff. The staff will generally increase their risk-taking behaviors in environments that follow extreme bureaucratic or pathological cultures.

The tenets of Westrum's representation are relevant to communication within hospitals too. It is important for hospital administrators to understand that introduction of state-of-the-art communication devices cannot essentially change the culture within the organization. Recent measures such as conducting short meetings before a surgery and allowing junior members of the team to speak up without fear in case they notice something untoward are undertaken to establish a generative type of communication patterns. For effective communication to occur, introduction of newer and more efficient ICT enabled communication devices has to be coupled with improving the existing communication patterns.

The Schramm Communication Model

The Schramm communication model is basically a modification of the Shannon-Weaver model and incorporates some of its components and other technical aspects of communication. Schramm was interested in the instructional role of communication. Therefore, the primary concerns of his model are the meaning and the communication of meaningful symbols. The Shannon-Weaver model has little to say about meaning. Schramm maintained that encoding and decoding is not a linear sequential process, but performed simultaneously by the sender and the receiver. The Schramm model views communication as a two-way exchange of information.

Major strengths of the Schramm model are its inclusion of a 'field of reference' (psychological framework), feedback, context (a message may have different meanings, depending upon the specific context or setting) and culture (a message may have different meanings associated with it depending upon the culture or society). Communication systems, according to Schramm, operate within the confines of cultural rules and expectations to which we all have been educated)[95].

One drawback of the Schramm model is that it does not allow for complex, multiple communications between more than two persons. The inclusion of context, field of reference, culture and feedback makes the Schramm model more relevant to hospital communication than the linear models.

Action/Linear, Interaction, Transactional Models

Several models categorized as linear, iteration or transactional models can be found in literature. They are presented together because each of them represents an improvement from the previous Schramm model.

Action / Hypodermic Needle / Magic Bullet Model

If we considered communication to be strictly action, we would study how the source could present clear messages to a receiver or an audience. We would not consider the reaction of the audience or feedback to it. This linear and one-way approach to communication has been labeled the hypodermic needle model or magic bullet model of communications. This action model suggests that communication is a simple process of injecting our messages into those we feel need to know the information. This model also has been referred to as linear communication model[77].

Interaction Model

In the interaction model the importance of feedback from the receiver is considered, we are looking not just at the message of the source but also the reaction of the receiver. An interactional view advances the action/linear/hypodermic needle model because it acknowledges that communication is not strictly a one-way process with direct and linear effects. This interaction model is simplistic.

Transactional Model

Most communication scholars today, however, conceptualize communication not as a linear or interactional process but in a transactional sense[77]. A transactional view of communication, like an interactional view, includes the important role of feedback. However, a transactional view goes further, in that it considers communication as a process with constant mutual influence of communication participants. The transactional view emphasizes the importance of context in the communication process. That is, not only do participants constantly influence each other, they are also influenced by the context in which they interact. There is considerable divergence or disagreement regarding whether communication is a social activity or is it an intrapersonal activity. Even scholars who see communication as a clearly social process involving two or more people also acknowledge the importance of internal states such as cognition and emotion on communicative interaction[77].

Berlo's Communication Process Model

The SMCR model (S - source, M - message, C - channel, R- receiver) is an adaptation of Shannon Weaver's model. Berlo's model consists of the following six components:

1. The communication source—someone with a reason for engaging in communication; factors include communication skills, attitudes, knowledge level and position within a social cultural system;
2. The encoder – who must have motor skills, such as vocal mechanisms that produce sound or muscle systems that produce gestures or writing;
3. The message—a systematic set of symbols;
4. The channel—a medium, a carrier of messages;
5. The decoder—the receiver's sensory skills that retranslates the message into a form he can use;
6. The communication receiver—the target of the communicator.

According to Speckhard, the SMCR model divides the communication process into source-receiver and receiver-source components; each having an encoder-decoder and a channel. The encoder-decoder unit performs the function of symbolizing or de-symbolizing the message flow in either direction. The source may be a receiver and vice versa. The direction of the message flow determines whether the encoding or decoding function is performed[96].

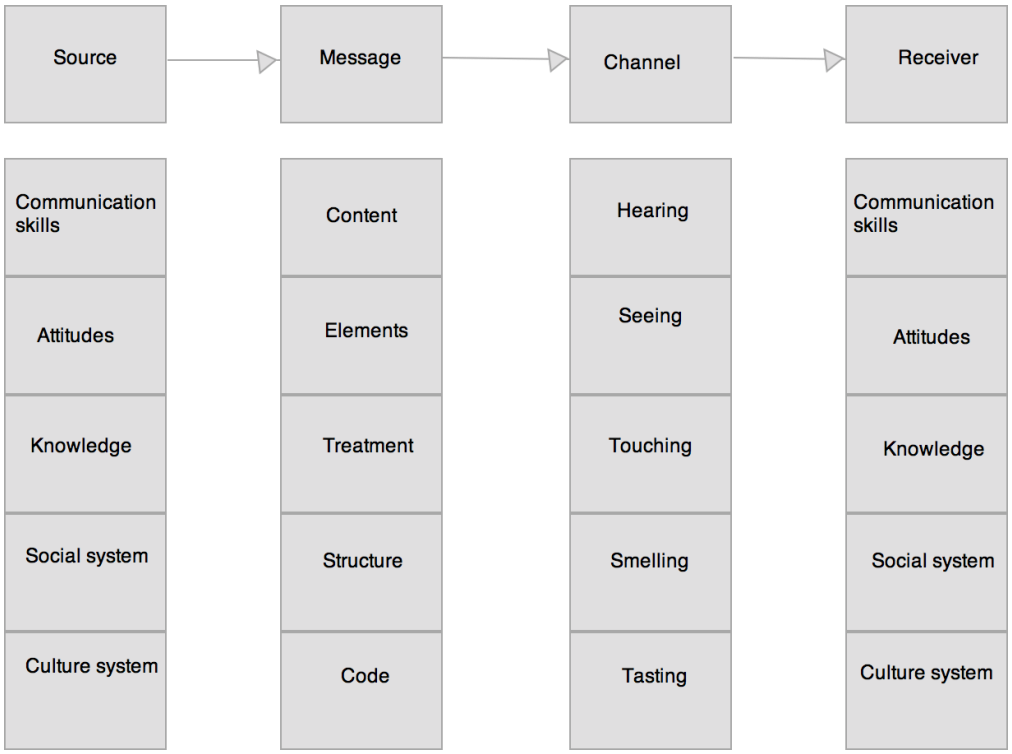

Figure 7: Berlo's Communication Process Model

Figure source: Berlo's SMCR Model Of Communication [Internet]2010

Mechanical Models

According to mechanical models, communication is a linear sequential and simplistic process whereby the message is created, encoded, transmitted through a channel and decoded. The model

is based upon the interaction between encoding and decoding. Both processes have to be neutral. Another important tenet of the mechanical model is that all language used in communication needs to be free of ambiguity. Apart from its linearity, the model has several shortcomings. It accords a quasi-causal relation to the sender and the receiver. Additionally, the model considers messages as objects with spatial and physical properties such as frequency, amplitude or duration. Any distortions are interpreted as "errors or noises to be eliminated as a result of the artificial belief that such errors or noises make it impossible to capture the nature of the message, which is considered neutral and previously defined"[98].

Psychological Model

The psychological model focuses on personal characteristics of individuals and how they process, filter and understand messages. According to Calabrese, "the conceptual filters adopted by the individual players allow the structuring of chaotic environments and thus form the locus of the communication"[98].

This psychological model, too, has several shortcomings. Studying individual conceptual filters is difficult. In addition, the assumption of linear causality and its focus on physiological aspects of communication at the expense of the physical also are pointed out as shortcomings of the model[98]. The psychological model is more abstract and related to individuals. Therefore it has limited direct application in hospital communication.

Systemic Interaction Model

The systemic interaction model has its origins in Calabrese and Krone's work. The model establishes the communication process as a set of processes that must be analyzed as a whole before the communication can be understood[60]. Unlike the mechanical approach, the systemic interaction approach does not assume that the entire communication process is equal to the sum of the individual acts. Rather, it is the communication process which determines the organizational behavior. The key to communication in the systemic interaction model is in the ordered rendering of structured behaviors discerned in terms of recurrence. Systemic interaction model is not a search of cause effect analysis connecting the ingredients of the process of communication. The systemic interaction model is closely related to systems theories. Like the systems theory, the systemic interaction model is highly relevant in today's hospitals because each unit in a hospital can be represented as a subsystem of the larger system (hospital).

Schein's Cultural Model

Schein's cultural model is not a communication model but is included because culture is an important factor in improving hospital communication. In this thesis we have concentrated on the safety culture of hospitals and therefore this model has many potential applications.

Edgar Henry Schein defines culture as "a pattern of basic assumptions-invented, discovered or developed by a given group as it learns to cope with its problem of external adaptation (how to survive) and internal integration (how to stay together)-which have evolved over time and are handed down from one generation to the next"[99]. His simplified version is "the way we do things around here"[98].

According to Schein, culture can be represented as a three layered model. Artifacts and behavior makes up the first level. These are the most visible manifestations of a particular culture - the way it is seen, heard or perceived. Often, factors which are evidence of performance strata are observed to be present at this level. This level of artifacts and behavior, however, does not clarify the reason behind a particular status. The second level at which culture can be explained is found in espoused values. These are the values individuals claim they support. An important point is that espoused values can be in conflict with artifacts and behaviors.

Basic assumptions are the final layer in Schein's model. They lie deeper than the other two levels and are the most difficult to discern. The assumptions are the set of fundamental beliefs which are engraved on to the collective inner psyche of a culturally distinct cluster of people. Basic assumptions develop over long periods of time from the group's antecedents, what made them successful or otherwise and from the opinions and practices of their founders[99].

Andersch, Staats and Bostom Model

The Andersch, Staats and Bostom (1969) model emphasizes environmental or contextual factors. This model, however, goes deeper than merely considering the effect of environment in communication processes. It gives emphasis to the transactional nature of communication in which the sender and the receiver are both interacting with the environment while the former is trying to convey a particular meaning and the latter trying to reconstruct and comprehend[99]. The Andersch, Staats, and Bostom model is drawn in Figure 8. The figure details the process of communication more explicitly than many previous communication models. We feel that the model could be developed further to classify errors in various stages of communication in the hospital setting.

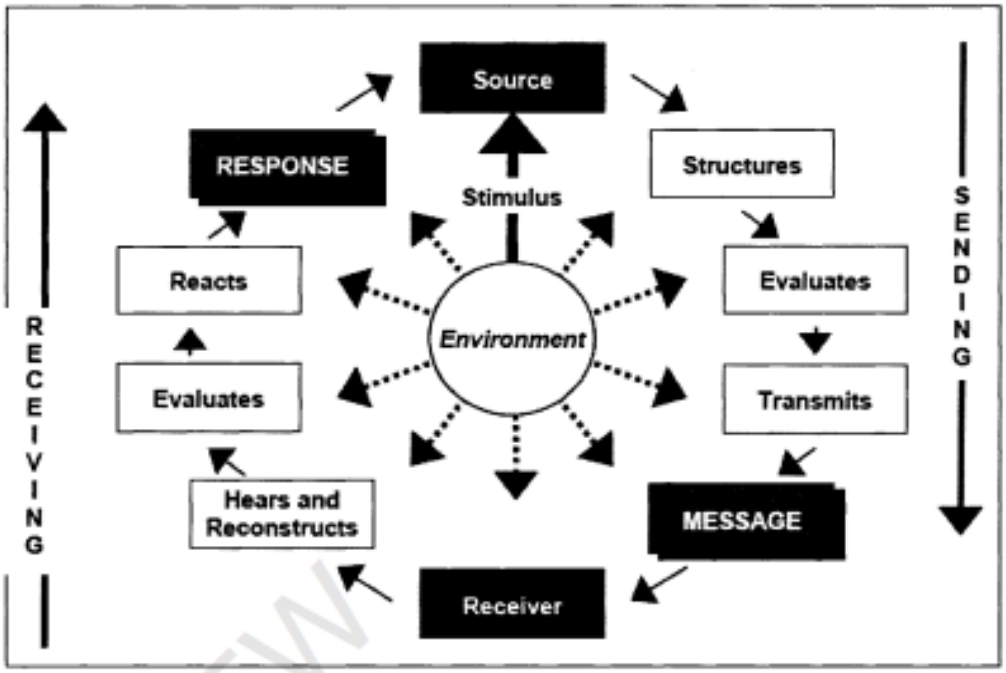

Figure 8: Andersch, Staats and Bostom Model

Figure source: Alexander EL. Safety Culture in the Nuclear Power Industry: Attributes for Regulatory Assessment [dissertation]. Massachusetts Institute of Technology; 200499.

The working conditions inside a hospital can be chaotic with multiple interruptions and need for prioritization of tasks. Member of the health team must exchange information and act in concert in such an environment. Context and interaction with the external environment is a vital factor to be considered while analyzing hospital communication.

Communication Analysis

Previous sections outlined several theories and models which could be used to understand the problems in communication process inside hospitals. The following section focuses on communication analysis methods which may be employed to find suitable solutions to those problems. Communication science employs a wide array of methods.

Traditional evaluations of communication have been done using two different research and data collection methods: self-reports and behavioral observations.

Self-Reports

Self-reports are based on research participant's written or oral responses to statements or questions posed. Questionnaires and interviews are the two techniques commonly used to gather self-report data. Self-reports are extremely effective for measuring respondent's beliefs, attitudes and values because these exist internally. Self-report methods also may be accurate in collection data on indicators of people's behavior. The self-reports may be problematic, however, because

participants do not always provide accurate information about their belief, attitudes, values and behaviors, especially when asked about controversial topics or ones with important ramifications. Self-reports also may be problematic because of the low correlation between what people say they do and what they actually do, as evidenced by the saying, "do as I say, not what I do".

Behavioral Observations

Behavioral observations involve the direct, systematic inspection and interpretation of communication phenomena. Two common behavioral observation techniques that are available to applied communication researcher are physiological measures and observers ratings. Physiological measures are used to determine the physical behavior involved before, during and after communication events occur. It requires instrumentation of some type. Direct observation methods can be accurate assessments of behavior although training and experience improve the accuracy of the data collected. Direct observation can be done in real time or using recorded actions of the people involved.

Survey Methods

Survey several methods are used to gather information about attitudes and behaviors of a defined population from questions posed to sample selected from the population. Descriptive surveys are the surveys in which the respondent is asked about "what, how and when they communicate"[100]. Explanatory surveys aims to find out "why people communicate as they do"[100]. Many kinds of surveys exist. A general classification of categories of surveys is in-person, mail, telephone, mall intercept, or computer administered[101]. Their salient features of surveys can be found in Table 8.

Table 8 : Comparison of Different Types of Surveys

Adapted from Watt J, Berg SV. Research methods for communication science. Recherche. 1995;67:02101.

Survey type	Obtaining sample	Cooperation rate	Cost per respondent	Strength	Weakness
In-person	Difficult	Medium	High	Visual and manipulative measurement, interviewer rapport	Respondent fear or evasion, expensive
Telephone	Easy	High	Medium	Fast, plus in-person advantages	Limited time for interview
Mall intercept	Easy	Medium	Medium	Fast, plus in-person advantages	Unrepresentative sample
Mail	Easy	Low	Low	Large sample is inexpensive	Unrepresentative sample, respondent errors
Computer administered	Difficult	High	Medium	Automatic data entry	Respondent must have computer

Ethnographic Methods

The word ethnography is derived from Greek language (ethnos = folk/people and grapho = to write[102]. It is a qualitative research design aimed at exploring cultural phenomena and was first used in the field of socio-cultural anthropology. Ethnography is naturalistic; ethnographers focus on real people and their everyday activities in their natural environment. Written ethnographies have changed over time from texts exhibiting a "disembodied, all-knowing perspective to experimental texts that are unconventional, polyphonic, and heteroglossic"[103]. In communication studies, ethnographic methods are used to observe and describe the communication behaviors of individuals within a particular natural setting[100]. Ethnographic studies and other qualitative methods are excellent methods for determining why and how people do things.

Textual Analysis Methods

Textual analysis is used to classify and evaluate the characteristics of written, electronic and visual transcripts of texts. Many textual analysis methods exist and we have included content analysis, conversation analysis, and unobtrusive measures.

Content analysis is a research technique for making inferences by systematically and objectively identifying specified characteristics within the text. Essentially, content analysis is the "measurement of constructs which can be observed within the messages produced in a communication process"[100]. The technique has wide ranged applications within communication research. It is used to analyze media content, the transcripts of interpersonal conversations or group discussions, organizational memos, and even nonverbal interchanges[101].

Conversation analysis (also called discourse analysis) is used by researchers to examine the messages exchanged during dyadic and group interactions to discover the systematic and orderly properties which are meaningful to conversations. Conversation analysis focuses on describing and understanding the content, function, structure and effects of conversation.

Finally, unobtrusive measures examine physical traces or artifacts to describe people and their communication. These methods can be broadly categorized as measures of erosion or measures of accretion. When researchers study the pattern of erosion of physical objects linked to communication behaviors it is called measures of erosion; when they study the accumulation of physical traces it is called measures of accretion. Archival research examines existing records of human behavior, such as public and private records including documents. Bibliometrics use clustering techniques, techniques that group things together, to study scholarly literature[100].

Field Research

Field research involves both field studies and field experiments. Field studies involve behavioral observation in natural settings without any type of intervention or manipulation of an independent variable. Field researchers observe naturalistic behavior and refrain from obtaining

information directly from research participants. The researcher's intent is to "disturb the behavioral system he or she is studying as little as possible so that the behavior observed is true or natural and is not influenced by the research procedures themselves"[100].

Field experiments, on the other hand, also are used to observe behavior in naturally occurring contexts, but manipulate one or more independent variable. Unlike field studies, which examine naturally occurring levels, field experiments modify conditions in the natural environment to determine the causal relationships between independent and dependent variables.

Field research offers a number of potential opportunities for applied communication researchers. These include opportunities to build clearly and to conduct research that is ecologically valid. Although not known as a theory building technique, field research provides researchers with opportunities to generate questions and test the hypothesis that lead to theory development.

Problems with Field Search

Subject selection: Researchers argue that a large portion of field research relies extensively on a particular convenience sample and hence may lack generalizability.

Cost: Field research usually costs more than laboratory research.

Ethics: Field research often involves difficult ethical choices. Subjects are often observed in the field without their awareness, and unobtrusive observation may infringe on the right to his or her privacy and may violate current ethical principles of research.

Disturbing the environment: Field researchers frequently manipulate variables in the natural environment that may alter conditions to such an extent that the ensuing behavior may not represent actual behavior without the manipulation. This phenomenon is known as the principle of uncertainty.

External validity: External validity refers to researcher's ability to generalize findings from one study to different persons, settings and times. Generally, three issues to be considered – statistical generalizability, replicability and ecological validity. Several reasons exist as to why applied research conducted in the field tends to be more generalizable than research conducted in the laboratory. First, behavior differs depending upon the setting and therefore certain behaviors can only be practically and reliably studied by altering field settings. Second, behavior in the field demonstrates a wider range of variation than is possible in the laboratory. Third, unanticipated events and behaviors often are present in the field that may affect the problem being studied. Field researchers can observe these natural events and incorporate them into the study. Fourth, field research allows researchers to investigate the natural time span of phenomena whereas in laboratory research the researcher him or herself must estimate and approximate the time span involved in naturalistic interactional sequences. Field settings usually

maximize the researcher's ability to generalize results to other settings that are similar in nature[100].

Focus Group Research

Emerging from the psychoanalytic tradition, focus groups are typically groups of 8 to 12 people gathered together to discuss issues important to them on a topic. Sessions are led by a trained facilitator and are time limited. According to some experts, a focus group is nothing more than an extremely well-targeted and designed meeting. The size of the group is important for two reasons; groups with too few members tend to cause discomfort by placing an undue burden on each individual participant. Small groups also run the risk of generating collectively few perceptions. On the other hand, in groups with too many members, each individual participant's allowable contribution time is shortened.

Leading the discussion is a moderator. According to one expert the moderator is like a conductor, orchestrating an improvised session[100]. Content is usually recorded and then transcribed for analysis.

Newer Methods for Communication Analysis

Several newer methods of communication error analysis were found during the literature review. An in-depth discussion of those methods is out of scope for the thesis. However, it was felt that hospital communication researchers might find their inclusion useful. Therefore, those methods and a brief outline have been included in tabular form in Tables 9, 10, 11.

Table 9: Communication Analysis Methods Based on Content Analysis

Evaluation method	Brief description	Application
Textual analysis using software	It has its origins in social sciences. It is essentially a qualitative and or quantitative analysis of text.	Used in social sciences and recently by military. US military used a software using N Vivo 3.0 (QSR International, Victoria, Australia) to reveal themes in electronic communication between combat soldiers in Iraq and their families[106].
Computer-based linguistic method of text analysis	Uses a Linguistic Inquiry and Word Count (LIWC) which "analyzes written or transcribed verbal text files by looking for dictionary matches to words in the text file"[107]. The software calculates word match percentage up to 85 language dimensions.	Used in aviation to find out communication patterns and to obtain new insights in to communication between team members.

Table 10: Communication Analysis Based on Cognition

Evaluation method	Brief description	Application
Cognitive Work Analysis (CWA)	CWA is defined as a "systems-based approach to the analysis, design, and evaluation of human-computer interactive systems that unifies psychological and technical considerations"[108].	CWA has been used for planning communication in military aviation. It is particularly suited for environments within which sudden unexpected events can occour[108].
Social Network Analysis	It is a survey that employs network approach to record interactions between employees. A diagram which maps the results is produced.	It has been used in healthcare by Westbrook and colleagues to comprehend flow of information in three hospital units[89].
Cognitive Archeology	Cognitive archeology involves the "elicitation, interception and capture of the cognitive activities that a user finds beneficial and essential to successfully complete a task" [109]. It studies cognitive artifacts[vi].	Artifact detection is important in "conducting an accurate user needs analysis and user interface design"[109].
CREAM(Cognitive Reliability Error Analysis Method)-	Based on communication error analysis method (CEAM), it reveals specific cause effect links to communication. It consists of a qualitative quantitative components	CEAM has been tested in nuclear power plants for communication error prediction and communication related accident analysis.

Table 1: Miscellaneous Communication Error Analysis Methods

Evaluation method	Brief description	Application
Communication and Teamwork Skills (CATS) Assessment	It is an instrument that can measure the quality of teamwork and communication skills. The tool uses behavior markers adapted from CRM training in aviation.	Frankel and colleagues piloted CATS in hospitals. Evaluators scored observed behaviors based on a pre-developed criteria concise and relevant [111].
C3TRACE (Command, Control, and Communication Techniques for Reliable Assessment of Concept Execution)	C3TRACE is a modeling environment that can study the effect of information technology on system and human performance. It includes a graphical user interface a discrete event simulation engine (Micro Saint Sharp), and data analysis module.	C3TRACE, can replicate any organization, employees and their duties. Internal and external communication can also be represented. Different permutation or scenarios can be studied without actual experiments. US army uses this technique to find out what effect new technology will have on organizational structures[112].
Case Based Reasoning (CBR)	CBR is a 4 step process which focuses on solving recurring problems by utilizing previous experience from similar situations.	Call centers and help desk applications where quick access to previous information is vital to serve customers [113].

[vi] These artifacts are those elements whose function is to ensure task success. Examples include check marks, post-it notes, logs[109].

Evaluation method	Brief description	Application
MIDAS (Man-Machine Integration Design and Analysis Systems)	MIDAS is a 3D rapid prototyping human performance modeling and dissimulation environment that helps in visualizing the design and to evaluate human –machine interaction	MIDAS has two main components – a virtual human, and a "computational cognitive structure that represents human capabilities and limitations". The cognitive structure is capable of visual and auditory perception and is capable of making decisions and respond to stimuli. The complex interaction between the components reveals unexpected scenarios. US military and NASA have used MIDAS[113].

CASE STUDY

Previous sections of the thesis dealt with various theories, models and analytic methods which may be allocable in hospital communication. The purpose of this section is to view a reported patient safety incident through the theoretical and analytical frameworks described before. For this purpose, one of the cases from the AHRQ web M&M has been chosen26. After describing the problem and its consequences, we provide a commentary rooted in the theories and models of communication previously described. This is followed by a proposed application of one of the methods of communication analysis to the problem.

The Case

"A 20-month-old boy was admitted to the intensive care unit (ICU) following a Fontan surgical procedure for hypoplastic left heart syndrome. The child initially made good progress. He was weaned from inotropic support and tolerated enteral liquids on the first postoperative day. That evening the child developed respiratory distress with acidosis and fever. The resident physician notified the on-call ICU attending, who came in from home to manage the child's respiratory status. The surgeon called from home to check on the child at midnight and spoke with the resident, who indicated that the child had suffered respiratory deterioration and that the ICU attending was at the bedside managing the patient. The surgeon requested an echocardiogram but did not speak directly to the ICU attending, and the cardiology fellow who performed the echocardiogram communicated results to the surgeon, the child's attending of record for this admission. After stabilizing and monitoring the child's respiratory status, the ICU attending returned home. The resident communicated with the ICU attending by phone and pager through the rest of the night, as the child's status was not improving as expected. The resident assumed the ICU attending was communicating with the surgeon, and did not contact the surgeon or cardiologist. The child suffered a cardiac arrest at 7:00 AM from low cardiac output. The surgeon and cardiologist arrived in the ICU for rounds just minutes before the arrest. Despite aggressive resuscitation efforts, the child suffered massive brain injury and subsequently died"[26].

Commentary

The patient was initially under the care of the surgery and cardiology teams and developed respiratory distress after surgery. The ICU attending focused on improving respiration but remained ignorant of the fact that the surgeon had ordered an electrocardiogram (ECG). The ECG showed low cardiac output, a condition which needed to be addressed immediately. The cardiology fellow who performed the ECG communicated the results to the surgeon. The surgeon did not directly speak with the ICU attending who remained unaware of the cardiac condition. The ICU attending, after stabilizing the patient went home and was in communication with the resident throughout the night. The resident assumed that the attending was aware of the cardiac condition. In the morning, the child suffered a cardiac arrest and died.

Initially the situation in the case may be seen as caused by the lack of oversight by individual members of the care team. Application of communication theory principles can aid in understanding the mechanism of communication lapse in this case more clearly.

Theoretical Considerations

In the not so distant past, healthcare relied less on team work than is current practice. Hospitals were smaller, largely physician centric enterprises. Recently, increasing emphasis on specialization and emergence of chronic diseases and ageing patients with multiple medical conditions have transformed medicine into a process that demands complex teamwork. Several challenges result from this development. Unlike other HROs such as aviation and nuclear power, the medical team composition is highly heterogeneous and dynamic. The team members possess extremely diverse educational backgrounds, educational cultures and at times, conflicting ideologies. Different units in the same hospital often function autonomously and may have different organizational cultures. Operating within the confines of these differences, a modern hospital is required to deliver exemplary care for its patients.

Caring for patients with multiple conditions is a complex process - several teams are often involved, a substantial amount of data of numerous types are generated; information needs to reach the correct team and team member at the right time and place. Information in healthcare is not homogenous. Data can be quantitative (e.g., white blood count), qualitative (the patient looks sick) or synthetic (a combination of quantitative and qualitative data). Medical information can be made redundant at times (e.g., changing biomedical parameters) or remain relevant throughout the patient's history. Much of the data are synthetic, i.e. a combination of two or more data types. Data can also be presented as time series to show the progression of disease or condition as for example, blood glucose values over time.

Information processing by computing devices can alter the presentation and communication of data. For instance, where once a team member had to compare a process parameter with its set-point, an advanced technical system can instead (or additionally) provide an alarm sound or a flashing light to indicate that this parameter has exceeded the set-point. An example of this

would be rate of oxygen saturation below 91% for a patient in the ICU. When the computer transforms the low-level quantitative value of the parameter into a higher-level qualitative state, the task of the team member is changed, from the observation and calculation of quantitative values to mere identification of qualitative indications.

Application of Systems Theory Principles

A hospital needs to be considered as a system made up of several individual units that interrelate with one another based on the shared goal of the patient's welfare. In the case which is discussed, the cardiology, surgery and ICU units are the subsystems. In other words, these three subsystems are embedded within the larger hospital system. Consistent with systems theory principle, each of the three subsystems has its own objects (team members) and attributes (culture). Once this distinction of objects and attributes is made, it is necessary to ascertain how the internal relationships among the units are processed by the system. Translating to the case, it means that the hospital needs to ascertain how the individual departments will communicate and coordinate the care of a patient under their combined care.

The hospital also needs to be clear who (i.e., which unit) will play the anchor role, making sure that critical information is given to the other units involved. This characteristic of the anchor role is a crucial defining the quality of systems and the primary theme in the model of communications performed by participants involved in the care of the patient. The prime objective of hospital communication is to create a shared mental model of the patient's care among the teams and their members. For the shared mental model to emerge, it is necessary that the subsystems be unambiguous about their own role and the units are kept informed assertively about changes in a patient's condition or situation.

The surgery department, but subsequently needed inputs from ICU and cardiology, admitted the patient. Surgery, being the admitting department, likely needed to play the pivotal anchor role in the case. As the patient progressed through the system, involving more teams, it became unclear who or what unit was actually coordinating the care beyond the point of referrals.

The attending surgeon and cardiologist were only briefed on the initial respiratory distress and did not have a complete picture of the child's condition. Similarly, the ICU attending focused on stabilizing the child's respiratory status and missed his low cardiac output. The resident physicians and nursing staff were confused about who was coordinating the child's care. They also had a lack of awareness of how to ensure effective team communication when multiple attending physicians were involved in caring for the child. The residents and nurses noted that having the ICU attending physician at the bedside left them with the impression that the surgeon and cardiologist were being updated about the child's continuing deterioration. The nurse observed the resident on the phone frequently discussing the case, and did not realize that neither he nor his peers were communicating with the other physicians involved. The resident and nurse either did not recognize the need to escalate the case beyond the ICU attending, or were not

comfortable doing so. The surgeon and cardiologist were under the impression the child's issues were respiratory, not multi-system, and because of this, as well as the belief that the attending ICU physician was in-house throughout the night, neither of them recognized a need to go to the hospital to evaluate the child. Information about the child's condition was present in the system but was not transmitted to all concerned.

Information theory provides a theoretical approach to understand a few other dimensions of the problem.

Information Theory

In information theory, every system is associated with a level of entropy (unpredictability). The amount of information as well as the number of messages needed to completely reduce uncertainty is inversely proportional to the level of entropy. That means higher the level of unpredictability; the more information is needed to eliminate uncertainty. Hospitals as a whole can be postulated to have high levels of unpredictability and hence more information is needed to keep the system in homeostasis. In the case of the youngster described above, the amount of entropy was high; the patient was a young child who had to undergo a complex surgical procedure and later developed respiratory and cardiac conditions, a complex situation which has less tolerance for improper information flow. Naturally, the amount of information needed by the teams to keep the child stable was high, hence the need for a large the number of messages was also high. It could be argued that more than the number of messages or content, context was the critical factor in the management of the case.

Network Theory

Network theory can also help us understand the case study. Network theory states that information within an organization can be absolute or distributed. Questions of absolute information deal with what is known while questions of distributed information deal with who knows it. The fact that information is present in an organization does not guarantee that it will be communicated adequately. The practical implication of network theory is that failures in distribution policies are due to failures by team leaders to identify which groups of people need to know certain things, or to establish where and how these groups are able to obtain the information they need. Many organizations fail to understand who should know which piece of the information and how each one should obtain the information. In the present case, the system contained enough information that might have possibly prevented the cardiac failure but no one was in control of who got what information and when.

Convergence Theory, Cultural Model

The number of members in the care team in such complex cases can be high. It is not known how many were involved in this particular case but in a recent article in the NewYorker, Atul Gawande had stated that 63 people (19 doctors, 23 nurses, 5 physical therapists, 16 patient care

assistants, radiology technician, ward boys) were involved in the care of his mother who underwent a knee replacement[103]. Each team involved in the present case (ICU, cardiology and surgery) consisted of a wide variety of professionals in established hierarchical structures. The organizational cultures of the teams can be analyzed using the three layers of the Schein's cultural model.

Artifacts and behaviors make the outermost layer of Schein's model. This layer consists of the way each group is seen, heard or perceived. ICU physicians, surgeons and cardiologists have their own set of artifacts and behaviors. The second layer in Schein's model is espoused values. These are the values which each set of individuals support. The third layer is basic assumptions, a set of fundamental beliefs which are engraved on to the collective inner psyche of each group. Being trained in highly specialized and unique educational systems, ICU physicians, nurses, surgeons and others may foster their own set of assumptions based on their priorities and espoused values. Values and assumptions are also derived from the opinion leaders of each group.

It is possible that the layers of each group were in conflict with those of the other. Moreover, organizational culture of such teams does not expect members of lower hierarchy to be assertive and confirm the registration of particular pieces of information. In the case, nurses and residents were reluctant to confirm whether the doctors had the necessary information. Both the nurses and residents were more comfortable in assuming that the attendings were in communication with each other. It is indicative of a closed system in which member's communication with each other is predominant than information exchange with external groups. Convergence theory states that in such systems, divergence will occur until a state of disarray ensues.

The stratification of professional groups inside hospitals raises the point of how to approach communication in such a chaotic unstructured group of subsystems. Socio-technical theory and the systemic interaction model might prove to be helpful. The first step in understanding should be to accept that the hospital is a socio-technical system where human to human and human to system/technological interactions take place. Communication in such systems should be analyzed as a whole to understand it. The mechanical model of communication which perceives communication as the sum total of all individual interactions does not represent complex systemic processes. Under the systemic model, communication process determines organizational behavior and not the other way round. To conclude, it was necessary for the care teams involved to undertake processes that reduced redundancy, improved situational awareness and used communication within themselves and with other stakeholders to reduce the uncertainty and to achieve a shared mental model of the patient's condition and treatment options. Each of the teams individually performed what they were intended to, but failed to work together as a system.

It must be noted here that this case demonstrates that providing advanced communication tools such as cell phones and pagers is only one step in the right direction. For maximizing the benefits

of such devices of hospitals need to move to a system mode from a rather mechanical exchange of communication.

Analysis

It was not the absence of information, communication tools or expertise that precipitated the loss of life of the child in the present case. Our ability to learn from the situation lies in carefully analyzing the information flow in the operational processes.

We are proposing the use of the H-H-S frame work (Human-Human-System Framework) previously used in nuclear power plants to evaluate and understand the case. The tool is chosen because, although not explicitly mentioned in the web M&M, large hospitals today are highly complex socio-technical systems where technology is a crucial component in the system. Human-to-human and human-to-system interactions need to be assessed to arrive at solutions. In hospitals, information management is supported by technological tools such as EMR systems and modern communication devices. From a system perspective, the way technology interacts with humans can have profound effects on the information flow and management.

Chung has argued that we need to extend the conventional framework for human–human communication analysis to include the information processed by the technical system. Advanced information processing by the system not only changes the characteristics of communication within the team, but also makes the analysis of human–human communication separately from the system's information processing pointless, because the communication between humans is only a portion of the total information flow[105].

The H–H–S framework is based on the decision-making model, and can be used to analyze team communication in depth, including the 'shifting' phenomenon that results from system information processing.

The first step in using the H-H-S model is to prepare a graphical illustration of information flow between the team members and the system in the context of a typically complex case such as the present one. It is common practice to use EMR systems and mobile communications as the means to facilitate the development of a shared mental model of a patient as required for managing such cases. However, EMRs were not designed to be communication tools, they were primarily designed to improve record keeping and archiving. Information flow diagrams for two distinct scenarios need to be created. Scenario A is reflective of co-working pattern where team members receive information from the system which they will pass on to another person. In this case, the term "system" represents the paper medical record and any other artifact used for information sharing in hospitals (analog white boards, for example).

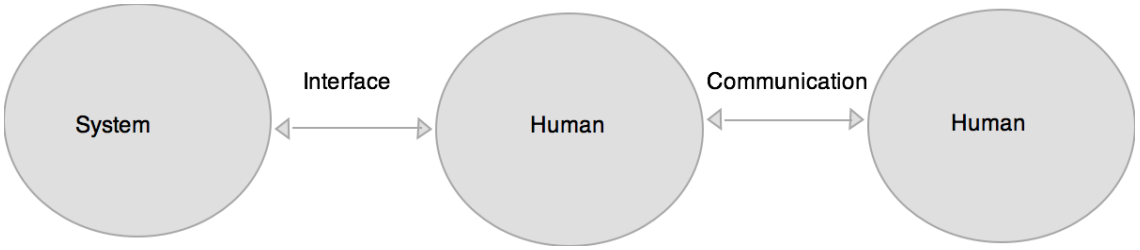

Figure 1: Information Flow Pattern A
Figure adapted from: Chung, YH, WC Yoon, and D Min[105]

Communication in such cases is presumed to be face-to-face or direct telephone consultation with feedback.

In the case of Scenario B, all team members (or teams) have access to the same information. In this case, system represents the hospital wide EMR.

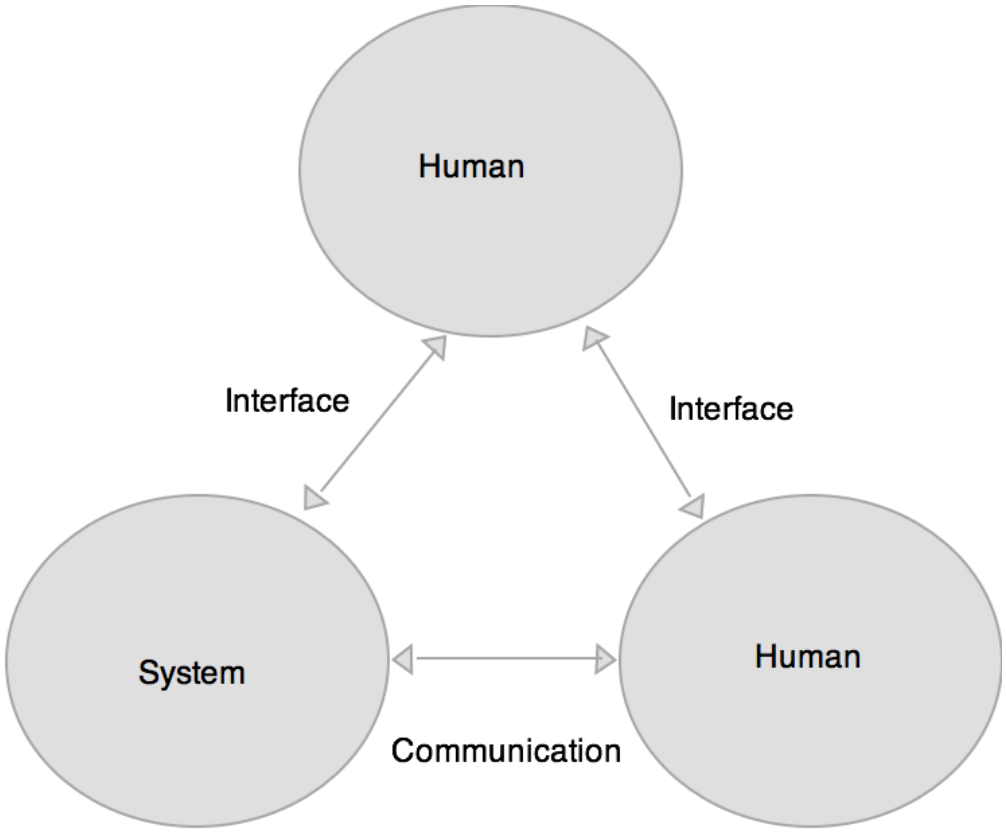

Figure 10: Information Flow Pattern B
Figure adapted from: Chung, YH, WC Yoon, and D Min (2009)[105]

And communication will involve greater amounts of electronic messaging via email, e-referrals, e-prescriptions, mobile devices, and automated responses.

A transcript of conversation between the teams and between team members needs to be made for analysis. Components of the conversation will be then categorized into the types of decision-

making behavior according to Rasmussen's decision ladder. Rasmussen divided decision-making behavior of humans into 8 stages. Chung et al used a simplified version of it. They recognized the following types of behaviors: intention, call, command, acknowledgement, reply, enquiry, announcement and suggestion.

The information flow diagrams will help in diagnosing whether a shift in communication has occurred. This shifting can be observed by mapping the information flow during various stages of the operational process. Next we need to find where exactly the shift occurs. That is where the H-H-S instrument is used. In the absence of such a tool, schematic diagrams need to be made for the study of entire set of interactions. The diagrams will be complex and difficult to analyze. The tool is intended to convert the text in to analyzable framework. A sample H-H-S tool intended for nuclear power reactors is shown below.

Time	State Assessment				State Assessment				Task Planning			
	SA	Det	Message	Abs.	SA	Obs	Message	Abs.	TP	Exe	Message	Abs.
02:00									SS		[We'll perform SPTA]	
02:04					SS		RO, verify reactor trip and start-up rate.					
02:09										SS	Stop EDG and maintain standby state.	Deabs Proc*
02:15										EO	Yepp.	
02:16					SS		Verify the primary pressure and temperature.					
02:16						EO	The wide range pressure of containment is 529.8 cmH2O and the temperature is 73℃					
02:22						SS	Did the turbine generator trip, TO?	Deabs				
02:27						TO	Yes.					
					RO		Stop conditions of HPSI pump are met.	Abs Sys*				
	Detection				Observation				Execution			

Figure 11: H-H-S Framework

Figure source: Chung YH, Yoon WC, Min D.(2009)[105]

(SS- shift supervisor; BO- board operator; RO – reactor operator; TO – turbine operator; EO – emergency operator).

The time axis is to time stamp the conversation. Three boxes are next to the time axis. Each box represents a communication path or channel. These channels are identified from the transcript based on the decision-making behavior type of the conversation. Analysis will identify one or more of the members as decision makers and others as those who execute the decision or provide information to the decision maker. In the case of nuclear power plants, three paths were identified: state assessment - detection, state assessment - observation and task planning - execution. Each path corresponds to message flows between the simplified cognition stages. That is, each path has its own message types and meaning for team communication. The H–H–S framework uses communication paths between the decision-maker and the assistants and incorporates elements such as the time frame and the speaking subject in order to supplement the analysis results on the data sheet.

Each communication path is described with four columns: two for the speaking subject, the communication message, and an indication of abstraction. The third column of each communication path contains the actual message.

The fourth column, 'Abstraction' shows whether abstraction or de-abstraction has occurred. Abstraction means information was processed by technical system and presented to the team member. The presence of information shared among the team members is indicated with an asterisk. Analysis of the transcript using this framework will help to locate where the 'shift' in communication occurred. The H–H–S framework is also useful for characterizing communication problems such as control jumps without responses because a transcript transformed with the H–H–S framework clearly shows the cognitive stages and the message flow. The number of threads in the analysis is also an indicator of workload.

Proposed Steps in Analysis

The chronology of events is an important first step. See Table 12.

Table 12

Number	Event	Care team
Day 1	Child admitted to hospital for surgery	Surgery
Day 1	Surgeon performs Fontan surgical procedure for hypoplastic left heart syndrome	Surgery
Day 1	Child is recovering well	Surgery
Day 2	Child weaned from inotropic support and tolerates enteral liquids	Surgery, ICU
Day 2 evening	Child develops respiratory distress with acidosis and fever	Surgery, ICU
Day 2 evening	The resident physician notifies the on-call ICU attending	Surgery, ICU
Day 2 evening	ICU attending comes from home to care for patient	Surgery, ICU
Day 2 midnight	The surgeon calls from home to check on the child at midnight, speaks with the resident, who indicated that the child had suffered respiratory deterioration and that the ICU attending was at the bedside managing the patient.	ICU, Surgery,Cardiology
Day 2 midnight	Surgeon orders an echocardiogram	ICU, Surgery,Cardiology
Day 2 midnight	Cardiology fellow performs ECG	ICU, Surgery,Cardiology
Day 2 midnight	ECG result communicated to surgeon, the admitting doctor`	ICU, Surgery,Cardiology
Day 2 late night	ICU attending returned home after stabilizing child	ICU, Surgery,Cardiology
Day 2 late night – early morning	Child not improving as expected; ICU resident communicates with ICU attending via phone, pager	ICU, Surgery,Cardiology
Day 3 morning	The child suffers a cardiac arrest	ICU, Surgery,Cardiology
Day 3 morning	Child dies despite resuscitation attempt.	ICU, Surgery,Cardiology

The next steps are preparing transcript of the conversations, identifying communication paths and application of HHS framework.

SUMMARY AND DISCUSSION

Anything powerful enough to heal can harm too. The case of medicine is a perfect example for this. In Canada, 7.5% of all hospital admissions were reported to be associated with an AE. Medical errors are said to cause 9,250 to 23,750 deaths in Canada and between 44-98,000 deaths in USA[7]. One out of 9 adults and 11 children contract a nosocomial infection during their hospital stay. Medical errors are costly not only in terms of harm to patients but also financial. Although precise data for communication errors is not yet available, different estimates have attributed loss of 8 to 29 billion USD annually due to medical errors in US[7,10]. Medical errors can be caused by systemic or human errors.

Faulty communication is the most common reason for sentinel events. Good communication between the members of healthcare team is vital for safety and wellbeing of the patient. As much as 20% of medication errors, 21% to 65% of discharge and hand over errors have been attributed to erroneous communication[10,22] . Despite substantial efforts to improve the safety of healthcare after the IMO report, faulty communication is reported to be the reason for two-third of all sentinel events[21].

Communication is critical in several other sectors such as aviation, defense and nuclear power generation. A pilot error or a mistake by a nuclear plant operator can cause heavy casualty. However, each of those industries is much safer than in the past. A notable difference in approach towards safety of medicine and those professions is that unlike them medicine is yet to base their communication improvement efforts on solid theoretical foundation.

This scoping review was undertaken to collect and compare communication theories, models, frameworks that have been used in the fields of aviation, nuclear power and defense as well as basic science and applied science domains such as cognitive psychology, human factors engineering, organizational behavior, sociology, and communication sciences. Particular attention was given towards those theories and models applicable to inter-professional communication in hospitals with the use of new ICT devices. The scoping review framework was complimented by intensive hand searching.

Fourteen theories and 12 models were deemed relevant to the aims and were included. Tables 3 and 4 lists the theories and models respectively. Acknowledging that tasks in medicine are essentially cognitive, relevant cognitive psychology concepts were explained as a precursor to the discussion of theories and models.

Application of the selected theories and models serve to clarify the complexity of hospital communication. Hospitals may be considered as a large socio-technical system made up of inter related subsystems (individual departments) with their own set of objects, attributes and culture.

The aim of communication systems should be to create a shared mental model of the patient's condition among the members of various teams which are involved in his or her care. Information is present within each subsystem as distributed. Mere presence of information doesn't mean that it reaches whoever it has to. Trying to integrate the functioning of the subsystems unmindful of their unique attributes might lead to failure. Not only that, the system (hospital) as a whole need to be flexible with some amount of redundancy built in. Designers need to be aware of the utility of various artifacts (example - white boards in emergency rooms) in the functioning of the system. If communication systems function primarily as means to dump information, cognitive overload and fatigue can be two undesirable effects. Instead, context needs to be conveyed and information should be transmitted in such ways that it reaches only the members who require to be informed. It is also important to develop mechanisms to let team members acknowledge the received message. There is evidence to show that communication error occur at the interface of transition from one point to another or between teams. Therefore, designers need to be cognizant of the fact that any study of information flow needs to be conducted across the entire continuum of care[114]. This will increase the utility of the communication intervention in question. Whenever possible, procedural complexity should be reduced so that errors resulting from increased complexity can be reduced[115].

A large number of methods used by the safety critical fields within the scope of this review were identified during the review process. To illustrate the utility of using error analysis methods based on a solid theoretical foundation a case study was proposed. In the case study section, an instance of faulty communication between care teams resulting in the death of a child has been described and analyzed. Relevant theories were applied to the situation to analyze the problem. It was obvious that it was not the absence of information, communication devices or expertise was behind the failure to prevent the cardiac arrest. The H-H-S framework was proposed for the analysis of the problem because it contains methods to analyze both human-human as well as human - technology information flow. Previously used in nuclear power industry, the tool helps to find out where the 'shift' in information occurred[105].

CONCLUSION

The present review was able to identify 14 theories, 12 models and 12 communication analysis methods from the basic science domains like cognitive psychology, communication science, and organizational behavior and from HROs such as aviation, nuclear power generation and defense. It is not known how well those theories, models and analysis methods can be adapted to medicine. Future research may be able to address the issue. However, it can be argued that it is time for medicine to move to a system based research to improve its communication problems.

It is also proposed that eHealth researchers adopt theories and models to hospital communication research, modifying existing theories and models to suit the unique requirements of hospitals or by developing a strategy to design them de-novo.

Appendix: Search Terms and Strings Used in Systematic Search

Database	Date	Keyword / combination
OVID Medline 1948 -Oct 2 week 2011		Communication exp Mesh
		Health facility exp Mesh
		Telephone.tw.
		Communication exp Mesh AND Health facility exp Mesh AND Telephone.tw.
OVID Medline 1948 -Oct 2 week 2011		Communication exp Mesh
		Health facility exp Mesh
		Cell phone.tw.
		Communication exp Mesh AND Health facility exp Mesh AND Cell phone.tw.
		Mobile phone.tw.
		Communication exp Mesh AND Health facility exp Mesh AND Mobile phone.tw.
		iPhone.tw.
		Communication exp Mesh AND Health facility exp Mesh AND iPhone.tw.
		Communication exp Mesh AND iPhone.tw.
		Communication exp Mesh AND Mobile Phone.tw.
		iPad.tw.
		Communication exp Mesh AND Health facility exp Mesh AND iPad.tw.
		Communication exp Mesh AND iPad.tw.
		Health facility exp Mesh AND Cell phone.tw.
		Internet exp Mesh
		Communication exp Mesh AND Health facility exp Mesh AND Internet exp Mesh
		Communication exp Mesh AND Internet exp Mesh
		Health facility exp Mesh AND Internet exp Mesh
		personal digital device.tw.
		tablet computer:.tw.
		Communication exp Mesh AND Health facility exp Mesh AND tablet computer:.tw.
		tablet computer.tw.
		Communication exp Mesh AND Health facility exp Mesh AND tablet computer.tw.
		exp Telephone

Database	Date	Keyword / combination
		Communication exp Mesh AND Health facility exp Mesh AND Telephoneexp Mesh
		exp Medical Informatics
		Communication exp Mesh AND Health facility exp Mesh AND Medical Informatics expMesh
		Videoconferencing exp Mesh
		Communication exp Mesh AND Health facility exp Mesh AND Videoconferencing exp Mesh
		Hospital communication systems.sh.
		Communication exp Mesh AND Health facility exp Mesh AND Hospital communication systems.sh.
		Internet.sh
		Communication exp Mesh AND Health facility exp Mesh AND Internet.sh
		handheld.sh.
		Computers, handheld.sh.
		Communication exp Mesh AND Health facility exp Mesh ANDComputers, handheld.sh.
		Psychological Theory/ or Systems Theory/ or Theories.mp. or "Theory of Mind"/
		Communication exp Mesh AND Health facility exp Mesh ANDPsychological Theory/ or Systems Theory/ or Theories.mp. or "Theory of Mind"/
		exp Models, Theoretical/
		Communication exp Mesh AND Health facility exp Mesh AND exp Models, Theoretical/
OVID Medline 1948 -Oct 2 week 2011	21-Oct	exp Nuclear Reactors/ or exp Nuclear Power Plants/
		exp Communication/ANDexp Nuclear Reactors/ or exp Nuclear Power Plants/
		exp Aviation/ or exp Accidents, Aviation/
		exp Communication/ANDexp Aviation/ or exp Accidents, Aviation/
		Civil defense.sh.
		Civil defense.sh.ANDexp Communication
		Military personnel.sh.
		Military personnel.sh.ANDexp Communication
		exp Medical Informatics/
		Telephone.tw.
		exp Medical Informatics/ANDTelephone.tw.

Database	Date	Keyword / combination
Psycinfo1806-2011 Oct	22-Oct	exp Communication/
		exp Hospitals/
		exp Telephone Systems/
		exp Communication/AND exp Hospitals/ANDexp Telephone Systems/
		exp Telephone Systems/AND exp Hospitals/
		exp Telephone Systems/AND exp Communication/
		telephone.tw.
		exp Communication/AND exp Hospitals/ANDtelephone.tw.
		exp Cellular Phones/
		exp Communication/AND exp Hospitals/ANDexp Cellular Phones/
		cell phone.tw.
		exp Communication/AND exp Hospitals/ANDcell phone.tw.
		cellphone.tw.ANDexp Hospitals/
		iPhone.tw.
		exp Internet/
		exp Communication/AND exp Hospitals/ANDexp Internet/
		exp Theories/
		exp Theories/ANDexp Communication/
		exp Theories/ANDexp Communication/ANDexp Hospitals/
		exp Scientific Communication/
		exp Scientific Communication/ANDexp Theories/
		exp Nuclear Technology/
		exp Nuclear Technology/ANDexp Communication/
		exp aviation/
		exp aviation/ANDexp Communication/
		exp Communication Theory/
		expwarANDexp Communication
Engineering village -		(({human factors} AND {hospitals}) WN CV), Journal article only
Embase 1980-2011		exp interpersonal communication/
		exp hospital personnel/

Database	Date		Keyword / combination
			exp mobile phone/ or cellphone.mp. orexp telephone/
			exp mobile phone/ or cellphone.mp. orexp telephone ANDexp hospital personnel/
			exp hospital personnel/ AND exp interpersonal communication/
CINAHL		Boolean/Phrase	(MM "Communication+")
			(MM "Health Facilities+")
		Filter - Nursing, ICU, Hospital, Patient safety	(MM "Communication+")AND(MM "Health Facilities+")
			(MM "Communication+")AND(MM "Health Facilities+")
			(MH "Aviation+")
			(MH "Accidents, Aviation")
			(MH "Communication+")
			(MH "Aviation+") OR(MH "Accidents, Aviation")
			(MH "Communication+")AND((MH "Aviation+") OR(MH "Accidents, Aviation"))
			((MH "Hospitals+"))OR (MM "Telephone") OR (MM "Wireless Communications")
			(MH "Hospitals+")
			((MH "Hospitals+"))AND9 (MM "Telephone") OR (MM "Wireless Communications")
			AB Team work
			(AB Team work) AND(MH "Communication+")
			"COMMUNICATION THEORY"
			(MH "Models, Theoretical+")
			((MH "Models, Theoretical+")) and(MH "Communication+")
			((MH "Models, Theoretical+")) and(MH "Communication+")AND(MH "Hospitals+")
			(MH "Conceptual Framework")
			(MH "Conceptual Framework")AND(MH "Communication+")
			(MH "Nurses+") AND(MH "Conceptual Framework")AND(MH "Communication+")
			(MW Evaluation)
			((MW EvaluationAND)(MH "Nurses+")) AND(MH "Conceptual Framework")AND(MH "Communication+")

Database	Date		Keyword / combination
Military and Intelligence Data base			Keyword (communication) LIMITS: Peer-Reviewed And Subject ("Organizational communication")
Psycarticles			(SU.exact("COMMUNICATION")) AND cabs(aviation)
Compendex			communicationAND"Nuclear power plants" AND Theory
Military and Intelligence Data base	28-Oct		communication
			Communicationmodel!
		Limit - Interpersonal communication	Communicationmodel!
		Limit - organizational communication	Communicationmodel!
		Limit -Physician	Communicationmodel!
			"COMMUNICATION THEORY"
		Limit - Information theory	"COMMUNICATION THEORY"
			Nuclear power plants AND communication*
Ovid - Embase			exp interpersonal communication/
			Health facility exp Mesh
			Telephone.tw.
			Telephone.tw.AND Health facility exp MeshANDTelephone.tw.
		Limit - Embase	Telephone.tw.AND Health facility exp MeshANDTelephone.tw.
			exp aviation/
			exp aviation/ANDTelephone.tw
			exp civil defense/
			exp civil defense/AND exp interpersonal communication/
			exp nuclear reactor/
			exp nuclear reactor/AND exp interpersonal communication/
			exp soldier/
		Limit - Embase	exp soldier/ANDexp interpersonal communication/
			navy.tw
			matine.tw.

Database	Date	Keyword / combination
		navy.tw.ANDexp interpersonal communication/
		Nuclear reactor:.tw.
		Air transport:.tw.
		Military.tw.
		coast guard.tw.
		airforce.tw.
		airforce.tw.ORcoastguard.tw.ORAir transport:.tw.ORMilitary.tw.ANDexp interpersonal communication/
		Information theory.sh.
		exp theoretical model/
		exp interpersonal communication/ANDexp theoretical model/ANDHealth facility exp
		exp conceptual framework/
		exp interpersonal communication/ANDexp conceptual framework/ANDHealth facility exp
		Exp videoconferencing
		ExpvideoconferencingANDHealth facility exp
		Wireless technology.sh.
		exp mobile phone/ or I-PHONE.mp.
		exp mobile phone/ or I-PHONE.mp.ANDexp interpersonal communication/
		smart phone.mp.
		pager.tw.
		iPad.tw.
		cell phone.tw.
		cellphone.tw.ANDHealth facility exp Mesh
IEEE		Communication errors in aviation
Scholar's portal		Communication AND error
		Communication AND Nuclear Power Plant AND analysis
		Communication AND Nuclear Plant
		Information theory
		organization*ANDcommunication theory
Wilson web		COMMUNICATION <In> Title AND AVIATION <In> Keyword AND
Business source complete	Narrow by SubjectThesaurus: - COMMUNICATION in organizations	communication model

Database	Date		Keyword / combination
		Limiters - Scholarly (Peer Reviewed) Journals	
The International Journal of Aviation Psychology		Hand search	
Google scholar			Effect of cellphone on organizational communication
international Journal of Human-Computer Interaction		Hand search	tablet computers
			mobile phone
			smart phone
			hand held
Proquest			ab(communication) AND su.EXACT("Analysis") AND su.EXACT("Communication" OR "Business communications" OR "Instant messaging" OR "Electronic mail systems" OR "Voice messaging systems")
			(EXACT("Task analysis")) AND su.EXACT("Communication")
		Limits saved in to the folder	cabs(computer mediated communication)
OVID Health and psychosocial instruments			communication.mp. [mp=title, acronym, descriptors, measure descriptors, sample descriptors, abstract, source]
			analysis.mp. [mp=title, acronym, descriptors, measure descriptors, sample descriptors, abstract, source]
			analysis.mp. ANDcommunication.mp.
ACM Special interest group - Human-comp interaction			communication
Journal of loss prevention			safety culture
Tayler and francis			Communication (Title)
computers in human behavior			Communication (Title)AND theory AND framework
Cognitive systems research			Communication (Title)

Database	Date	Keyword / combination
		cOMMUNICATION and Theory (Both in abstract) communication AND analysis(Both in abstract)
Human Resource Management Review		Communication (Anywhere)
Science Direct		Communication AND Theory (both in Title or Abstract or keywords)
Computer Supported Cooperative Work	Hand search	Communication

LIST OF ABBREVIATIONS

ADE - Adverse Drug Event
AE -Adverse Events
AHRQ -Agency for Healthcare Research and Quality
AIDS - Acquired Immunity Deficiency Syndrome.
C3TRACE - Command, Control, and Communication Techniques for Reliable Assessment of Concept Execution
CATS - Communication and Teamwork Skills
CBR - Case Based Reasoning
CEAM - CREAM-based Communication Error Analysis Method
CREAM -Cognitive Reliability Error Analysis Method
CRM -Crew Resource Management
CSP - Cognitive Speaking Process
CWA - Cognitive Work Analysis
HCI - Human Computer Interaction
HIV - Human Immune Virus
HRO - High Risk Organization
ICT- Information and Communication Technology
ICU - Intensive Care Unit
IOM - Institute of Medicine
JCAHO - Joint Commission on Accreditations of Healthcare Organizations
LIWC -Linguistic Inquiry and Word Count
LTM - Long Term Memory
MIDAS - Man-Machine Integration Design and Analysis Systems
MRM - Multiple Resource Model
PDA – Personal Digital Assistant
RAM - Random Access Memory
STM - Short Term Memory
U.S. - United States

REFERENCES

1. Perrow C. Normal accidents: Living with high-risk technologies. Princeton Univ Pr; 1984.
1. Ellis PB. The great fire of London: an illustrated account. New English Library; 1976.
2. Crosby AW. America's forgotten pandemic: the influenza of 1918. Cambridge Univ Pr; 2003.
3. Clarisse. Difference Between 2004 Tsunami and 2011 Tsunami [Internet]. 2011[updated March 15 2011; cited May 29 2012]. Available from: http://www.differencebetween.com/difference-between-2004-tsunami-and-vs-2011-tsunami/
4. Brennan TA, Leape LL, Laird N et al. Incidence of adverse events and negligence in hospitalized patients: results of the Harvard Medical Practice Study I. Qual Saf Health Care. 2004;13(2):145-151.
5. Brennan TA, Leape LL, Laird NM et al. Incidence of adverse events and negligence in hospitalized patients. N Engl J Med. 1991;324(6):370-376.
6. Institute Of Medicine. To Err Is Human: Building a Safer Health System. National Academies Press. 1999;1-312.
7. Nordenberg T. Make no mistake: Medical errors can be deadly serious. FDA Consumer. 2000;34(5).
8. Baker GR, Norton PG, Flintoft V et al. The Canadian Adverse Events Study: the incidence of adverse events among hospital patients in Canada. CMAJ. 2004;170(11):1678-1686.
9. Kondro W. Canadian report quantifies cost of medical errors. The Lancet. 2004;363(9426):2059.
10. Altman DE, Clancy C, Blendon RJ. Improving patient safety—five years after the IOM report. N Engl J Med. 2004;351(20):2041-2043.
11. Stelfox HT, Palmisani S, Scurlock C, Orav E, Bates D. The "To Err is Human" report and the patient safety literature. Qual Saf Health Care. 2006;15(3):174-178.
12. Handler SM, Nace DA, Studenski SA, Fridsma DB. Medication error reporting in long term care. Am J Geriatr Pharmacother. 2004;2(3):190-196.
13. Antonow JA, Smith AB, Silver MP. Medication error reporting: a survey of nursing staff. J Nurs Care Qual. 2000;15(1):42-48.
14. Barach P, Small SD. Reporting and preventing medical mishaps: lessons from non-medical near miss reporting systems. BMJ. 2000;320(7237):759-763.
15. Henriksen K, Battles JB, Keyes MA et al. Improving Clinical Communication and Patient Safety: Clinician-Recommended Solutions. Agency for Healthcare Research and Quality (US); 2008.
16. Kaissi A, Johnson T, Kirschbaum MS. Measuring teamwork and patient safety attitudes of high-risk areas. Nurs Economics. 2003;21(5):211-218.
17. Kesten K. Role-play using SBAR technique to improve observed communication skills in senior nursing students. J Nurs Educ. 2010;50(2):79-87.
18. Coiera E. When conversation is better than computation. J Am Med Inform Assoc. 2000 ; 7(3): 277–286.
19. Bogenstatter Y, Tschan F, Semmer NK, Spychiger M, Breuer M, Marsch S. How Accurate Is Information Transmitted to Medical Professionals Joining a Medical Emergency? A Simulator Study. Hum. Factors. 2009;51(2):115-125.

20. Joint Commission. Sentinel Event Data-Root Causes by Event Type 2004-Fourth Quarter 2010[Internet]. 2011[cited 2012 March 12].Available from: http://www.jointcommission.org/Sentinel_Event_Statistics/
21. Ford CD, Killebrew J, Fugitt P, Jacobsen J, Prystas EM. Study of medication errors on a community hospital oncology ward. J Oncol Pract. 2006;2(4):149-154.
22. Bates K, Beddy D, Whirisky C, Murphy MO, Mahony J, Mealy K. Determining the frequency of prescription errors in an Irish hospital. Ir J Med Sci. 2010;179(2):183-186.
23. Hartel MJ, Staub LP, Reeder C, Eggli S. High incidence of medication documentation errors in a Swiss university hospital due to the handwritten prescription process. BMC Health Services Research. 2011;11(1):199.
24. Caplan J. Cause of Death: Sloppy Doctors. Time. 2007 Sep ;Sect. 79.
25. 26. AHRQ. Cases & Commentaries. 2012; [citedMay 29 2012] Available from: http://www.webmm.ahrq.gov/home.aspx
26. Kripalani S. What have we learned about safe hand overs? Web M&M. 2011. [cited May 29] Available from: www.webmm.ahrq.gov/perspective.aspx?perspectiveID=100
27. Avtgis TA, Polack EP, Martin MM, Rossi D. Improve the communication, decrease the distance: the investigation into problematic communication and delays in inter-hospital transfer of rural trauma patients. Commun Educ. 2010;59(3):282-293.
28. Haig KM, Sutton S, Whittington J. SBAR: A shared mental model for improving communication between clinicians.Jt Comm J Qual Patient Sa. 2006;32(3):167-175.
29. Lardner R. Effective shift handover A literature review. Offshore Technology Report-Health And Safety Executive. 1996.
30. Cheung DS, Kelly JJ, Beach C et al. Improving handoffs in the emergency department. Ann Emerg Med. 2010;55(2):171-180.
31. Arora VM, Manjarrez E, Dressler DD, Basaviah P, Halasyamani L, Kripalani S. Hospitalist handoffs: a systematic review and task force recommendations. J Hosp Med. 2009;4(7):433-440.
32. Haller G, Laroche T, Clergue F. Undesirable events during the perioperative period and communication deficiencies. Ann Fr Anesth Reanim 2011(12):923-929.
33. Coiera E, Aarts J, Kulikowski C. The dangerous decade. J Am Med Inform Assoc. 2012;19(1):2-5.
34. Webster JL, Cao CGL. Lowering communication barriers in operating room technology. Hum Factors. 2006;48(4):747-758.
35. Roberts KH, Bea R, Bartles DL. Must Accidents Happen? Lessons from High-Reliability Organizations [and Executive Commentary]. The Academy of Management Executive (1993-2005). 2001;70-79. 37.
36. Haig KM, Sutton S, Whittington J. SBAR: A shared mental model for improving communication between clinicians. J Qual Patient Sa. 2006;32(3):167-175.
37. Horwitz LI, Detsky AS. Physician Communication in the 21st Century. J Am Med Inform Assoc. 2011;305(11):1128-1129.
38. Weick Sutcliffe A. Models of HRO. [Internet] 2012 [cited: Aug 12 2012]. Available at: http://high-reliability.org/pages/High-Reliability-Organizations
39. Lee P, Allen K, Daly M. A. Communication and Patient Safety-A training programme for all healthcare staff: can it make a difference?. BMJ Qual Saf. 2012;21(1):84-88.

40. Mutha S, Norman G, O'Neil E. Medical practice 2010: how we get there? West J Med. 2000;172(4):274.
41. Laxmisan A, Malhotra S, Keselman A, Johnson TR, Patel VL. Decisions about critical events in device-related scenarios as a function of expertise. J Biomed Inform. 2005;38(3):200-212.
42. Prince SB, Herrin DM. The role of information technology in healthcare communications, efficiency, and patient safety: Application and results. J Nurs Adm. 2007;37(4):184-187.
43. Vankipuram M, Kahol K, Cohen T. Patel V.L. Visualization and analysis of activities in critical care environments. AMIA Annual Symposium Proceedings. 2009.662.
44. International Civil Aviation Organization. Safety Management Manual (SMM). 2009.
45. Coiera E, Aarts J, Kulikowski C. The dangerous decade. J Am Med Inform Assoc. 2012;19 (1):2-5.
46. Classen DC, Pestotnik SL, Evans RS, Lloyd JF, Burke JP. Adverse drug events in hospitalized patients. J Am Med Inform Assoc. 1997;277(4):301-306.
47. Bates DW, Spell N, Cullen DJ et al. The costs of adverse drug events in hospitalized patients. J Am Med Inform Assoc. 1997;277(4):307-311.
48. Hug BL, Keohane C, Seger DL, Yoon C, Bates DW. The Costs of Adverse Drug Events in Community Hospitals. J Qual Patient Sa. 2012;38(3):120-126.
49. Zhan C, Miller MR. Excess length of stay, charges, and mortality attributable to medical injuries during hospitalization. J Am Med Inform Assoc. 2003; 290(14):1868-1874.
50. Suh DC,Woodall BS,Shin SK, Hermes-D Santis. Clinical And Economic Impact Of Adverse Drug Reactions In Hospitalized Patients. Ann Pharmacother. 2000; 34(12):1373-1379.
51. Kaushal R, Bates DW, Franz C, Soukup JR, Rothschild JM. Costs of adverse events in intensive care units. Crit Care Med. 2007;35(11):2479-2483.
52. Burton MM, Hope C, Murray MD, Hui S, Overhage JM. The cost of adverse drug events in ambulatory care. AMIA Annual Symposium proceedings. 2007;Oct 11:90-93.
53. Friedman CP. A fundamental theorem of biomedical informatics. J Am Med Inform Assoc. 2009;16(2):169-170.
54. D Levac, H Colquhoun, KK O'Brien. Scoping studies: advancing the methodology. Implement Sci. 2010;5:69.
55. Hopewell S, Clarke M, Lefebvre C, Scherer R. Handsearching versus electronic searching to identify reports of randomized trials. Cochrane Database Syst Rev. 2007;2.
56. HLWIKI International. Hand-searching [Internet]. 2012 [cited July 29 2012]. Available from: http://hlwiki.slais.ubc.ca/index.php/Hand-searching
57. Miller K. Communication Theories Perspectives, Processes and Contexts. Second ed. NewYork: McGraw-Hill; 2004.
58. Littlejohn SW, Foss KA. Theories of Human Communication. Wadsworth Pub Co; 2007.
59. Esgate A, Groome D, Baker K. An Introduction to Applied Cognitive Psychology. Psychology Pr; 2005.
60. Baddeley A. Working memory and language: an overview. J Commun Disord. 2003;36(3):189-208.
61. Johannsdottir KR, Herdman CM. The role of working memory in supporting drivers, A situation Awareness for Surrounding Traffic. Hum Factors. 2010;52(6):663-673.

62. Gonzalez VM, Mark G. Constant, constant, multi-tasking craziness: managing multiple working spheres. Proceedings of the SIGCHI conference on Human factors in computing systems. 2004;113-120.
63. Holden RJ. Cognitive performance-altering effects of electronic medical records: an application of the human factors paradigm for patient safety. Cogn Technol Work. 2011;13(1):11-29.
64. Bacharach SB. Organizational theories: Some criteria for evaluation. Acad Manage Rev. 1989;496-515.
65. Poole MS, Van De Ven AH. Using paradox to build management and organization theories. Acad Manage Rev. 1989;562-578.
66. Casimir.L Fred. Role of Theory and Theory building. In: L CF, editor. Building communication theories: a socio/cultural approach(1). New Jersey: Lawrence Erlbaum Associates; 1994. p. 7-46.
67. Laudan L. Progress and its problems: Towards a theory of scientific growth. Univ of California Pr; 1978.
68. Kuhn TS. The structure of scientific revolutions. University of Chicago press; 1996.
69. Mortensen CD. Communication: The study of human interaction. 1972.
70. Chapanis A. Men, machines, and models. Am Psychol. 1961;16(3):113.
71. Kaplan MF, Anderson NH. Information integration theory and reinforcement theory as approaches to interpersonal attraction. J Pers Soc Psychol. 1973;28(3):301-312.
72. Thompson DS, Estabrooks CA, Scott-Findlay S, Moore K, Wallin L. Interventions aimed at increasing research use in nursing: a systematic review. Implement Sci. 2007;2(1):15.
73. Scott P, Briggs J, Wyatt J, Georgiou A. How important is theory in health informatics? a survey of UK academics. Medical Informatics Europe. 2011;28-31.
74. Berg M, Toussaint P. The mantra of modeling and the forgotten powers of paper: a sociotechnical view on the development of process-oriented ICT in health care. Int J Med Inform. 2003;69(2-3):223-234.
75. Duldt B. 'I, thou' in Nursing: Research supporting duldt's theory. Perspect Psychiatr Care. 1991;27(3):5-12.
76. Miller K. Communication theories. NewYork:McGraw-Hill; 2002
77. Seeger MW. Chaos and crisis: Propositions for a general theory of crisis communication. Public Relations Review. 2002;28(4):329-337.
78. Seeger MW, Sellnow TL, Ulmer RR. Communication and organizational crisis. Praeger Publishers; 2003
79. Plsek PE, Greenhalgh T. The challenge of complexity in health care. BMJ. 2001;323(7313):625-628.
80. Arndt M, Bigelow B. Commentary: the potential of chaos theory and complexity theory for health services management. Health Care Manage Rev. 2000;25(1):35.
81. Covello VT, Peters RG, Wojtecki JG, Hyde RC. Risk communication, the West Nile virus epidemic, and bioterrorism: responding to the commnication challenges posed by the intentional or unintentional release of a pathogen in an urban setting. J Urban Health. 2001;78(2):382-391.
82. Sellnow TL, Ulmer RR, Seeger MW, Littlefield R. Effective risk communication: A message-centered approach. Springer Verlag; 2008

83. Chess C. Organizational theory and the stages of risk communication. Risk Anal. 2001;21(1):179-188.
84. Fischhoff B. Risk perception and communication unplugged: Twenty years of pszrocess. Risk analysis. 1995;15(2):137-145.
85. Carroll JM. Designing interaction: Psychology at the human-computer interface. Cambridge Univ Pr; 1991
86. Wears R, Perry S. Status boards in accident & emergency departments: support for shared cognition. Theor Issues Ergon. 2007;8(5):371-380.
87. Harris J, Henderson A,editors. A better mythology for system design. CHI'99 Proceedings of the SIGCHI conference on Human factors in computing systems: the CHI is the limit . ACM New York ;1999.
88. Westbrook JI, Braithwaite J, Georgiou A et al. Multimethod evaluation of information and communication technologies in health in the context of wicked problems and sociotechnical theory. J Am Med Info Assoc. 2007;14(6):746-755.
89. Wickens CD. Multiple resources and performance prediction. Theor Issues Ergon. 2002;3(2):159-177.
90. Wickens CD. Multiple resources and mental workload. Hum Factors. 2008;50(3):449-455.
91. Weaver S. Mathematical theory of communication. University Illinois Press; 1963
92. Church GM. The human-computer interface and information literacy: Some basics and beyond. Information Technology and Libraries. 1999;18(1):3-21.
93. Isaac A, Shorrock ST, Kirwan B. Human error in European air traffic management: the HERA project. Reliability Engineering & System Safety. 2002;75(2):257-272.
94. Schramm W, Roberts DF. The process and effects of mass communication. Urbana,IL;1971.
95. Stead BA. Berlo's Communication Process Model as Applied to the Behavioral Theories of Maslow, Herzberg, and McGregor. Acad Manage J. 1972; 15(3):389-394.
96. Berlo's SMCR Model Of Communication [Internet].2010[last updated:2010.cited date:June23 2012] Available from: http://communicationtheory.org/berlos-smcr-model-of-communication
97. Calabrese A. The evaluation of quality of organizational communications: a quantitative model. Knowledge and Process Management. 2004;11(1):47-67.
98. Alexander EL. Safety Culture in the Nuclear Power Industry: Attributes for Regulatory Assessment [dissertation]. Massachusetts Institute of Technology; 2004.
99. Kreps GL. Applied communication theory and research. Lawrence Erlbaum; 1990
100. Watt J, Berg SVD. Research Methods for Communication Science. Portland, Or: Allyn & Bacon Publishers.1995.
101. Dictionary.Com. Ethnology [Internet]. 2012 [cited on: July 25 2012].Available at: http://dictionary.reference.com/browse/ethnology?s=t
102. Lapan SD, Quartaroli MLT, Riemer FJ. Qualitative Research: An Introduction to Methods and Designs. Jossey-Bass; 2011
103. Gawande A. Big Med. [Internet] Newyorker. 2012 [cited date: Aug 1,2012].Availableat: http://www.newyorker.com/reporting/2012/08/13/120813fa_fact_gawande
104. Chung YH, Yoon WC, Min D. A model-based framework for the analysis of team communication in nuclear power plants. Reliab Eng Syst Safe. 2009;94(6):1030-1040.

105. 106.Durham SW. In their own words: Staying connected in a combat environment. Mil Med. 2010;175(8):554-559.
106. Pronovost PJ, Wu AW, Sexton J. Improving patient care. Acute decompensation after removing a central line: practical approaches to increasing safety in the intensive care unit. Ann Intern Med Quality grand rounds series. 2004;140(12):1025-1033.
107. Mcilroy RC, Stanton NA. Getting past first base: Going all the way with Cognitive Work Analysis. Appl Ergon. 2011;42(2):358-370.
108. Spillers F. Task Analysis through Cognitive Archeology. In: Diaper D, Stanto N, editors. The handbook of task analysis for human-computer interaction. Mahwah, New Jersey: Lawrence Erlbraum associates;2004.
109. Lee SM, Ha JS, Seong PH. CREAM-based communication error analysis method (CEAM) for nuclear power plant operators communication. J Loss Prevent Proc . 2011;24(1):90-97.
110. Frankel A, Gardner R, Maynard L, Kelly A. Using the communication and teamwork skills (CATS) assessment to measure health care team performance. J Qual Patient Sa. 2007;33(9):549-558.
111. Plott B, Quesada S,Kilduff P. Swoboda, J. Using an Information-Driven Decision_Making Human Performance Tool to Assess US Army Command, Control, and Communication Issues. Proceedings of the Human Factors and Ergonomics Society Annual Meeting.2004; 48(20); 2396-2400.
112. O,`Hara J, Plott C, Milanski J et al. Trends in HFE methods and tools and their applicability to safety reviews. (BNL Tech Report No. BNL-90424-2009). Upton, NY: Brookhaven National Laboratory; 2009.
113. Nagpal K, Vats A, Ahmed K, Vincent C, Moorthy K. An evaluation of information transfer through the continuum of surgical care: a feasibility study. Ann Surg.
114. 2010;252(2):402-407.
115. Patterson ES. Communication strategies from high-reliability organizations: translation is hard work. Ann Surg. 2007;245(2):170-172.

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