Assessment of the Impact of new medical technology on Teamwork and Patient Safety within the OR

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Under the authority of:
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Master thesis

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Executive Summary

Problem description

In the operating room new medical technologies are being developed and introduced that are becoming increasingly complex and involve constant changing interactions of multiple disciplines. Not only are the technologies becoming more complex, but they are also being developed and introduced at a faster rate. As a consequence it becomes even more difficult to assess the effects of a medical technology on patient safety and teamwork.

Research in recent years has shown that many errors in the operating room are being caused by the non-technical skills of the clinical team. These skills encompass dynamic relational aspects of the team performance, among them are communication, situation awareness and teamwork.

With the development of highly complex technological environments within the operating rooms in the very near future, health care professionals and technology developers need to incorporate measures in their designs and organisation. A valid tool to assess the impacts of medical technology on teamwork and patient safety has yet to be developed.

Research question

How should the impact of the introduction of a new medical technology on teamwork and on patient safety within the OR be evaluated?

Method

Based on the literature two framework are constructed. A framework to assess the direct impacts of a medical technology on patient safety and a framework to assess the indirect effects on teamwork. For each framework a list of variables and factors is designed. The first framework assess both the impact of the technology and the likelihood of disruptions. The second framework consists of input variables that are affected by the introduced technology, combinations of these variables together comprise factors that influence the different elements that make up the construct of teamwork. A case study on the use of the Da Vinci Surgical System for the procedure of radical prostatectomy was used to observe changes in the teamwork behaviours and to assess the completeness of both frameworks.

Conclusion

The expected results of both frameworks did adequately reflect the observed situation. The framework to assess the direct effects was able to trace different observed incidents and contains a complete set of variables.

The framework to assess the indirect effects, reflected the observed situation to a lesser extend. This was attributed to the fact that the Da Vinci Surgical System is a technology that incorporates similar tasks, skills and required knowledge as with previous technologies and procedures. Furthermore, the team has been accustomed to working with this highly standardized technology for a long period, thus further increasing the effectiveness of the teamwork. The framework did indicate effects that could be observed. As an early conclusion I believe that the framework poses a complete set of variables and factors that reflect the actual situation.

However a number of issues are identified. First, all relations were assumed to share an equal weight in the determination of the proposed effects. Second, the scores and results of the framework suggest an exactness that can not be determined. The results should only be used as an good indication of the degree and direction of the expected effects. Finally, only one technology was observed during five observations which undermines the strength of the validation.

The frameworks can be used for every phase of technology development, except for the framework to assess the indirect effects. This framework can not be used to assess a technology which is in a very early phase of fundamental development and testing.

Recommendations
The twelve proposed factors should be thoroughly scrutinized in future research, on their completeness since they are essential in explaining the effects of changed input variables on teamwork elements.

Furthermore, as an addition to the strength of the framework, the actual weight of each separate factor should be investigated. With the identification of the contribution of each factor to the teamwork attributes a possible simplification of the framework can be established.

Both frameworks need to be further validated on their completeness and predictive abilities through the use of controlled trials and observations on different medical technologies, especially technologies that involve the cooperation of multiple disciplines such as the advanced image fusion technology.

Preface

This report is my master thesis for the conclusion of my master program of the MSc Health Sciences at the department of management and governance, University of Twente. It is also the conclusion of my internship at the Netherlands Cancer Institute and the Antoni van Leeuwenhoek Hospital (NKI-AVL) in Amsterdam. I really appreciated the many people who helped me at the project.

I would first thank my supervisor at the NKI-AVL, Professor Wim van Harten. He gave me a lot of trust and flexibility on the project. A project that not only provided me with the opportunity to work within an exiting and challenging environment and research field, but also an opportunity to combine my two professional passions, aviation and health care. Although I organized a mental concept to tackle the research very early in my mind, he provided me a sizable amount of options, opinions and thoughts to expand and build on.

Along with my thanks to Professor Wim van Harten, I would like to thank Dr. Marjan Hummel who helped me to organize my thoughts on the project with valuable advise.

I also want to extend my gratitude to the surgeons and assistants that provided me with the opportunity to observe their performance on the OR.

Last but certainly not least I want to thank my family and friends who have motivated me to pick up where I left of before I lifted off. With their help and support I was able to finish a decade long challenge. A special thanks goes to Dorothee, for all your love!

Amsterdam 1 October 2011,

Gerke Kleinsmit

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1 Introduction

1.1 Problem Description

The Netherlands Cancer Institute - Antoni van Leeuwenhoek Hospital (NKI-AvL) is the only dedicated cancer centre in the Netherlands and maintains a focus on top clinical research and treatments. The NKI-Avl is a frontrunner on the adoption of new medical technology. Current plans are being made to invest in the "future OR". This will be an environment that encompasses and combines the latest in imaging and surgical technologies to provide better en more precise operations. The decisions to invest in these high tech environments will have a big impact on the current organisation of the health care process.

In the operating room new medical technologies are being developed and introduced that are becoming increasingly complex and involve constant changing interactions of multiple disciplines. Not only are the technologies becoming more complex, but they are also being developed and introduced at a faster rate.

This higher rate of introduction and the increased complexity can have a serious effect on the decision making and performance of the clinical team and the patient safety. First, the organisation of the clinical process requires more planning and coordination between the different disciplines to facilitate an effective use and operation of the technology. And second, the faster rate of introduction is giving health care organisation less time to adapt to the new technology and to plan for possible unforeseen negative implications.

Research in recent years has shown that many errors in the operating room are being caused by the non-technical skills of the clinical team. These skills encompass dynamic relational aspects of the team performance, among them are communication, situation awareness and teamwork.

To provide a high level of clinical care and assure patient safety it is important for health care providers to be able to assess the impacts new technologies will have on the future non-technical skills and teamwork behaviours of the clinical team. The time constraints, that the rapid development of technology places on the abilities of health care providers to these changes, necessitates the need for a framework to assess the effects as early as possible in the decision process.

1.2 Research Methods

1.2.1 Research Objective

The object of this study is to develop a framework to asses the impact on teamwork and patient safety related to the introduction of a new technology within the operating room. This framework is to be based on a literature study and the validity of the framework shall be investigated in a pilot of a recently introduced technology.

1.2.2 Research Questions

In order to construct the theoretical framework, insights in the relationship between teamwork and patient safety need to be obtained. Besides these insights a further general knowledge of the different types of technology change and their impact on the organisation of the clinical healthcare processes is required. With this in mind the following main research question is formulated:

> ***How should the impact of the introduction of a new medical technology on teamwork and on patient safety within the OR be evaluated?***

The research question is made operational in three specific sub-questions. The first two sub-questions investigate the relation and impact of medical technology on the dependent subjects patient safety and teamwork. The last sub-question addresses the evaluation of the relationships between the independent and dependant subjects of the research question.

1. What is the influence of the introduction of technology on patient safety?
    a. What is Patient Safety?
    b. What are the types of classification of errors?
    c. How does the introduction of new technology directly affect patient safety?

2. How does technology affect teamwork and team performance?
    a. What is teamwork?
    b. Which attributes determine teamwork?
    c. What inputs have an effect on teamwork performance?
    d. What inputs of teamwork are affected by technology?

3. How to evaluate the feasibility of the framework in practice?
    a How are the impacts of technology on teamwork measurable?
    b How should the attributes and element of teamwork be measured?
    c Are all relevant attributes and variables identified by the framework?

1.2.3 Research Design

To explore the relationships between technology and teamwork and patient safety a set of qualitative research methods is used. These are divided in Data Collection and Data Analysis.

Figure 1 depicts the supposed relations between de dependent and independent subjects of the research questions. A preliminary search on the literature provided little information on existing models to study the subject and therefore a prospective “bottom up” type research is not chosen to execute since there is uncertainty on what needs to be measured. For this thesis I will perform a retrospective “top down” approach using a qualitative research strategy to uncover causal relationships and attributes that need to be evaluated by the proposed framework. Once the framework has been constructed a case study is performed to assess the completeness of the framework.

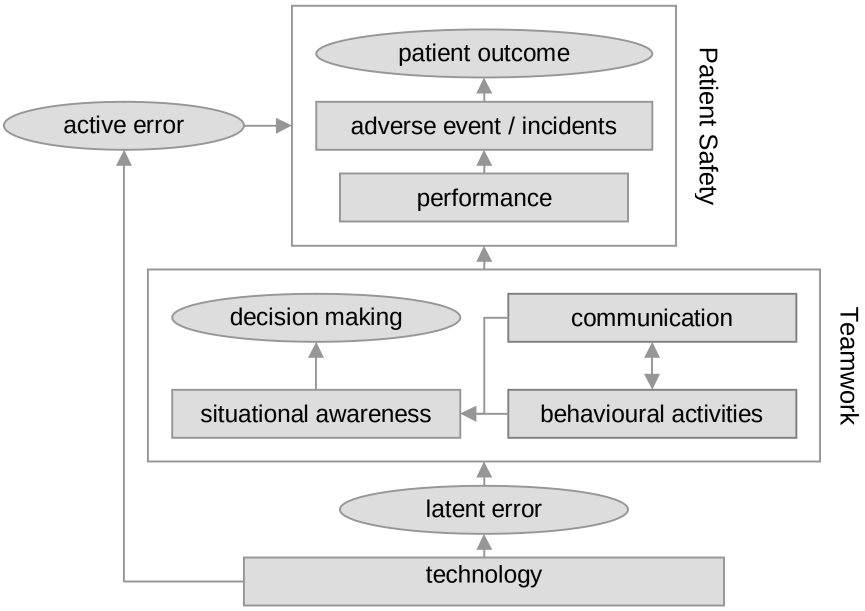

Figure 1. Preliminary proposed relations between dependent and independent subjects.

1.2.3.1 Data Collection

Literature Review: The Theoretical Framework

To gather relevant information and to uncover the different attributes of teamwork that are affected by the introduction of a new technology a literature search strategy for each research question was used on PubMed, the National Library of Medicine and PiCarta. The search included only English-language articles published between 1998 and 2011 for research on humans. From the collected literature I performed a scan in the reference on other relevant articles.

For this master thesis I have searched three main areas of interest in literature these are: human error classification and patient safety, teamwork behaviours and performance and finally work team design and team efficiency models.

Human Error Classification / Patient Safety

In 1999 the American Institute for Healthcare improvement published the report "To err is human", on the effects of adverse events on patient safety within health care institutions. They estimated that between 44000 and 98000 people die each year as a consequence of adverse events, of which a great number was classified to be preventable[1]. After the publication of this report a number of studies on the causes of the adverse events revealed that most of the incidents that lead up to an adverse event were caused by human error.

There is a great amount of research on the classification on human error in health care and other industries such as aviation and the petrochemical industry. Methods like Crew-Resource-Management on improving the quality of human interactions to reduce errors were adopted from these industries and studied in the field of health care[2]. Literature provides a great amount of research on human error and team performance.

For this research the concept of patient safety and the causes of error and according classification model need to be determined. Appendix A provides an overview of the search terms and results of the literature search on human error classification and patient safety.

Within these articles a search is done to reveal additional relevant literature on the development of error classification models and theories on human error. These articles were either theory based or were based on research of patient and incident records.

The literature search resulted in articles that provided a clear description of the structure of human error in the OR, definitions of key terms and a broad classification of root causes of human error.

The articles, however did not provide definite insights in specific technological attributes causing latent human errors and the specific technological related errors on teamwork and patient safety.

Teamwork and Team Performance

The literature on teamwork can be divided in two main objects of research. The first is a focus on the effects of teamwork interventions on team performance. These studies are mostly empirical studies performed within the OR and measured outcomes of team performance before and after interventions. The outcome measures were among others, the number of errors and incidents, the duration of the procedure, the duration of the admission and perception of team performance of the health care professionals.

The second object of research was to determine the elements of the construct teamwork itself. The goal of this body of literature is to define elements and behavioural markers to be able to measure team performance. These elements are referred to as non technical skills of medical professionals. The elements and markers were identified using task analysis by health care professionals and with the use of statistical methods to identify clusters. Other approaches used surveys and literature reviews. Across the different studies the same type of elements were identified and broadly classified in a cognitive and interpersonal category.

Appendix A provides an overview of the search terms and results of the literature search with the inclusion criteria.

The literature search on the construct teamwork resulted in a description of the main elements of teamwork applicable to health care. The body of literature does not provide a clear insight in the interactions and relationships between the elements of teamwork or on the antecedents of the teamwork.

Work Team Design and Team Efficiency Models.

To be able to answer the second research question it is important to understand what variables influence the effectiveness of teamwork. The search strategy on teamwork in health care did not provide me with a clear understanding of these dynamics. To complete the top down approach in order to identify the variables that are affected by technology a literature search outside health care on behavioural theories on group dynamics and work design was performed.

From behavioural sciences the role based approach provides a useful tool to identify these variables and the antecedents of teamwork performance. Barley has performed extensive research on how technology can influence interpersonal networks and structures[3].

The role based approach is used in the studies on work team design and team effectiveness models. A direct search on team effectiveness models resulted in a comprehensive literature reviews of the majority of models[4,5]. The main structure for all models is alike and it encompasses an input-process-output approach of describing team effectiveness.

These models provide different classifications of input variables that are affected by a new technology. They do not, however, provided a complete description of how these variables impact the different elements of teamwork.

Additional literature on antecedents of Teamwork Attributes.

From the literature search I could construct a set of input variables, teamwork attributes and elements and performance measures. These results comprise all three elements of the general team effectiveness models, Input-Process-Output. To be able to explain the transformation of teamwork performance brought about by changes input variables it is necessary to create a fourth element within the team effectiveness models, the moderator. This element should clarify how teamwork attributes are affected by different variables.

An additional literature search was performed on the background for each teamwork attribute and sub element that was identified. This information made it possible to construct different factors that moderate the influence of the input variables onto the teamwork attributes.

Interviews and observations: Pilot study Da Vinci Surgical System.

Interviews: Pilot study Da Vinci Surgical System

To evaluate the completeness of the framework interviews will be held with persons directly involved with working with the Da Vinci Surgical System. An open and topic interview list will cover all input variables and the attributes of the framework. The results of the questionnaire will provide the basic information to assess the effects on teamwork with the use of the constructed framework. The questionnaire is presented in appendix B.

Observations of teamwork performance: Pilot study Da Vinci Surgical System

To validate the framework the expected effects of a new medical technology on teamwork performance should be compared to the actual teamwork performance. For this use observations within the Operation Room and measurement of the teamwork attributes and elements are necessary.

To measure and rate the interdisciplinary teamwork attributes and performance of the medical professionals involved, an adapted version of the non-technical skills for surgeons rating system (NOTSS) for use in surgery will be used. This rating system is taken from the aviation industry and adjusted to conform with the team dynamics of the operating room[6]. The NOTSS rating system is comparable to other behavioral rating systems and covers the same teamwork dimension applicable to the operating room. The rating system has been validated and found reliable in a number studies covering a large amount of observations in the operation room[7]. The NOTSS rating scale shall be adjusted to encompass the different teamwork elements found in literature.

Given the scope and goal of this research 4 operations with the Da Vinci technology are sufficient to observe since the standardized operations make it possible to provide a good indication of the behaviors of the disciplines involved within a limited amount of time and observations.

2 The Influence of Medical Technology on Patient Safety

2.1 Introduction

In order to gain insights in the relationship between the interactions of the healthcare process and the dimensions of patient safety I will discuss in this chapter the definition of patient safety and the different types of errors and incidents that impact it. The subsequent findings will provide an answer on the following research questions:

What types of errors are related to the introduction of technology on patient safety?

a. What is Patient Safety?
b. What are the types of classification of errors?
c. How does the introduction of new technology directly affect patient safety?

In the first paragraph I will define patient safety and place this concept within the quality of care. In paragraph 1.2 the key terms on the types of risks that determine patient safety are described. In the last paragraph a classification and origin of human failures is described that can impact the risks of the healthcare process.

2.2 What is Patient Safety

To define patient safety and its scope within this thesis it is important to distinguish between safety and quality.

The institute of Medicine defines quality of care as "the degree to which health care services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge"[8]. Problems with the quality of care thus arise from components of the system of healthcare services. These problems are able to cause a negative impact on the outcome and cause harm to the patient.

According to the Merriam-Webster's medical dictionary safety is "not causing harm or injury"[9]. Combining the two definition makes clear that it is not the outcome of the health services, but the services itself that determines patient safety.

Because even the best health services are affected by the fallibility of humans, errors are to be expected to occur. These errors are a consequence of the complexity of the health care system. To reduce the chance of error a systems approach is required to overcome and change deficiencies in the health care system. Patient safety therefore is an attribute of health care aimed at increasing reliability under potential errors affecting the medical process.

The following definition of patient safety captures this systems approach:

*"**Patient safety is the freedom from accidental injury: ensuring patient safety involves the establishment of operation systems and processes that minimize the likelihood of errors and maximizes the likelihood of intercepting them so they won't occur**[1]."*

2.3 Patient Safety Outcomes

As described in the previous paragraph, patient safety is the freedom from accidental injury and the measures to minimize risks and to prevent errors. The next step is to define the different types of risks that affect patient safety. The main goal is to prevent injury caused by the medical process. When this process does cause injury to the patient the result is named an adverse event. From research[10,11] it is indicated that adverse outcomes occur almost one in every ten operations and even leading to death in one in every 150 patients. From these adverse outcomes nearly half were classified as preventable.

The definition of adverse event is dependent on the context it is being used in. Usually an adverse event is defined as an unintended injury or complication which results in disability, death or prolonged hospital stay, and is caused by health care management[12]. By this definition the cause of the event lies within the range of the health care system rather then with the personal inherent risk of the patient, disease and treatment.

With patient safety there are two main concepts involved to determine an adverse event, incidents and complications[13] that are related to respectively the process and the outcome of healthcare. In figure 2 the relations are graphically depicted.

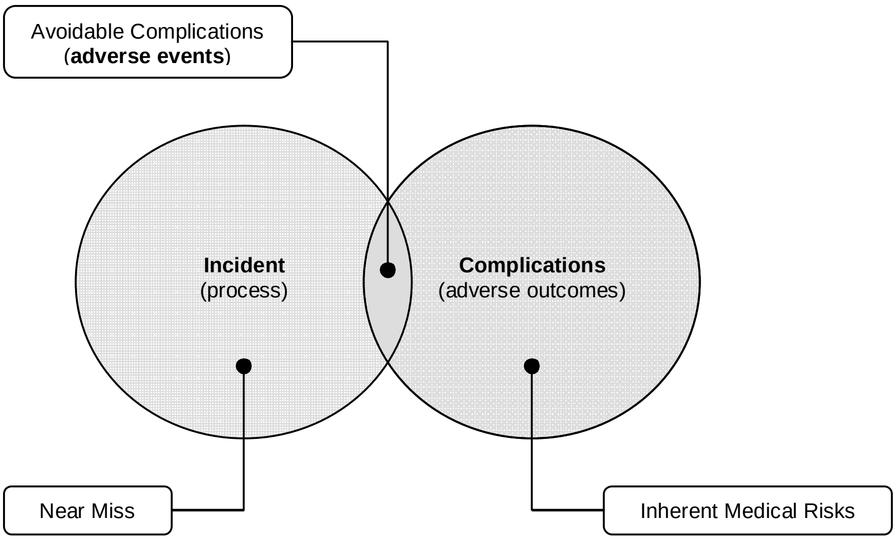

Figure 2. Relationship between incidents and complications[13]

Complications are diseases or injuries that arise subsequent to another disease and/or health care intervention[12]. A complication is a condition that necessitates further treatment or establishes as long-lasting damage to the patient. In many cases complications arise from underlying diseases, side effects of the treatment or individual characteristics of the patient that express themselves in risks associated with the treatment. A complication is then seen as an *inherent medical risk* that lies outside the reach of the health care system.

Incidents are unintended events, processes or practices that are noteworthy by virtue of the hazard they create for, or the harms they cause, patients[12]. Normally incidents are intercepted before they can cause harm or do not affect the outcome of the process. An incident is then called a *near miss*. When an incident leads to a complication it is, by the definition stated above, an ***adverse event***.

2.4 Origins of Incidents and Adverse Events

Incidents arise due to human failure induced by deficiencies of the health care system, they are therefore the result of a failure. A systems approach acknowledges this human fallibility and concentrates on the conditions under which individuals work and tries to build defences, organisational and human, to avert these failures[14]. The use of the different terms such as incidents, failures and errors is depicted in figures 2 and 3 and will be explained in the following paragraphs.

2.4.1 Classification of factors influencing Incidents

In a highly complex environment, such as a hospital, a single defence barrier is prone to errors and causes a weakness in the system. Multiple defences are thus created to serve as a back up and usually intercept incidents effectively. Though incidents do occur to happen when these weaknesses in defences momentarily line up and allow for a trajectory of incident opportunity. These weaknesses arise from two reasons: active failures and latent conditions[14]. And nearly all events involve a combination of these two factors.

Active failures are the unsafe acts committed by the people who are in direct contact with the patient or system. These active failures have a direct and usually short lived impact on the integrity of the defences. Active failures are human errors[15].

Latent conditions on the other hand, are the inevitable resident pathogens within a system that arise from decision made by designers, builders, procedure writers and management. They can translate into error provoking conditions with the local workplace or they create long-lasting weaknesses in the defences. Latent failures are technical or organisational of origin[15].

2.4.1.1 Active Failure

The description of active failures indicates that they are represented by human error. The definition of error is a failure of planned actions to achieve their goal[16] and this error can further be dived on three levels of behaviour according to the SKR-model of Rasmussen[17]. Each level of behaviour refers to the degree of conscious control exercised over activities.

1. *Skill-based behaviour,* involves automatic tasks with little conscious monitoring.

2. *Rule-based behaviour*, involves the application of existing rules to the management of familiar situations.

3. *Knowledge-based behaviour,* involves the conscious application of knowledge to novel situations. The performance is goal driven and requires mental models for reasoning and decision-making using stored rules.

Based on the SKR-model a broad classification of human errors can be made. In figure 3 an oversight is provided of the classification of errors. On the level of skill-based errors slips and lapses are identified. Slips are actions of competence that deviate from the current correct intention, a failure of execution. Lapses are relate to a momentarily failure of memory, missed actions and omissions. Slips and lapses are associated with a form of attentional capture guided by strong habits under situations of distraction or unfamiliar actions embedded in a familiar context.

Besides the failures of execution, errors are also associated with an inadequate plan to achieve an intended outcome. This is recognized as a failure of intention or mistakes. Mistakes are rule- and knowledge-based errors and relate to mental processes of planning, diagnosis, formulating intentions and problem solving once a problem is occurred.

When an incorrect or inappropriate diagnose is made an rule-based error can arise. The application of a incorrect rule can be influenced by the tendency to force a situation onto experiences of previous events while being unable to notice differences. An other use of inadequate rules can be attributed to the use of uncorrected bad rules stored in the array of learned problem solutions.

Finally mistakes can occur at the level of knowledge-based behaviour. This occurs when a novel situation is encountered that requires an evaluation of the situation and is directed at problem solving and decision making without the use of existing rules, procedures and routines. The novel situation demands considerable effort of the individual and team information processing capabilities and therefore it is a very likely situation for errors to occur. Limited mental capacity, incomplete and incorrect metal models of the situation and a tendency to fixate and reassure on a specific line of thought all contribute to the difficulties with knowledge-based mistakes.

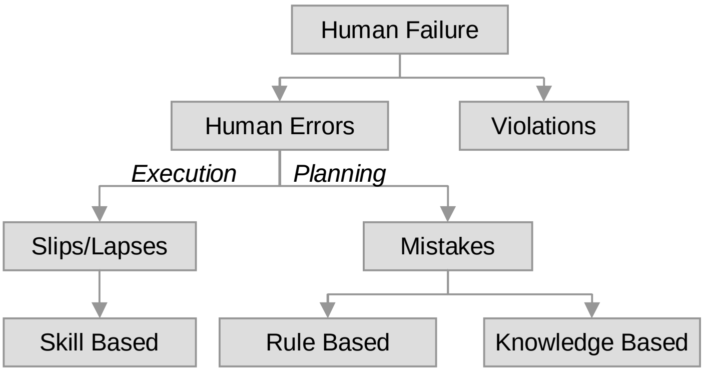

Figure 3. Classification of Active Human Failure[18]

With the three types of human error, error recovery is most efficient on the level of skill-based behaviour since discrepancies between the action and the intended outcome is directly observable and feedback can be provided accordingly. Mistakes on the other hand are very resistant to disconfirming information because people are looking for information to reassure the pre-conceived perception of the situation.

In the classification of human failure a distinction is further made between errors and violations. Violations are deliberate deviations from safe operating practices, procedures or rules. Violations are motivational in origin in contrast to the informational problems of human errors. Whereas errors can be reduced by improving the quality of information delivery violations require organisational and motivational measures.

2.4.1.2 Latent conditions

It is the latent conditions that shape the working environment and they are influenced by organisational and technological considerations. Technical errors occur when there are problems with physical items such as equipment, installations and materials.

Organisational errors do arise when problems are encountered with protocols and procedures, transfers of knowledge, management priorities, the organisational culture and the collective approach to safety and risk[15].

Unforeseen flaws in the design of these conditions set up ineffective work environments that create the opportunity to provoke human errors and let these errors develop almost unseen into an incident. Human errors are in essence consequences rather then causes of incidents.

2.5 Effects of a Technology on Patient Safety

With the classification of human failure and error described, the important question of how exactly a technology affects patient safety remains to be answered.

First an understanding of the term medical technology is required[19].

A medical technology is any device, instrument, material or other article, whether used alone or in combination, including the software necessary for its proper application intended by the manufacturer to be used for human beings for the purpose of:

- *Diagnosis, prevention, monitoring, treatment or alleviation of disease;*
- *Diagnosis, monitoring, treatment or alleviation of or compensation for an injury or handicap;*
- *Investigation, replacement or modification of the anatomy or of a physiological process;*
- *Control of conception, and which does not achieve its principal intended action in or on the human body by pharmacological, immunological or metabolic means, but which may be assisted in its function by such means.*

This definition gives a clear description of the purposes of the technology and furthermore differentiates between categories that comprise the concept of technology, these are defined as[20]:

- Devices: equipment that is used during the surgery procedure. Needs to be powered and gives information and/or has moving parts.
- Instruments: equipment that is durable and does not need power. Most instruments are treated by the sterilisation department.
- Materials: products that are disposable after use. Furthermore, durable products that do not need sterilisation or to be powered.

Next the pathway of an error needs to be described to uncover the indirect and the direct effects of a technology on patient safety.

2.5.1 Indirect effects

According to the definition of an error it includes actions that did not achieve the desired outcome as well as actions that did not proceed according as planned. The development of these human errors are a consequence of the latent conditions of organisational and technological based decisions and designs which set up error provoking conditions within the workplace such as personal stressors, high workload, poor communication, reduced situational awareness and procedures that permit the provocation of active errors and violations by professionals in direct contact with the patient.

A second indirect effect of technology is its influence on the defence measures, such as teamwork deficiencies to detect and intercept errors. Both latent pathways are presented in figure 4.

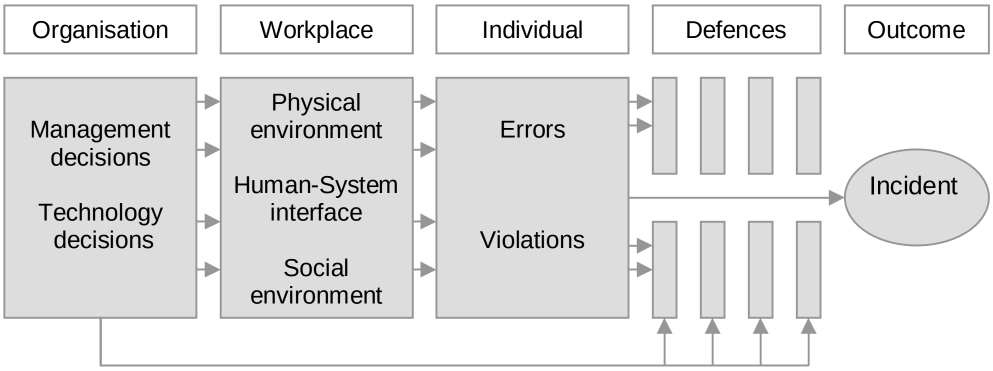

Figure 4. Stages in the development of an organisational incident through the latent failure pathway[14]

2.5.2 Direct effects

The direct effect of a technology on patient safety, besides the clinical safety of the procedure, is the ability to disrupt the surgical process. A surgical flow disruption is defined as any issue in teamwork, technology, training or the environment that results in deviation from the natural progression of any operation, thereby compromising safety[21].

Disruptions, potentially degrade the ability of the health care team to perform the medical procedure successfully. The number of disruptions have been negatively related to the capacity of the team to adapt and compensate for complications and adverse events. And as a consequence, the amount of surgical errors is positively related to the amount of surgical flow disruptions[21].

From the definition of and research on flow disruptions, a direct effect of technology on patient safety is implied. Although teamwork and communication related errors are associated with the majority of events and incidents, technology still contributed for roughly 10% of the disruptions[21,22]. More important, the interruptions due to technology and instruments were infrequent but they did have a significant negative impact on the medical performance[23]. Therefore the direct influence of technology is an important factor in assessing patient safety.

The direct and indirect effects of medical technology on the surgical performance and medical outcome is presented in figure 5.

On the left side the latent pathway is presented which accounts for the majority of flow disruption, but with a moderate impact on the medical process. These disruptions present themselves through ineffective teamwork induced by a medical technology[21,22,23] which set up the possibility of human failures and errors.

On the right side the relationship between technology and flow disruptions is due to the direct effects of technological malfunctions, failing equipment, misuse of the equipment and the unavailability of instruments and materials.

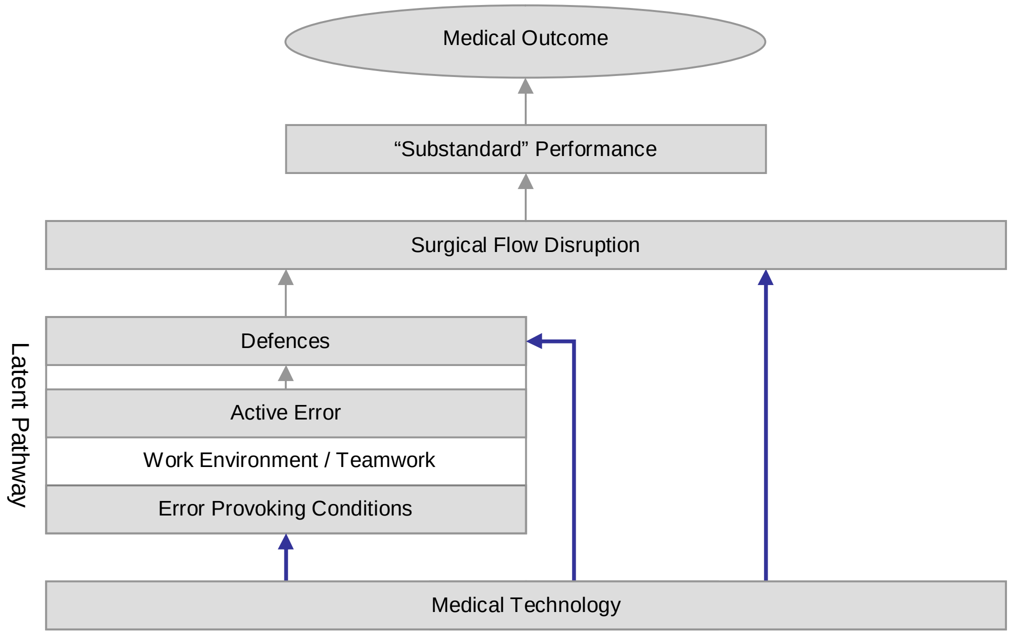

Figure 5. The direct and indirect influence of a medical technology on medical performance and outcome

For the assessment of a medical technology different process models of health technology assessment are used that differentiate between a number of main elements where the use of the technology may have consequences, such as technological, clinical, user, economical, patient-related and organizational[24]. The indirect effects on teamwork are a part of the assessment of the user element whereas the direct effects are related to a clinical and technological assessment[24]. Because of the difference in the focus of the assessment, the construction of the frameworks will be discussed separately. The framework to assess the direct effects will be discussed in this chapter and the indirect effects will be discussed in detail in chapter three.

To assess the technical reliability and clinical safety of a medical technology, the appropriate risks should be determined. Risk is the combination of the impact on patient safety along with the likelihood of any disruption.

2.5.2.1 The impact of a disruption of the surgical flow on patient safety

According to European regulations, the clinical risks of a medical technology on patient safety is classified into four categories[25]. These are respectively category I, IIa, IIb and III with category III covering the highest risk products. This classification system of a medical technology follows a set of 16 rules[26] which depend upon a series of factors that include:

- The degree of invasiveness;
- The duration of contact;
- Whether or not the device is active and exchanges or administers energy;
- The body systems affected, specifically the central circulatory and nervous system.

An invasive device is any technology which penetrates inside the body through the surface of the body, with the aid or in the context of a surgical operation[27]. An active device is any technology of which the operation depends on a source of electrical energy. This includes technologies intended to transmit energy, substances or other elements to the patient with a significant change in the nature, level and density of energy[27].

The duration of the contact along with the timing of the disruption is furthermore related to the phase of the operation respectively the pre-operative, operative and post-operative phase of the medical process. Disruptions during the operative phase poses a greater impact on patient safety then those during the other two phases.

Another important factor besides the clinical risk, that determines the impact is the ability to restore and continue the surgical process or to take counter measures to reduces the effects of the disruption. The ability to restore the disruption or to take counter measures and to initiate an alternate course of action depends on:

- The ability to obtain and change parts and materials;
- The ability to reset or reassemble the technology;
- The degree to which other technologies and procedures are dependent on the technology;
- The ability to continue the medical procedure;
- The ability to perform an alternate medical procedure.

For each of these factors the physical layout and the construction of the technology may impact a smooth transgression from a planned procedure to the actions to restore the procedure or initiate an alternate course of action.

Table 1 provides a framework that combines these different factors to be able to assess the potential impact of a technology disruption on patient safety.

Impact of Medical Technology on Patient Safety								
	Clinical Risk				Ability to Respond to a Disruption			
Degree of invasiveness	none	low	moderate	high	The ease to obtain and/or change parts and materials	easy	moderate	difficult
Duration of contact	none	short	moderate	long	The ease to reset and/or reassemble the technology	easy	moderate	difficult
Active device	non active		active		Degree to which other technologies and procedures are impacted	low	moderate	high
Degree of transmitted energy change	none	low	moderate	high	Possibility to continue or restore the medical procedure	easy	moderate	difficult
Type of body systems affected	none	other	circulatory	nervous	Possibility to initiate an alternate course of action	easy	moderate	difficult
Phase of the operation of the technology	pre-	operative	post-		Degree to which the physical arrangement hinders the response to a disruption	low	moderate	high
Clinical Risk*	Low (1)	Moderate (2)	High (3)		**Ability to Respond to a Disruption***	Low (1)	Moderate (2)	High (3)
Impact of the Medical Technology on Patient Safety**					Low (<4)	Moderate (4)	High (4>)	

*Scores on low, moderate and high are respectively scored with 1,2 and 3 points
**The combined scores of the clinical risk and ability to respond are less then 4 for low, 4 for moderate and more then 4 for a high impact

Table 1. Framework to assess the impact of a medical technology on patient safety.

2.5.2.2 Potential sources of errors and disruptions

Besides the potential impact of a disruption on patient safety, the likelihood of a disruption should be assessed. To be able to do this, the potential sources of errors and disruption need to be determined. Errors of medical technologies occur throughout the lifecycle of the technology and in different settings and context which makes it difficult to determine the cause of technological errors.

In a recent study seven different phases of the life cycle of a medical device have been described along with common sources of errors[28]. The different phases of the life cycle are presented in Table 2.

Table 2 furthermore provides a classification for each different source of error. Five classes of technological failure have been identified, these are device errors, user errors, external factors, support system failures and errors due to tampering and sabotage[29]. Technological malfunctions and failing equipment constitute device errors whereas misuse of the equipment and the unavailability of instruments and materials constitute the support system failures The user errors and errors due to tampering and sabotage are respectively active errors and violations which are a part of the indirect effects of the technology on patient safety and are not depicted in table 2.

Phase		Potential Source of Errors	Failure Class	Responsibilities
Pre-market	**Conception and Development**	Human Factor errors	Device	Manufacturer
		System integration difficulties	Device	
	Manufacture	Poor product materials	Device	
		Poor production quality	Device	
	Packaging and Labeling	Poor manuals, instructions	Device	
Placing on market	**Advertising**	Misrepresentation of attributes	Device	Vendor
	Sale	Poor implementation support	Support	
		Poor pre-purchase evaluation	Support	
Post-market evaluation	**Use**	Lack of training	Support	User
		Inadequate maintenance	Device	
		Poor incident reporting	Support	
		Environmental factors	External	
	Disposal	Re-use errors in sterilization and maintenance	Support	

Table 2. Phases of the life cycle of a medical technology and common sources of errors.

The seven phases of the life cycle of a medical technology can be roughly divided into three main separate groups, pre-market, placing on market and post-market evaluation.

The pre-market phase is concerned with the quality assurance of the technology. The design and manufacturing of a medical technology must comply with international standards to overcome poor designs or lack of manufacturing control. The responsibility for this quality assurance lies with the manufacturer of the technology. Sources of errors that should be assessed relate to the device class among which the integration with other systems on the operation room and the effective incorporation of human factors and intuitive operation of the technology in the design are important factors of flow disruption[22].

Placing the device on the market requires the responsibility of the vendors to ensure that their products comply with regulatory requirements and to provide after sale service in the form of training and support. During the advertising and sale phase it is difficult to easily assess potential sources of errors. Misrepresentation of attributes and poor pre purchase evaluation become more visible during the use of the technology.

The post-market evaluation is a crucial part of assessing the safety of a technology. Incidents reporting systems and surveillance studies are used to collect data to re-affirm product safety to assess differences between pre-market safety claims and actual use. Sources of errors are grouped into three general classes of failure that are important in assessing the likelihood of disruptions. Device related errors are due to the quality and availability of maintenance support. Support systems address the quality of training possibilities to use the technology and the control measures to overcome mis-use of the technology. Errors related to the support systems occur due to ineffective incident reporting systems and errors in sterilization and availability of materials and components required to perform the surgical procedure. Finally external factors contribute the chance of disruptions caused by technology, these factors address issues such as power supply failures and environmental controls (dust, humidity and temperature).

Table 3 provides a framework to assess the likelihood of disruptions in surgical flow caused by a medical technology based on a number of potential sources of errors.

Likelihood of Disruptions Caused by Medical Technology

Class	Potential Source of Error and Disruption		low	moderate	high
Device	Human factor errors	The operation of the technology is counter- intuitive			
		The access of controls is difficult			
	System integration difficulties	The interaction with other devices is complex			
		The interaction with other procedures is complex			
	Poor product materials	The materials are sensitive / delicate			
		The number of required materials and equipment			
	Poor production quality	The quality of the materials is inconsistent			
	Poor manuals and instructions	Manuals and instructions are unclear / inaccurate			
	Inadequate maintenance	In house maintenance capabilities are insufficient			
		The timing and execution of maintenance is erratic			
		The quality of maintenance is sub-standard			
Support	Lack of training	Incomplete training on the use of the technology			
		Inability to train and acquire skills and knowledge on the use			
	Poor incident reporting	Incident reporting is incomplete and / or infrequent			
	Re-use errors in sterilization and maintenance	Lack of / or inadequate pre-use inspections			
		Improper cleaning and sterilization			
		Inadequate / insufficient storage of materials and devices			
External	Environmental factors	Dependency on a limited source of power supply			
		Lack of environmental control (temperature, light, humidity)			
Potential likelihood of disruptions caused by a medical technology			**low**	**moderate**	**high**

Table 3. Framework to assess the likelihood of a disruption caused by a medical technology.

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2.5.2.3 Framework to assess the direct effects of a technology on patient safety

The direct effects of a medical technology on patient safety is the ability to disrupt the surgical flow of the medical process. As discussed previously in this chapter, the amount of disruptions caused by a medical technology failure, mis-use or availability of materials and components is positively related to the amount of surgical errors[21].

This risk and chance of this ability to disrupt the surgical flow to occur can be assessed by combining the impact a disruption has on the patient safety and the likelihood of any occurrence of a disruption. Table 4a,b and c is the combination of the results of table 1 and 3 and provides an indication of the potential risk of a medical technology on the continuation of the medical process.

To assess the technical reliability and clinical safety of a medical technology, the appropriate risks should be determined. Risk is the combination of the impact on patient safety along with the likelihood of any disruption.

Framework to Assess the Direct Effects on Patient Safety Part I: Impact of Medical Technology on Patient Safety

Clinical Risk					Ability to Respond to a Disruption			
Degree of invasiveness	none	low	moderate	high	The ease to obtain and/or change parts and materials	easy	moderate	difficult
Duration of contact	none	short	moderate	long	The ease to reset and/or reassemble the technology	easy	moderate	difficult
Active device	non active		active		Degree to which other technologies and procedures are impacted	low	moderate	high
Degree of transmitted energy change	none	low	moderate	high	Possibility to continue or restore the medical procedure	easy	moderate	difficult
Type of body systems affected	none	other	circulatory	nervous	Possibility to initiate an alternate course of action	easy	moderate	difficult
Phase of the operation of the technology	pre-	operative		post-	Degree to which the physical arrangement hinders the response to a disruption	low	moderate	high
Clinical Risk*	Low (1)	Moderate (2)		High (3)	**Ability to Respond to a Disruption***	Low (1)	Moderate (2)	High (3)
Impact of the Medical Technology on Patient Safety**					Low (<4)	Moderate (4)	High (4>)	

*Scores on low, moderate and high are respectively scored with 1,2 and 3 points
**The combined scores of the clinical risk and ability to respond are less then 4 for low, 4 for moderate and more then 4 for a high impact

Table 4a. Framework to assess the risk of a surgical flow disruption caused by a medical technology.

Framework to Assess the Direct Effects on Patient Safety Part II: Likelihood of Disruptions Caused by Medical Technology

Class	Potential Source of Error and Disruption		Low	Moderate	High
Device	Human factor errors	The operation of the technology is counter- intuitive			
		The access of controls is difficult			
	System integration difficulties	The interaction with other devices is complex			
		The interaction with other procedures is complex			
	Poor product materials	The materials are sensitive / delicate			
		The number of required materials and equipment			
	Poor production quality	The quality of the materials is inconsistent			
	Poor manuals and instructions	Manuals and instructions are unclear / inaccurate			
	Inadequate maintenance	In house maintenance capabilities are insufficient			
		The timing and execution of maintenance is erratic			
		The quality of maintenance is sub-standard			
Support	Lack of training	Incomplete training on the use of the technology			
		Inability to train and acquire skills and knowledge on the use			
	Poor incident reporting	Incident reporting is incomplete and / or infrequent			
	Re-use errors in sterilization and maintenance	Lack of / or inadequate pre-use inspections			
		Improper cleaning and sterilization			
		Inadequate / insufficient storage of materials and devices			
External	Environmental factors	Dependency on a limited source of power supply			
		Lack of environmental control (temperature, light, humidity)			
Potential likelihood of disruptions caused by a medical technology			low	moderate	high

Table 4b. Framework to assess the risk of a surgical flow disruption caused by a medical technology.

Framework Part III: Potential risk of the direct effects of a medical technology on patient safety

Impact \ Likelihood of disruptions	Low	Moderate	High
Low			
Moderate			
High			

Table 4c. Framework to assess the risk of a surgical flow disruption caused by a medical technology.

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3 The Influence of Medical Technology on Teamwork

3.1 Introduction

With the different types of errors related to teamwork, and the latent conditions that are of influence on these errors established, a focus on the construct teamwork is needed to determine how these latent conditions affect the team performance. This will result in a comprehensive model of teamwork. Furthermore I will discuss the attributes of a medical technology that shape these latent conditions. These findings will provide an insight in how a medical technology can affect the latent conditions in which a team of health care professionals operate. In this chapter the following research questions will be discussed:

How does technology affect teamwork and team performance?

a What is teamwork?
b Which attributes determine teamwork?
c What inputs have an effect on teamwork performance?
d What inputs of teamwork are affected by technology?

3.2 What is Teamwork

In healthcare literature much has been written on teamwork and how it can contribute to improve patient outcomes. The importance of teamwork on patient safety has been emphasized in research, and it is suggested that effective teams contribute to positive effects on patient outcomes[30]. Several studies have investigated the impacts of teamwork training and assessment of teamwork behaviours on teamwork performance. Teams that have been identified to show more effective behaviours, based on different behavioural scales, have been linked to fewer surgical problems and errors, higher intra-operative performance and shorter duration of medical operatio[31,32,33,34,35]. The reduction in errors and problems is a direct enhancement of patient safety while other benefits contribute to better performance and increased ability to detect errors through effective teamwork processes.

Unfortunately, these effects of team training of team effectiveness are diverse and often have only a poor to moderate impact on patient outcomes. The inconsistent findings are believed to originate form an unclear understanding of what comprises the concept of effective teamwork in healthcare[30,36,37].

To overcome this problem, a clear definition of the terms team and teamwork will make it possible to determine the different attributes of teamwork.

In common a team can be defined as “a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal, who have each been assigned specific roles or functions to perform, and who have a limited life-span membership.”[38]

This definitions reveals some characteristics that distinguish teams from groups and form the antecedents of teamwork. The antecedents provide insights on the context in which the concept teamwork is used. Antecedents for teamwork include: multiple professionals, common health goals, understanding of specialized tasks and roles and communication and information sharing.

Besides antecedents, the definition also provides characteristics that define the attributes of teamwork. Teamwork involves team members to exercise a concerted effort, employing interdependent collaboration and coordination and perform an adaptive strategy to shared decision making.

With these characteristics teamwork can be defined as:

"a dynamic process involving two or more health professionals with complementary backgrounds and skills, sharing common health goals and exercising concerted physical and mental effort in assessing, planning or evaluating patient care, which is accomplished through interdependent collaboration, open communication and shared decision-making."[36]

To be able to answer the question how medical technologies affect teamwork it is necessary to understand the requirements for effective teamwork performance. Team performance as described in this chapter depends on the extend to which a team executes the actions required in order to be effective. It pertains to how the task- and teamwork is carried out. The effectiveness is determined specifically by the accomplishment of the goals and objectives defined by the requirements of the organization and that of the patients.

To understand what factors influence a team's effectiveness, behavioural scientist have developed models on team performance that describe team effectiveness in terms of input, process and output[39]. In this chapter the input and process factors of teamwork performance are discussed.

3.3 What variables influence effectiveness of teamwork performance

Input factors facilitate or inhibit the nature of teamwork processes, they include any antecedent on an individual, team and task level and operate with contextual characteristics in the background. Individual characteristics are distinct qualities that each team member brings to the team. Team characteristics are factors that define team composition. Task characteristics determine which individual task and team competencies are required for successful performance. Contextual characteristics are the organizational and situational factors that impact several aspects of the functioning of teams.

The requirements for these input factors are determined by the work roles of the individual team members[3]. The role based approach of team effectiveness is helpful to determine how input factors such as medical technologies are able to change organizational structures and team processes. A role is a set of rules and expectations from the team members which directs the occupational behaviours[3]. These rules and expectations emerge from the task, social, physical and organizational environment. As such a role not only describes the task domain but also incorporates the wider social/team and organizational context.

Technologies are believed to change individual tasks and skills of non-relational elements of work roles. Non-relational elements of a work role encompass all the behaviours individuals perform that result from their position and are independent from a complementary position. These elements include skills and tasks that are impacted immediately by technology.

Through the strong interdependencies between team members and various disciplines in health care, changed non-relational roles impact the form and structure of interactions of relational elements and the team processes that constitute teamwork.

Team effectiveness is therefore mediated through the transformation of the composition, content, structure and environment within which individual roles are performed. It is concerned with which individuals perform work, what tasks are being performed and the relationship of the different work elements within the broader social and organizational context.

***Individual characteristics*:**
The individual traits of team members include task knowledge, skills and abilities[4]. Along with individual traits effective team require a set of interpersonal and self-managements skill such as, conflict resolution, team communication, goal setting and task coordination. Besides these team oriented variables individuals should posses traits that facilitate team interaction and functioning. These personality variables include adaptability, learning capacity, initiative, experience with teamwork and the use of mental models[38,39,40].

Characteristics	Variables	Definition
Individual	Task KSA	Knowledge, skills and attitudes required for individual task performance.
	Team KSA	A set of interpersonal and self-management attributes essential for effective team performance.
	Personality	Traits of individual team members that facilitate team interaction and functioning.
	Mental models	Knowledge structures that pertain to the task and team related aspect of situations.

Table 5. Individual input variables of team effectiveness models.

***Team Characteristics*:**
The main variables that comprise the team composition are team size, member homogeneity, power distribution and team stability[39,40]. Besides team composition, the cohesion of teams has been discussed to influence the quality of team performance[41].

Characteristics	Variables	Definition
Team	Team Composition • Size • Homogeneity • Power and knowledge distribution • Team stability	The collection of attributes of the team members, the distribution of these attributes within the team and the stability of the team over time.
	Team and task cohesion	The strength of the group's focus on a task and the level of attraction between team members.

Table 6. Team input variables of team effectiveness models.

***Task and work characteristics*:**
Specific task characteristics that facilitate or inhibit team coordination include task variety, the requirements on information processing, task complexity and specialization[40]. Variables that focus on the organisation of tasks have been identified to influence team work processes, these include autonomy on scheduling, methods and decision making[42]. A significant task characteristic is workload and time constraints that is closely tied to workload. Perceived workload strongly influence the performance of team members[43].

Besides the task specific characteristics, variables that relate to the manner in which the work is carried out have an impact on team processes. An important input factor is the architecture of teams. Team architecture refers to task variables that define how members interact. Three variables constitute team architecture: member proximity both physical and psychological, communication modality and distribution and the allocation of functions through team structure[5,38].

Allocation of function refers to the assignment of task to individuals and the nature of the interactions that ensure effective coordination and task completion. This variable is generally referred to as team interdependence which reflects the extent to which team members are connected to each other with respect to the task, goal and outcome[42].

The last variable that is of importance to the functioning of work is the social support and feedback provided within teams. Support and feedback is the extent to which members are presented with opportunities to participate in decision making and provide feedback, advice and assistance to other members[42].

Characteristics	Variables	Definition
Task and work	Task variety	The extend to which various skills are needed for task performance. This addresses the breadth of activities.
	Task complexity and uncertainty	The extend to which a job is multifaceted and difficult to perform.
	Task specialization and accuracy	The degree to which specialized task are performed, or specialized knowledge and skill is required for task performance. This addresses the depth of knowledge and accuracy of performance.
	Workload and time constraints	The perceived amount of work required to perform the task in respect to the capacity of the individual team member.

	Team architecture
	• Member proximity
	• Communication modality
	• Interdependence
	  • Task
	  • Goal
	  • Outcome
		Those systems or task variables that define or influence how team members interact.

	Support and feedback	The extend to which a job imparts information about individuals' performance and provide opportunities to gather assistance and advice.

Table 7. Task and work input variables of team effectiveness models.

***Organizational and situational characteristics*:**

Organizational support is an important aspect of the context of the work environment. The variables are often amendable to change and create a work environment that is conductive to effective teamwork performance. Organizational support includes the reward and training structure, information systems that distribute relevant process knowledge, available resources and managerial support to the team[5,38,42]. Organizational arrangements include regulations, procedures and the need to focus attention across the boundaries within the organization[5].

Situational factors comprise the organization's internal environment. These variables are difficult to change and therefore represent potential barriers and constraints to effective team performance. The physical environment and technological systems comprise the different variables[4].

The physical environment describes the actual conditions of the work that influences the amount of stress that is experienced. Technological systems are identified to poses great influence on the effectiveness of teamwork processes[38]. Variables that originate from the technology are the use and the ergonomics of the equipment, which is the extent to which work allows for correct movements and the complexity and variety of the technology. Other variables are the degree of automation which will impact the workload by increasing the compounded load on the cognitive abilities of the team members. The cognitive load is further increased by complacency due to over reliance on automation and systems complexity and interface designs[44].

Characteristics	Variables	Definition

Organizational and situational	Organizational factors
	• Support
	  • Reward and training structure
	  • Information systems
	  • Available resources
	• Arrangements
	  • Procedures and regulations
	  • Boundary spanning needs
		Variables outside the context of the team, providing direction, support and constraints on the functional abilities of the team.

	Physical environment	The actual physical context in which the work has to be performed.

	Technological systems
	• Use of equipments
	  • Equipment complexity
	  • Interface design
	  • Equipment variety
	  • Ergonomics
	• Level of automation
		Systems of components directly involved in acting on and/or changing and object from one state to another.

Table 8. Organizational and situational input variables of team effectiveness models.

A complete list of all 30 input variables is presented in table 9. The variables are categorized according to the context in which they influence the work roles and individual characteristics. The three contexts are the task, social and environment.

In the next paragraph the process factors that comprise teamwork will be discussed along with the different input variables that impact theses processes.

Input Variables of team effectiveness						
		Task		**Social**		**Environment**
	T01	Task variety		*Team Composition:*		*Organizational Support:*
	T02	Task complexity and uncertainty	S01	-Size	E01	-Rewards and training structure
	T03	Task specialization and accuracy	S02	-Homogeneity	E02	-Information systems
	T04	Information processing needs	S03	-Power and knowledge distribution	E03	-Available resources
	T05	Workload and time constraints	S04	Team stability		*Organizational arrangements:*
	T06	Autonomy		*Team architecture:*	E04	-Procedures and Regulations
			S05	-Member proximity	E05	-Boundary spanning needs
Work characteristics			S06	-Communication modality	E06	Physical environment
			S07	-Interdependence		*Technological systems*
			S08	Support and feedback		*-Use of equipments*
			S09	Task and team cohesion	E07	-Equipment complexity
					E08	-Interface design complexity
					E09	-Equipment variety
					E10	-Ergonomics
					E11	-Level of automation
Individual characteristics	T07	Task KSA	S10	Team KSA		
	T08	Task Mental models	S11	Personality		

Table 9 Input variables of team effectiveness

3.4 Which attributes make up the construct teamwork

Based on the definition of teamwork it becomes clear how critical teamwork is for the delivery of healthcare and patient safety. Any medical decision requires knowledge from specific functional roles as from a common shared goal and understanding of the situation. These decisions not only directly affect the medical process but, because of the interdependence between health care professionals, require a great amount of coordination and communication to optimize the activities and the performance level of the entire team.

Teamwork depends on each team member being able to anticipate and adjust to each other's needs and actions. Thus besides a distinct set of task work skills a team requires a wide range of cognitive and interpersonal knowledge, skills and attitudes (KSA's) to be effective in a complex environment.

Cognitive skills are defined as the mental processes used for gaining and maintaining situational awareness for solving problems and taking decisions[45]. And interpersonal skills are regarded as communications and a range of behavioural activities associated with teamwork[45].

In 1996, from research on crew resource management in aviation, a system was developed to determine the non technical skills of teams. The resulting Oxford NOTECH system comprises a set of four main skills, cooperation, leadership and managerial skills, situation awareness and decision making[32,45].

In addition to this system later research then designed a method to describe the processes of healthcare teams using task analysis with subject matter experts[46,47]. This research resulted in the non technical skills for surgeons (NOTSS) and non technical skills for anaesthetists (ANTS) systems. These system use the categories situation awareness, decision making, communication and teamwork and finally leadership to describe the teamwork processes.

Another research on teamwork skills and requirements in surgical teams led to the observational assessment for teamwork in surgery (OTAS) system and focuses on assessing cooperation, leadership, coordination, monitoring and communication[48].

In studying teamwork skills in intensive care units[49] a similar set of four categories that was identified. The skills that were identified are communication, leadership, coordination and decision making.

In a review of the literature on teamwork skills in health care in 2008 a number of aspects were found to be relevant to the quality and safety of patient care[2]. These include the quality of the collaboration, shared mental models, coordination, communication and leadership.

An earlier review in 2005 and 2006 identified five characteristics of effective teamwork[50,51]. These elements are leadership, mutual performance monitoring, backup behaviour, adaptability and team orientation. However, in order to fully realize the performance improvements, research indicates that a number of coordinating skills are needed in addition. These are the use of shared mental models, trust and communication[38,51,52].

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The mentioned studies all define the important requirements for teamwork skills in a variety of disciplines. Although the researchers have used different terminology, the generic skills can be clustered into a set of six main categories of teamwork skills. Table 10 provide a summary of the attributes.

Among the cognitive skills are situational awareness, decision making and shared mental models. Leadership, communication and cooperation and teamwork make up the interpersonal skills.

Teamwork Attributes	
Main Attributes	**Element and Reference**
Decision Making	Decision making - Mishra et al.[32] Decision making - Yule et al.[46] Decision making – Flin[47] Decision making - Reader et al.[49]
Situational Awareness	Situational awareness – Mishra et al.[32] Situational awareness – Yule et al[46] Situational awareness – Flin[47] Monitoring – Healey et al.[48] Mutual performance monitoring – Baker et al[51]
Leadership	Leadership and managerial – Mishra et al.[32] Leadership – Yule et al[46] Leadership – Flin[47] Leadership – Reader et al.[49] Leadership and coordination – Healey et al.[48] Leadership – Manser[2] Leadership – Baker et al[51]
Co-operation and Teamwork	Cooperation – Mishra et al.[32] Teamwork – Yule et al[46] Teamwork – Flin[47] Coordination – Reader et al.[49] Cooperation – Healey et al.[48] Collaboration and coordination – Manser[2] Back-up behaviour and team orientation – Baker et al[51]
Communication	Communication – Salas et al.[38] Communication – Yule et al[46] Communication – Flin[47] Communication – Reader et al.[49] Communication – Healey et al.[48] Communication – Manser[2] Communication – Baker et al[51]
Shared Mental Models	Shared mental models – Salas et al.[38] Shared mental models – Manser[2] Shared mental models – Baker et al[51] Shared mental models – Zhou et al[52]

Table 10. Attributes of skills for effective teamwork performance

3.4.1.1 Decision Making

It is the generation and selection of an alternative course of action based on available information, knowledge, prior experience, expectations, context and goals[45].

Decision making is a critical skill on the outcome of team performance, as decisions set up actions that require coordination and collaboration and shape the requirements for updated situational awareness. It involves problem identification, information exchange, generation and evaluation of solutions, implementation and evaluation of consequences[41].

The benefits of decision making in a team context is that groups generate more correct solutions, they are better in identifying errors and a group is better at choosing, judging and problem solving compared to individual decision making[53]. From a perspective of a functional theory of group decision making it is suggested that groups make use of effective team processes to gather, analyze and comprehend information. Figure 5 shows a general model of decision making for groups and distinguishes 4 separate stages.

- *Orientation:*

  The decision process starts with the recognitions of needs and deficiencies in the current state of the situation[54]. In this first phase a team must then organize and plan the procedures it will use to reach a decision. This phase is concerned with attaining and maintaining a good level of situational awareness. This is a separate construct that will be discussed later on.

  The result of a successful orientation phase is the development of a shared mental model. This model will facilitate the team's ability to act adaptively to the situation by understanding and recognizing the tasks and goals of the other team members. The shared mental model is another cognitive construct of teamwork that will be discussed later on.

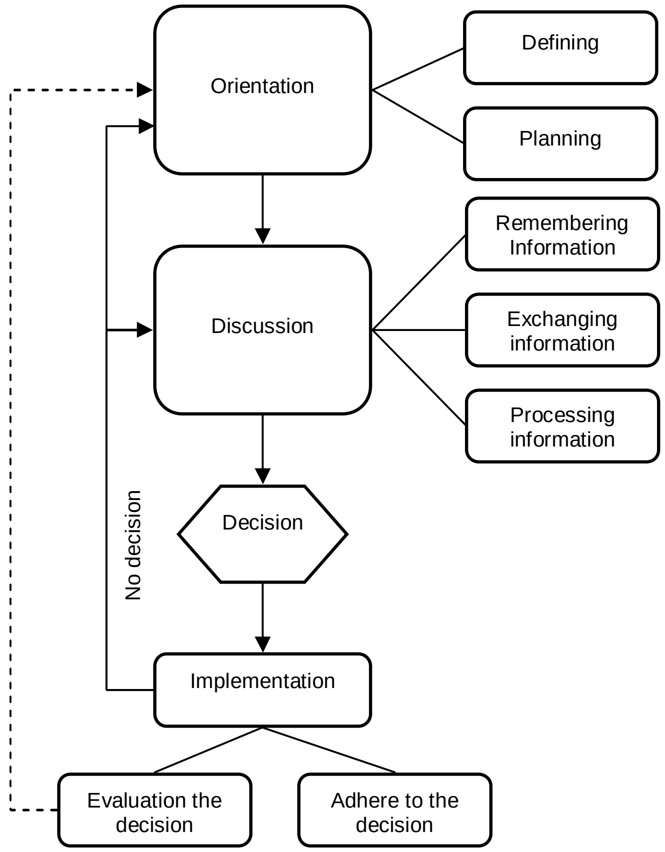

Figure 5. Functional model of group decision making[55]

- *Discussion:*

  In this phase the team gathers and processes the information needed to make a decision. The collective processing of relevant information requires the remembering, exchange and processing of information by the team members in active discussion to formulate decisions, choices and judgements.

  The discussing phase within groups benefits greatly from a collective memory and group information sharing that provides other members with cues to gather more relevant information. A pitfall with group discussion is the use of misleading cues or reliance on other members to gather information. Also distribution of knowledge and ineffective discussion can enhance area's of expertise among teams invisible to the other members.

  Furthermore the processing of information is enhanced through correct use of discussion in decision making. Questions about the information and the discussion of options by a group greatly improves on an individuals ability to uncover errors in judgement and corrections to options. Information sharing and critical evaluation of ideas show strong correlation with judgemental accuracy[56].

- *Decision:*

  The manner in which team reach a decision may vary according to the situation. For healthcare teams it is important to understand who actually makes the decision since these teams consist of multiple disciplines that possess unique knowledge and abilities. According to the normative model of decision making five basic types of methods for decision making are identified, these are: decide by one leader, consult (individual or group), facilitate in discussion and delegate decisions.

  Factors of the situation that determine the best type of decision method are the importance of the problem and the consequences of the decision, the knowledge of the leader and the group, the need for support of the decision by the team and the level of conflict and interdependence.

- *Implementation:*

  After a decision is reached two significant processes are needed to resolve the problem. First the option needs to be implemented. And second, the quality of the decision must be assessed and evaluated.

  The implementation is affected by the perception by the team members on the quality and fairness of the decision process. People are more likely to support a decision if the procedure was consistent, without self interest, on the basis of accurate information, following moral and ethical standards and with the interest of all concerned represented[57]. An important factor that influences the perception is the believe that members had an active role in the process to express any concerns.

3.4.1.2 The influence of input variables on Decision Making.

Cognitive limitations of the team members have significant influence on the decision making process. Sometimes the situation may demand too much cognitive capacity from the members and result in judgemental and confirmation biases. These biases involve the manner in which information is perceived. Information can be misused, overlooked of inappropriately used with incorrect mental rules. When these errors of cognition in decision making result in groups being reluctant to disagree on decisions the process is then known as groupthink and results in conformity pressure, illusions, misperceptions and faulty decision making[41].

Three sets of antecedents of groupthink are identified, these are: group cohesion, structural faults of the group or organization and situational context[58].

In a cohesive group, members refrain from speaking out against decisions. The cohesiveness is necessary for groupthink but requires structural faults of the group or organizations that inhibit information flows and promotes carelessness in the decision making process. Insulation of group members and barriers raised by a dominant leadership style are the most prolific structural faults that contribute to groupthink. Both insulation and dominant leadership are examples of the physical and psychological distance that construct member proximity. Greater distances negatively influence cohesion and decision making[38]. Increased distance between team members and subgroups require the use of different communication modalities which affect the engagement of team members and reduce involvement in the decision making process[59].

Also the situational context influences groupthink. Factors that increase workload and time constraints force members to come to a decisions induces stress. This stress can cause oversimplification of omissions of information.

Besides groupthink, the collective information processing to reach a decision is impacted by social factors. Increasing the size and homogeneity of a team introduces opposing forces to group performance and productivity[59]. Larger groups tend to generate less ideas when individual members become less sensitive to exploration of different points of view and rely more on others for this process. Team members adapt a more mechanic method of information sharing that is less effective and more distracting then the adaptive style needed in group decision making. The distribution of knowledge and power within subgroups and disciplines increases with team size and interdependence further impacts the group information sharing. Last, increased autonomy affects the option selection and implementation when increased autonomy reduces participation and the need for support.

Aspects of technological systems influence the decision making process through interface design and data visualisation and the level of automation. The availability of large amount of data through the use of complex systems and interface designs greatly affects the workload and team decision making[60]. Lack of knowledge of systems or complex and increased variety of systems used can distort the data visualization which then is misinterpreted and misused[61].

The level of automation can affect team decision making. Automation bias refers to the use of automation as a heuristic replacement for vigilant information seeking and processing[59]. Option generation and selection using human-machine levels of automations distract members from task and reduces team performance[44].

The different influencing factors and input variables are presented in table 11.

Cognitive Process	Influencing Factor	Input Variable
Information procession	groupthink	-Team cohesion -Member proximity -Communication modality -Information processing needs -Time constraints
	Collective memory	-Team size -Homogeneity -Power and knowledge distribution -Autonomy
	Information observability	-Interface design complexity -Level of automation -Task KSA
Selecting	Authority	-Autonomy -KSA -Interdependence -training and rewarding
Assessing	Participation	-Autonomy -Team size -Member proximity -Power and knowledge distribution -Support and feedback

Table 11. Input variables influencing information processing and group decision making

In conclusion to this paragraph on decision making figure 6 and table 12 summarize the main cognitive processes, required behaviors and their influencing factors that determine the quality of the decision making process.

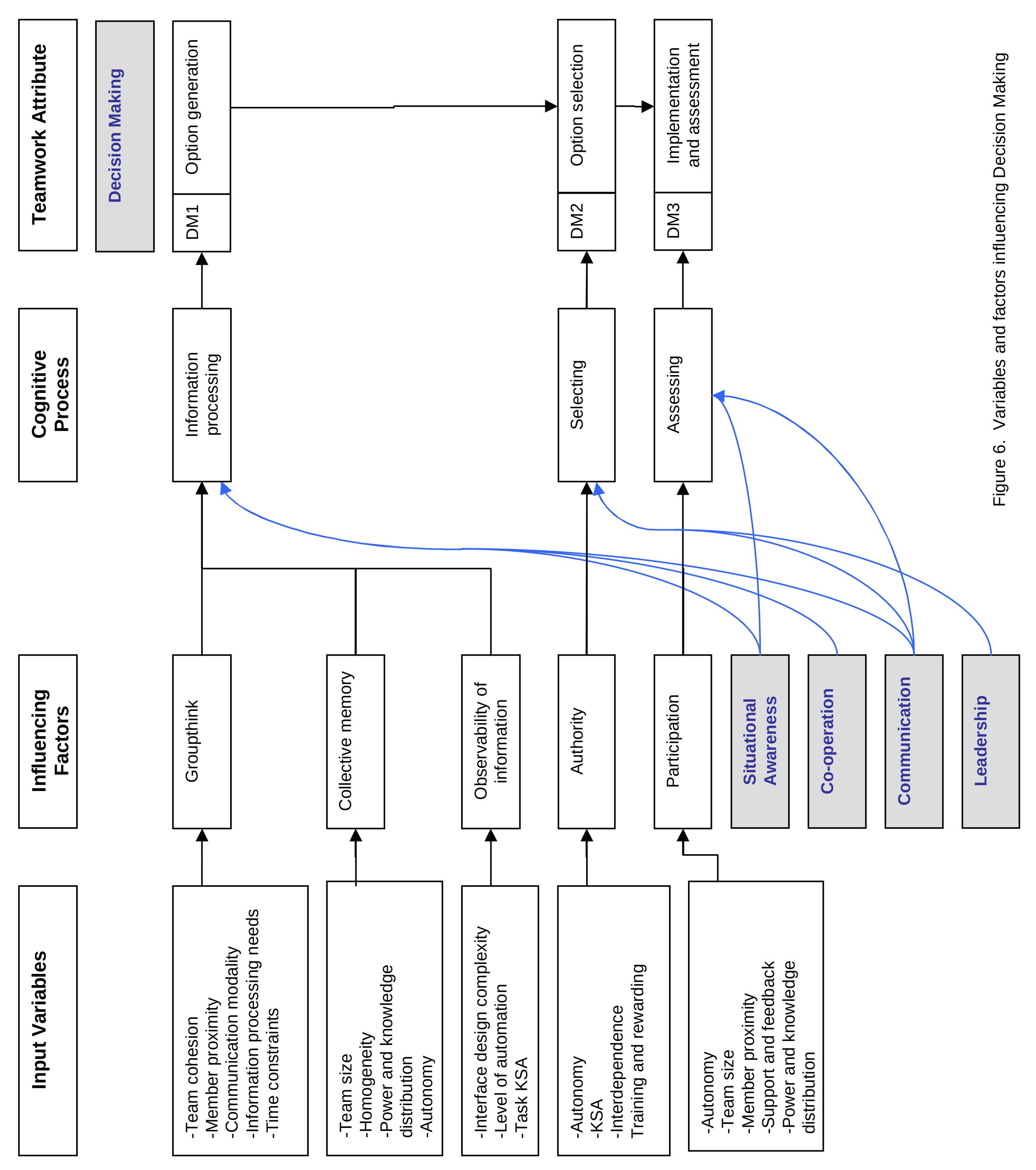

Figure 6. Variables and factors influencing Decision Making

Decision Making The generation and selection of an alternative course of action based on available information, knowledge, prior experience, expectations, context and goals.					
Element	**Definition**	**Cognitive process**	**Influencing factor**	**Input variables**	**Main behaviours**
Option generation	Gathering and processing the information needed to make a decision.	Information processing	Groupthink Collective memory Information observability Communication Co-operation Shared mental models	**Task** • Information processing needs • Time constraints • Autonomy • Task KSA **Social** • Team size • Homogeneity • Knowledge and power distribution • Member Proximity • Interdependence • Communication modality • Team cohesion **Environment** • Interface design complexity • Training and rewarding • Level of automation	Share information Recognize problem Formulate problem Discuss and formulate options Use opinions from the team
Option selection	Choosing a solution to a problem and inform relevant personnel.	Selecting	Authority Communication Leadership		Asses risk Communicate decisions Provide alternate options
Implementation and Assessment	Undertaking the chosen option and continually reviewing its suitability in light of changes in the situation.	Assessing	Participation Communication Situational awareness		Confirm selected course Update team on progress Discuss progress

Table 12. Elements, behaviours and influencing variables of Decision Making

3.4.2.1 Situational Awareness

It is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the future[62]. Shared situational awareness occurs when team members possess contextual task and team information about the awareness that must be communicated to and understood by the other team members.

Figure 7 represents a general model of situation awareness placed within a dynamic decision making environment. In this model situation awareness is represented as a precursor to decision making and is divided into three levels according to the definition. The model furthermore reveals several influencing factors. These factors all relate to different cognitive mechanisms for the development of awareness such as perception, attention, pattern matching and analysis.

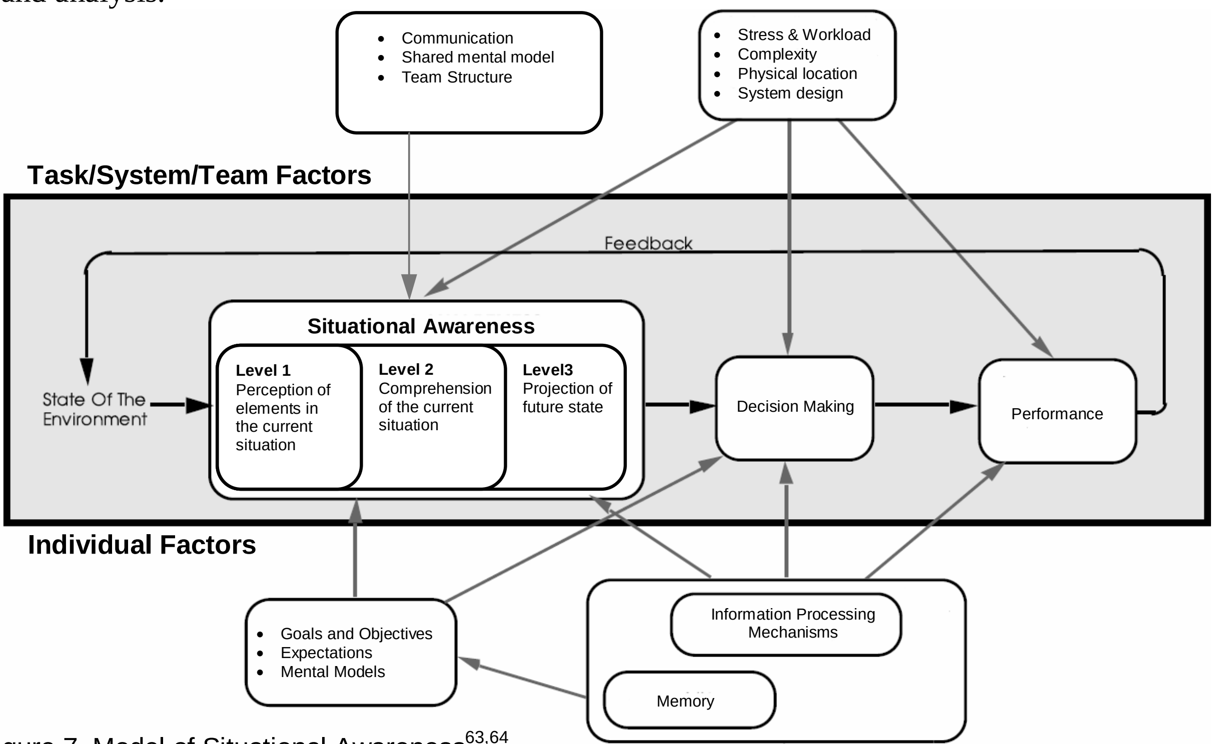

Figure 7. Model of Situational Awareness[63,64]

- *Level 1: Perception*

  The subconscious and intuitive perception of the elements in the environment. This is achieved through scanning for cues and patterns on the status and attributes relevant to the medical process.

  Observations can be made direct from the environment, brought forward through other team members or indirect via systems. The latter requires system and interface knowledge to understand how cues are transformed and displayed[65].

  The behaviours needed to gain a high degree of level 1 awareness involve understanding the current plans and goals, monitoring for expected cues, communicating cues and changes, updating the team on changes of the situation or to the systems and procedures and scanning the environment for conditions that may affect the abilities of perception such as workload and possible problems[45,46].

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- *Level 2: Comprehension*

  The comprehension of the meaning of the information, which entails the creation of a mental model of the situation. This model is then compared against existing knowledge structures to identify any differences between the situation with the expected situation and selected goals.

  The cognitive mechanism of pattern matching structures the manner in which the situation is perceived and comprehended. This mechanism is reliant on memory, the use of mental models and goals and expectaions[65].

  Memory is critical to the ability to act consistently and develop knowledge. It is thus an essential mechanism to extract and apply information from and to the situation. It is the storage and retention of learning, experience and knowledge. However the human capacity to use memory is strongly limited. Short term working memory is limited by attention and workload. Strategies to overcome limitations with short term memory are chunking, encoding and prioritizing information and restructuring information displays.

  An addition to overcome the limitations associated with short term memory the human information processing mechanisms use long term memory to structure the awareness more efficiently using mental models of the situation based on experience, knowledge and goals.

  These models serve to direct the limited attention efficiently, integrate information without loading the working memory and assist in projecting future states of the situation. Mental models have a strong relation to situational awareness[65,], but can negatively impact awareness through information bias, incorrect models and over reliance of defaults in the model. The accuracy of the mental model must be confirmed by team members by sharing information on the perception of the situation and the statement of any intentions.

- Level 3: Projection

  The projection of events or actions in the future based on the comprehension of the mental model of the situation. This is the highest level of awareness and is achieved through knowledge of the status and dynamics of the medical process.

  Projection involves the same mechanism that are required to attain a high degree of level 2 awareness but an analysis based on knowledge and expectations is used to anticipate on changing needs and requirements.

  The use of the mental model depends on the selection goals and expectations. The selection is critical in attaining a proper degree of situational awareness. Once a goal is selected the mental model will direct attention for goal driven purposes to attain information required to perform the set goals, or it will direct attention for data driven purposes to identify changing goals[65,66]. Dynamic switching between these purposes is an essential mechanism for good awareness and assessment and can be degraded by misinterpretations, attentional narrowing and information bias.

A high degree of situational awareness is paramount in team performance by enabling team members to identify and avoid incidents and strengthens the quality of decision making by the health care professional. Along with a shared mental model, situational awareness serves a the foundation for teams be adaptive and in such being able to implicitly and effectively coordinate their behaviours[38,67]. Recent studies have indicated that situational awareness is strongly associated with errors[33], and that the accuracy and similarity of shared mental models among team members predict the quality of team processes and performance[68.]

Limitations by a team member to achieve a high degree of awareness on anyone of the three levels will result in an increase of the likelihood of errors on the next level. These errors are directly linked to effective decision making and performance[69]. From investigations in aviation it is found that roughly 88% of the identified human errors are attributed to errors with Situational Awareness[63].

Errors with SA differ fundamentally with errors observed with decision making, in that the decision a team has made is correct in accordance with the understanding of the situation, but that this understanding is inaccurate. These errors are thus difficult to understand and to correct because their causes are often irreconcilable with the understanding of the situation. The distribution of errors for each level[70] were found to be 80% for level 1, 17% level 2 and 3% for level 3.

Based on the review of literature on human information processing and cognition a taxonomy for classifying errors is presented in table 13. These errors result from ineffective cognitive mechanisms to perceive and process the information. Factors influencing the attention and the required memory capacity to process them have the greatest impact on the errors related to situational awareness.

	Description	Examples
Level 1	Failure to correctly perceive the situation	-Data not available -Data difficult to detect -Failure to monitor or observe data -Misperception of data -Memory loss
Level 2	Failure to comprehend the situation	-Poor mental model -Use of incorrect mental model -Over-reliance on default values in model
Level 3	Failure to project the situation into the future	-Poor mental model -Over projection of current trends

Table 13. Error Taxonomy Situational Awareness[70]

On level 1 the majority of errors (47%[70]) occur with the failure to monitor or observe data. This failure is caused by distractions of other tasks such as equipment failures, information relays and performing procedures. Besides the distractions, omissions and a high workload are the main influencing factors. On level 2 and 3, most errors arise with poor mental models.

3.4.2.2 The influence of input variables on Situational Awareness.

As stated above, the main cognitive capabilities that influence the degree of awareness are attention and the required or limited memory capacity for pattern matching and dynamic switching. The influence of variables on errors related to the use of poor mental models and limited memory capacity will be investigated in the discussion on the other cognitive construct of shared mental models.

Attention is the main cognitive process that affects the perception of cues from the environment. Input variables that are important are those that increase the workload, the amount of distraction and factors that hinder the ability to observe data.

Workload is affected by the nature of the task, such as the physical and mental demand. It is further affected by the circumstances under which the task is performed and by the state and skills and experience of the team member[45]. Task complexity and uncertainty and information processing needs have been indicated to increase the mental workload[71]. The mental workload furthermore is impacted by the degree of automation[38,44]. Awareness has been shown to decrease as a result of increased automation when performing multiple tasks. Performance decreases due to lowered vigilance and increased monitoring demands of automation. The circumstances of the task are influenced by the degree of task specialization and accuracy[71], time constraints[45] and task variety[45].

A general framework has been developed[72] that describes the factors that contribute or hinder the ability to observe the environment. The arrangement of work determines the portion of a task that can be observed by each individual, as such it closely resembles the input variable of team architecture, specifically the member proximity and interdependence[71]. Another characteristic is the openness of interaction that refers to the degree to which interactions provide opportunities to team members to make relevant contributions. It depends on the nature and openness of the communications and refers to the communication modality variable. The last characteristic is the openness of the technology tool. This is the degree to which an observer is able to infer relevant information. This is influenced by the interface design and complexity of the equipment.

Finally, distractions affect the amount of attention team members can direct to the task of perception. Distractions may arise from the organizational arrangements as well as the physical environment and the ergonomics. Table 14 provides an overview of the different variables discussed above that affect situational awareness.

Cognitive Process	Influencing Factor	Input Variable
Attention	Workload	-Complexity and uncertainty -Information processing needs -Level of automation -Specialization and accuracy -Time constraints -Variety -Task KSA
	Ability to observe	-Member proximity -Interdependence -Communication modality -Interface design complexity -Equipment complexity
	Distraction	-Organizational arrangements -Physical environment -Ergonomics -Interface design complexity

Table 14. Input variables influencing attention

In conclusion to this paragraph on situational awareness figure 8 and table 15 summarize the main cognitive processes, required behaviors and their influencing factors that determine the degree of situational awareness.

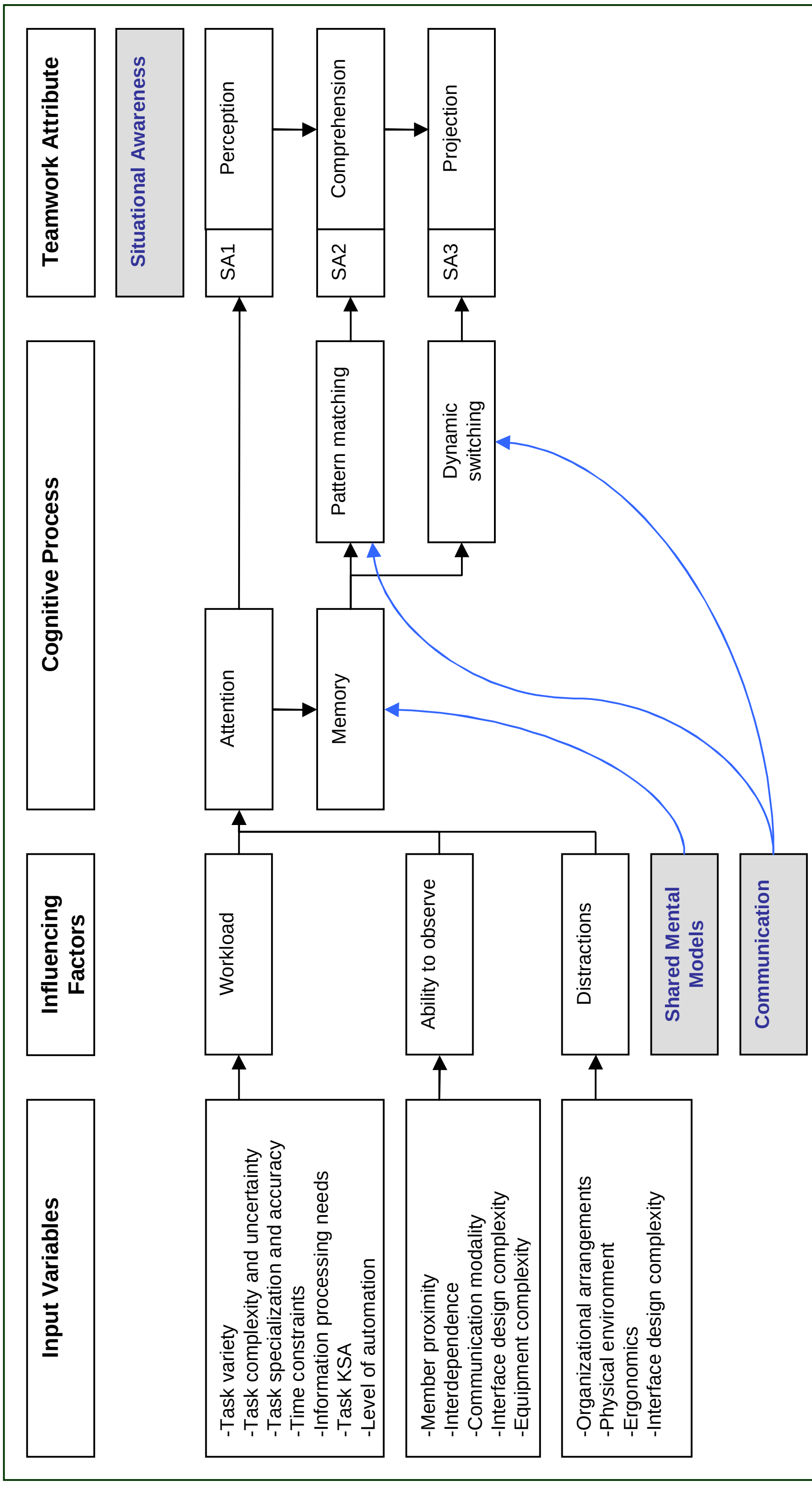

Figure 8. Variables and factors influencing Situational Awareness

Situational Awareness The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the future.					
Element	**Definition**	**Cognitive process**	**Influencing factor**	**Input variables**	**Main behaviours**

Perception	The subconscious and intuitive perception of the environment. This is achieved through scanning for cues and patterns on the status and attributes relevant to the medical process.	Attention	-Workload
			-Ability to observe
			-distraction
				Task
				• Complexity and uncertainty
				• Variety
				• Specialization and accuracy
				• Time constraints
				• Information processing needs
				• KSA's
				Social
				• Member Proximity
				• Interdependence
				• Communication modality
				Environmental
				• Organizational arrangements
				• Physical environment
				• Technological systems
				  • Equipment complexity
				  • Interface design complexity
				  • Ergonomics
				  • Level of automation
					Review goals
					Monitor environment
					Share information
					Acknowledge changes

Comprehension	The comprehension of the meaning of the information, which entails the creation of a mental model of the situation and the comparison with shared mental models.	Pattern Matching	-Limited memory -Communication -Shared mental models		Discuss information Request updates Inform on situation and goals Describe cues
Projection	The projection of events or actions in the future based on the comprehension of the mental model of the situation.	Dynamic switching	-Limited memory -Communication -Shared mental models		Assess future environment Describe expectations Communicate plans Scan team workload

Table 15. Elements, behaviours and influencing variables of Situational Awareness

3.4.3.1 Leadership

Leadership is the guidance of others in their collective pursuits, by organizing, directing, coordinating, supporting and motivating their efforts[41]. It is a collection of interpersonal processes whereby cooperating members influence and motivate others to attain the goals of the team. These processes are reciprocal, transactional, transformational, cooperative and adaptive[41].

The reciprocal characteristic of leadership implies that a leader must display qualities and skills that enhance interactions and cooperation between the leader and the follower. This will result in transactional processes of team members exchanging skills and capabilities to achieve a desired performance. Good leadership will also transform the members motivation and satisfaction by changing their beliefs, values and needs. These processes will enhance the ability of the leader to adopt an adaptive goal seeking process that organizes and motivate team members efforts to attain their goals. Leadership is thus distinct from other forms of influence, such as management and supervision.

From literature, a coding technique identified a set of seven leadership behaviours categories regarding surgeons[73]. In Table 16 these categories are presented and described. Two of these leadership behaviours, making decisions and communicating, are part of other teamwork constructs and will be left out in the discussion of the attribute of leadership.

Behavioural category	Description of behaviours
Maintaining Standards	Behaviours that reinforce standards to follow rules and establish procedures.
Managing Tasks	The ability to maintain task performance while ensuring timely and effective task completion.
Making Decisions	The individual ability to seek out and synthesise appropriate information and make informed judgements.
Managing Resources	Refers to both the people in the OR team and equipments required for surgery. Effectively assign resources according to the situation or context.
Directing & Enabling	Interpersonal behaviours that promote accomplishments of task and interpersonal goals through team members.
Guiding & Supporting	Behaviours for a teaching and coaching perspective, involving team decisions and allowing input from the team.
Communicating	Behaviours to enable information exchange to perform as a team unit by concerted and synchronized performance of work.

Table 16. Categorisation of intra-operative leadership behaviours[73]

To determine which behaviours a leader must develop, a task-relational model of leadership is constructed[74]. With this model behaviour is classified as either performance/task maintenance or relationship/team maintenance.

Task maintenance leadership relates to the team's work and its goals. It involves promoting task completion, regulating behaviour, monitoring communication and reducing goal ambiguity. Three of the seven behaviours focus to ensure goal achievement and therefore are classified to task maintenance. These are: the maintaining standards, managing tasks and managing resources

Relational maintenance leadership relates to the interpersonal relations within the group. This is achieved by maintaining and enhancing a positive team climate, mutual trust, openness and recognizing team member's performance. The remaining two behavioural categories, directing and enabling and guiding and supporting are aimed to ensure that the leader focuses on enhancing the team climate and functioning.

3.4.3.2 The influence of input variables on Leadership.

Factors that influence the required behaviours of task and relational leadership are divided in aspect of the team members, task or the organization of the team[75], table 17 indicates these different aspects that reduces the need for leadership.

According to the contingency theory a leader's success is determined by two factors, the leadership style and the favourability of the group situation[76]. Leadership style is by large determined through the personality traits of each individual team members.

The favourability of the group situation is also referred to as situational control. Situational control will determine if leaders will be able to accomplish decisions, actions and suggestions. It is influenced by the strength of relationships among team members, the task structure and the distribution of power and knowledge.

Characteristic	Reduces the need for leadership	
	Task	Relational
Team member		
Skills, knowledge and experience	X	
Need for independence, autonomy	X	
Professional orientation	X	X
Indifferent to group rewards	X	X
Task		
Unambiguous and routine	X	
Methodologically invariant	X	
Provides feedback on accomplishment	X	
Intrinsically satisfying		X
Organization of the team		
Formalized	X	
Inflexible	X	
Specific staff functions	X	
Cohesive group	X	X
Rewards not controlled by leader	X	X
Physical distance between members	X	X

Table 17.Factor that impact task and relationship leadership[75]

The strength and cohesiveness of the team relations determine the need for monitoring and team climate behaviours. The structure and clarity of the task influence the need to discuss the correctness of decisions and the team's goals. Finally, the position of power refers to the authority of the leader and increases the control over the situation.

Table 18 presents the input variables that affect leadership.

Process	Influencing Factor	Input Variable
Control	Task structure clarity	Task complexity and uncertainty
		Task variety
		Task KSA
		Support and feedback
	Authority and style	Autonomy
		Team cohesion
		Member proximity
		Interdependence
		Power and knowledge distribution
		Information systems
		Available resources
		Procedures and regulations
		Boundary spanning needs
		Personality

Table 18. Input variables influencing Leadership

In conclusion to this paragraph on leadership figure 9 and table 19 summarize the main processes, required behaviors and their influencing factors that affect leadership.

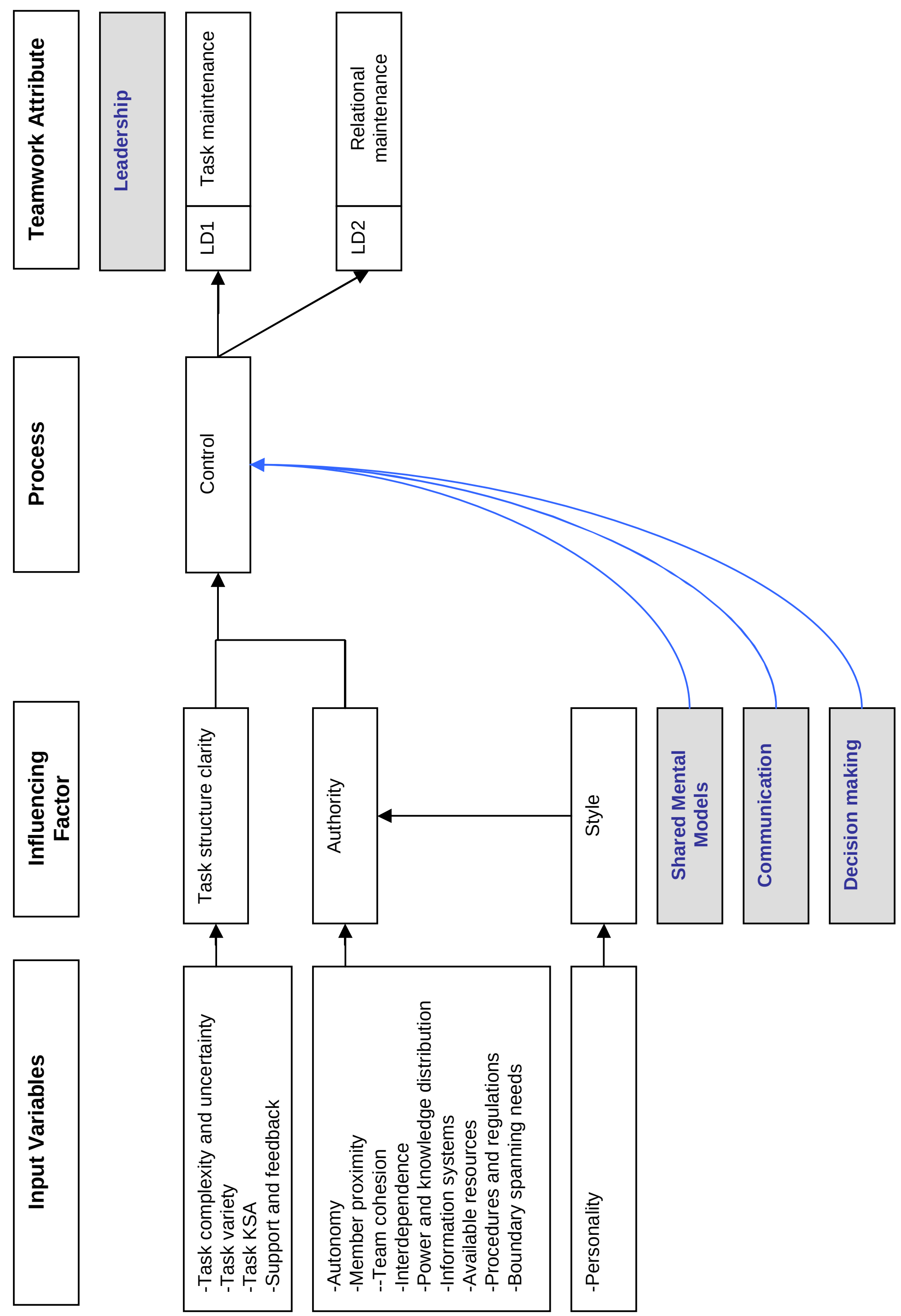

Figure 9. Variables and factors influencing Decision Making

Leadership Leadership is the guidance of others in their collective pursuits, by organizing, directing, coordinating, supporting and motivating their efforts.					
Element	**Definition**	**Process**	**Influencing factor**	**Input variables**	**Main behaviours**
Task maintenance	Promoting task completion, regulating behaviour, monitoring communication and reducing goal ambiguity to facilitate the achievement of group goals.	Control Leading	Task structure Authority Decision making Communication Shared mental models	**Task** • Complexity and uncertainty • Variety • Autonomy • KSA's **Social** • Member Proximity • Knowledge and power distribution • Interdependence • Team cohesion • Support and feedback • Personality **Environmental** • Organizational arrangements • Organizational support	Maintain standards Manage and delegate tasks Delegate workload Manage resources Scan boundaries Utilize and plan resources
Relational maintenance	Maintaining and enhancing a positive team climate, mutual trust, openness and recognizing team member's performance.				Direct and enable team Use authority and assertiveness Guide and support team Consult with team Coaches member behaviours

Table 19. Elements, behaviours and influencing variables of Leadership

3.4.4.1 Co-operation and Teamwork

Co-operation is the ability to work effectively in a team[45]. It is difficult to distinguish between the behaviours for cooperation and those of team communication and leadership. Both are precursors for effective team co-operation. The behaviours are focussed on building and maintaining a strong and cohesive team.

The oxford NOTECHS system distinguishes four separate elements that support a strong team oriented approach[32]. Team building and maintaining, providing support to others, understanding team needs and conflict solving are the interpersonal skills involved.

Team building and maintaining is about the ability to establish positive interpersonal relation between team members and their active participation in fulfilling the tasks. Desired behaviours include the establishment of an atmosphere for open communication and participation, encourage inputs and feedback and avoid hostilities. The element of conflict resolving can be included into team building since its behaviours are required to articulate different interpersonal positions and provide suggestions on what is right.

Providing support to others relates to providing help to team members when they require assistance in demanding situations. It is closely connected to understanding team needs. This is the acceptance of others and understanding their personal condition and abilities. In other research both elements are grouped as back-up behaviour[48,67], where team members anticipate the needs through accurate knowledge of team responsibilities and allocate workloads accordingly.

3.4.4.2 The influence of input variables on Co-operation and Teamwork.

Strong cohesion among teams brought about by positive team building has a direct and positive influence on performance, which in turn reinforces this cohesion further[41,77]. The success of cohesive teams to outperform less cohesive teams, when tasks require high levels of interaction and interdependence, is due to the enhanced coordination of their members. The sharing of a mental model facilitates the coordination and requires team members to actively participate in the team. A number of factors determine the degree of cohesiveness and participation, including attraction and structure of the team.

Attraction is a form of social cohesion and is determined through individual attitudes and personality that foster team work. The input variable team and task cohesion depicts the degree of perceived attraction to the team, despite the confusion name this is a variable of cohesiveness. These attitudes are further influenced through the team structure and social factors. The team size, homogeneity, stability, member proximity, communication modality and interdependence[41,59] determine the frequency of interactions between team members. A final factor that impacts social cohesion is organizational support which enhances the cohesion of groups through training and rewards structure. Task cohesion and the depth and frequency of interactions required to perform the task is impacted through the level of autonomy and the distribution of knowledge and power.

Providing support and back-up to team members requires individuals to be able to monitor each other's needs and capabilities. Team KSA's and teamwork experience increases the individual abilities to recognize situations of overload. Member proximity and the chosen communication modality influence the degree to which capacities can be observed.

Table 20 lists all the input variables that affect the co-operation and teamwork processes.

Process	Influencing Factor	Input Variable
Creating Team Cohesion	Attraction	Personality
		Team KSA
		Team cohesion
	Task structure	Team size
		Team homogeneity
		Team stability
		Member proximity
		Communication modality
		Interdependence
		Organizational support
		Autonomy
		Power and knowledge distribution
Supporting	Observability team capabilities	Team KSA
		Member proximity
		Communication modality

Table 20. Input variables influencing co-operation and teamwork

In conclusion to this paragraph on co-operation and teamwork figure 10 and table 21 summarize the main processes, required behaviors and their influencing factors of co-operation and teamwork.

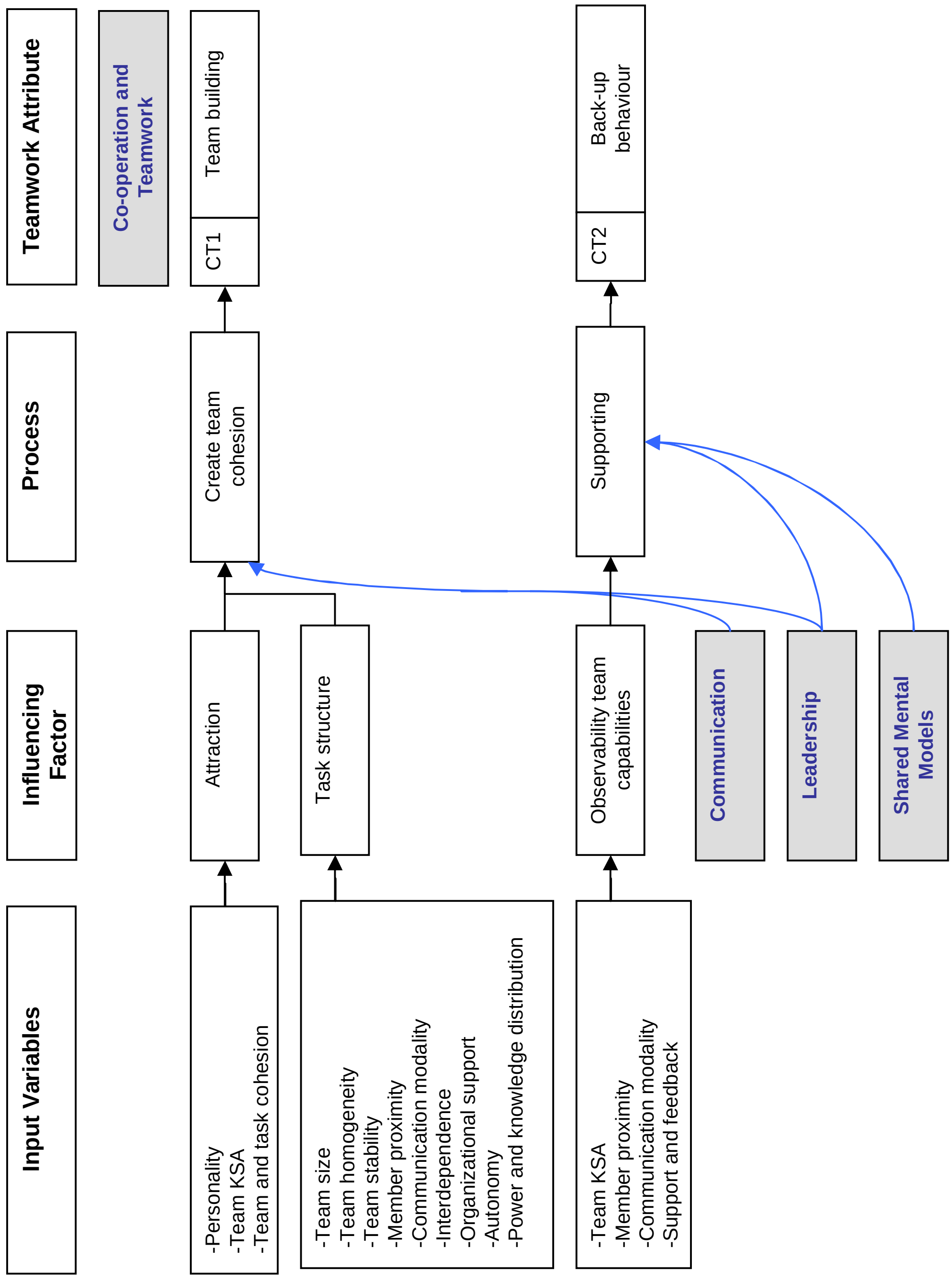

Figure 10. Variables and factors influencing co-operation and teamwork

Co-operation and Teamwork Co-operation is the ability to work effectively in a team.					
Element	**Definition**	**Process**	**Influencing factor**	**Input variables**	**Main behaviours**
Team building	The ability to establish positive interpersonal relation between team members and their active participation in fulfilling the task.	Creating team cohesion	Attraction Task structure Communication Leadership	**Task** • Autonomy • KSA's **Social** • Team Size • Team homogeneity • Knowledge and power distribution • Team stability • Member Proximity • Communication modality • Interdependence • Support and feedback • Team KSA • Personality **Environmental** • Organizational support	Establish open communications Establish participation Maintain positive atmosphere Avoid hostilities, resolve conflicts Provide feedback, suggestions
Back-up behaviour	Providing help to team members when they require assistance in demanding situations.	Supporting	Observability of capabilities Shared mental models Leadership		Assists others Recognize abilities of team Allocate workload State team responsibilities

Table 21. Elements, behaviours and influencing variables of Leadership

3.4.5.1 Communication

Team communication relates to the transfer of information, ideas and opinions among the members of a team[49]. It is the primary and necessary coordinating skill to realize effective team performance[51,52,78].

The main functions of communication skills are to exchange information across the members of the team to develop a shared mental model of the situation among the team, support shared problem solving and contribute to the decision making process and finally to establish a good interpersonal climate between the team members. Thus communication serves to support and enhance most of the characteristics that entail teamwork. More information exchange is related to higher performance and strongly supports teamwork and task allocation[34]. Next to supporting these dimensions research has shown that team leadership is identified as particularly important for structuring and regulating the communication process[49].

3.4.5.2 The influence of input variables on Communication.

Failure with communication is classified into four categories; occasion, content, purpose and audience[79]. Occasion relates to problems with the delivery of the information in time and space. Content consists of communication transfers that contain incomplete or inaccurate information. Purpose failures include behaviours in which incorrect response or handling is presented that prompt for repeated requests. Finally failure with audience are those in which a key person in the communication process is excluded. In the processing of relevant information these failures occur approximately in 30% of the procedures. Most errors are related to content failures, which occur in half of these instances[79].

These failures go undetected when team members make assumptions, based on context and expectations, that the information is received and understood correctly. To reduce the problems caused by wrong assumption information should be unambiguous and guided by closed loop communication through proper feedback.

Expectations are influenced by culture, experience, the use of a common code for interpretation through shared mental models, the nature of the task and the current situation and workload. First, shared mental models affect the degree of communication success. With correct models, communication becomes more efficient and accurate in assisting in task completion[80]. Expectations are further influenced by the communication network structure and the related distribution of communication, often referred to as centrality. Centrality is determined by the nature of the task and the required interdependence and distributed knowledge. A high degree of task complexity and variety and increased autonomy require less centralized communication networks[41]. Interdependence and team size on the other hand increase the need for centralized communications to direct coordination and the allocation of roles. The effectiveness of more centralized networks is impacted by the information processing needs of the members involved in communicating. Communication network can be saturated through increased workloads and time constraints and the need to process information[41].

The context in which information is exchanged also influences the ability of team members to effectively communicate with each other. Member proximity and knowledge distribution have a direct impact on the exchange of information. Increased distance reduces communication frequency and the recognition of the quality of the content[38]. The communication modality can be chosen to adapt to the degree of communication distribution. The modality consists of eight factors that determine the effectiveness and the nature of the team environment are presented in table 22[81].

Characteristic	Face to Face	Real time A/V	Audio only	Real time e-mail	E-mail
Co-presence, members share a physical space	X				
Visibility, ability to see each team member	X	X			
Audibility, ability to hear each team members	X	X	X		
Contemporarily, time between transmission and receiving information	X	X	X	X	
Simultaneity, ability to communicate simultaneous	X	X	X	X	
Sequentially, requirement to communicate in sequence	X	X	X	X	
Reviewability, ability to review each others message				X	X
Revisability, ability to revise each others message				X	X

Table 22. Communication characteristics of team environments[81]

These characteristic resemble the framework that describes the factors that contribute or hinder the ability to observe the environment. This framework was discussed in the paragraph on situational awareness and consist of the openness of the tools, interactions and horizon of observations. Relevant input factors are the proximity, interdependence, support and feedback, interface design complexity and equipment variety. Closer and instant forms of communication require the ability to observe the information more clearly.

Table 23 provides a summary of the input variables that influence the exchange of information and communication.

Process	Influencing Factor	Input Variable
Expectations	Communication network and distribution	Task complexity Task variety Autonomy Information processing needs Time constraints Team size Member proximity Communication modality Interdependence Power and knowledge distribution
Exchange context	Observability of information	Power and knowledge distribution Member proximity Communication modality Interdependence Support and feedback System variety Interface design complexity

Table 23. Input variables influencing communication

In conclusion to this paragraph on communication figure 11 and table 24 summarize the main processes, required behaviors and their influencing factors that determine the degree of information exchange.

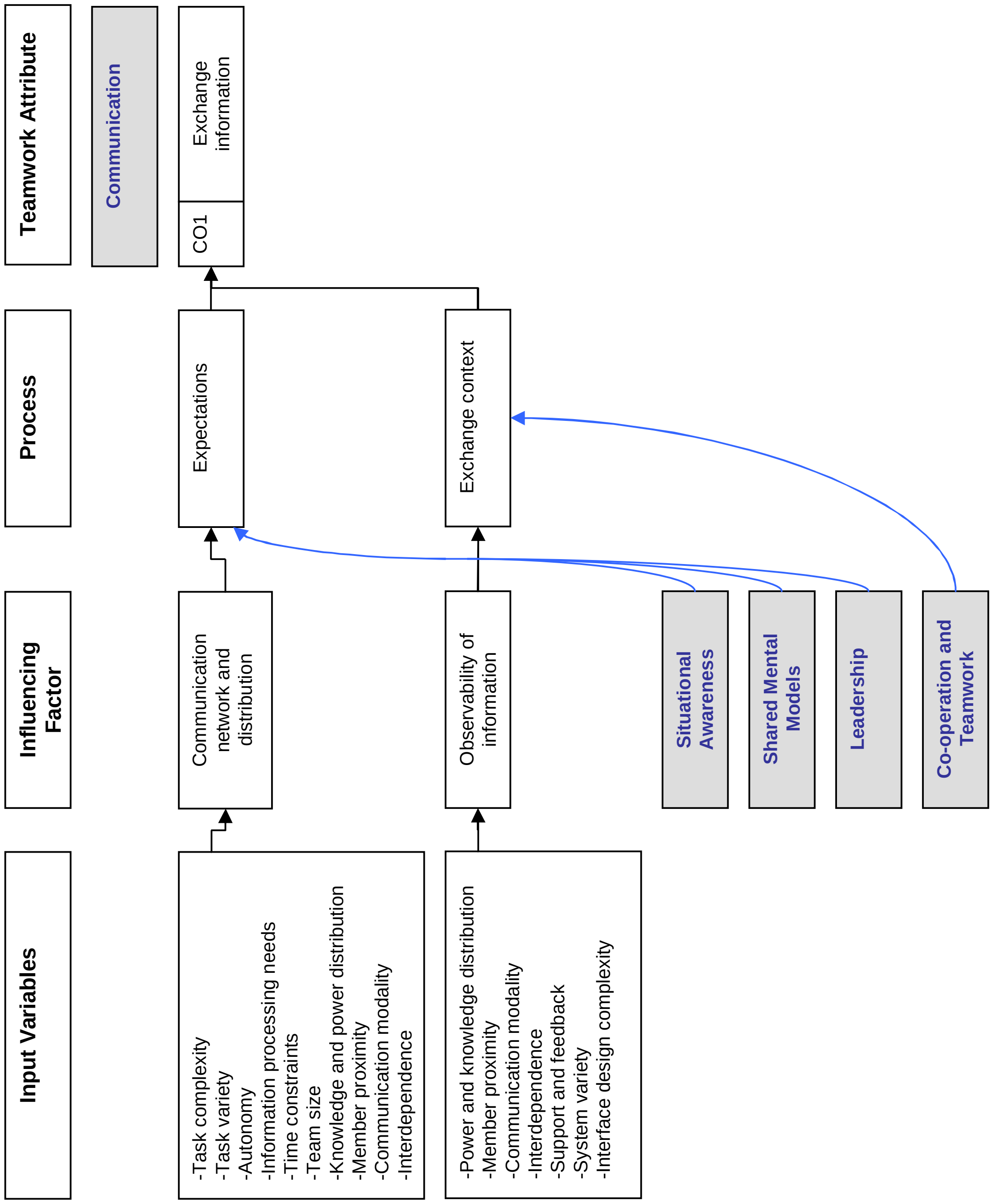

Figure 11. Variables and factors influencing communication

Communication The transfer of information, ideas and opinions among the members of a team.					
Element	**Definition**	**Process**	**Influencing factor**	**Input variables**	**Main behaviours**
Exchange Information	Giving and receiving knowledge and information in a timely manner to aid establishment of shared understanding among team members.	Expectation Exchange context	Communication network Observability of information Shared mental models Situational awareness Leadership Co-operation and teamwork	**Task** • Autonomy • Task complexity • Task variety • Information processing needs • Time constraints **Social** • Team Size • Knowledge and power distribution • Support and feedback • Member proximity • Communication modality • Interdependence **Environment** • Team Size • System variety • Interface design complexity	Exchange information clearly Exchange information timely Acknowledge information Check information is understood Clarify ambiguity Use of information cues

Table 224. Elements, behaviours and influencing variables of Communication

3.4.6.1 Shared mental models

Shared mental models are knowledge structures, cognitive representations or mechanisms which humans use to organize new information, to describe, explain and predict events, as well as to guide their interactions with others[38]. Shared mental models allow team members to implicitly and more effectively coordinate and adapt their behaviours, enhance their information processing and recognize and expect the shared information needs for a specific task[82].

Behaviours related to shared mental models include proactively providing information and support, promote team initiative and communicating situational awareness. Research shows that these indicators explain between 13% and 23% of the variance in performance outcomes[82]. Other research indicates that medical teams with low levels of shared mental models were more likely to make errors due to poor communication[82]. This suggest that mental models are needed to utilise team members' teamwork skills. As noted with the previous attribute team communication, information exchange is a crucial mechanism in high performing teams and communication errors may be explained by a lack of shared understanding of roles, tasks and team goals.

The key to successfully utilizing and coordinating the team's skills is the ability of the team to form appropriate expectations and explanations so that they may anticipate the behaviour and needs of the other team members. The extend to which the different mental models on the use of skills overlap within a team determines the strength of the team's performance. A greater extend of overlap improves the coordination of skills and performance[83].

A framework of the components along with determinants to shared mental models and the related team behaviours is depicted in Figure 12. Shared knowledge will enable team members to enhance their shared expectations and in turn their attitudes.

Team performance models generally distinguish between three components in mental models: knowledge, behavioural expectations and attitudes[84.] Determinants are classified according to the technology context, task environment and team characteristics.

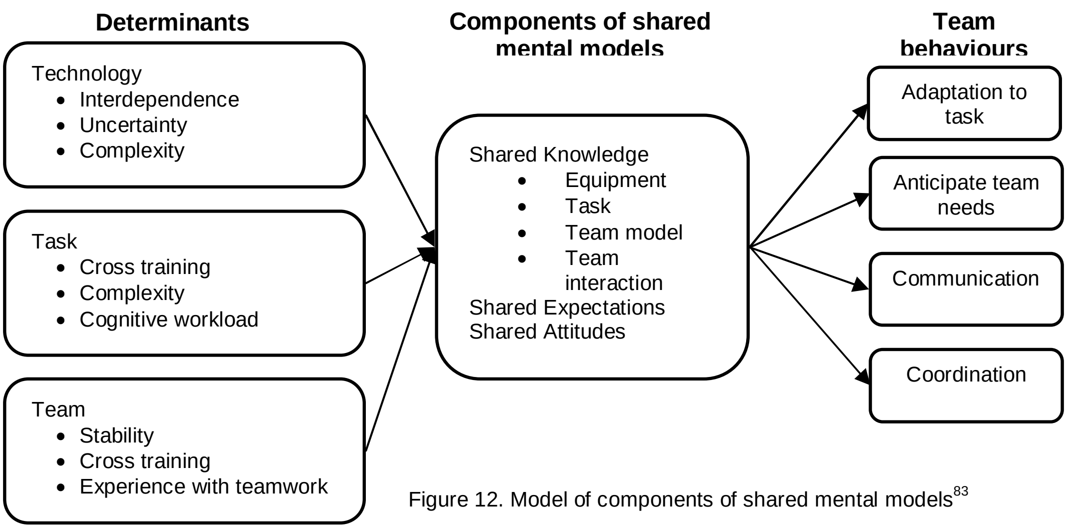

Figure 12. Model of components of shared mental models[83]

Mental models are a form of knowledge structures, therefore the manner in which members structure knowledge about their skills is a critical element of the mental model. Without this knowledge coordination is impossible since team members would lack procedural and explanatory knowledge that drives the task performance. With shared knowledge information can be interpreted and communicated and behavioural needs can be predicted.

Shared knowledge is classified into two broad domains, task work and teamwork models. Each separate model depicts knowledge on either the use of equipment for specific tasks or knowledge on the composition and relationships within teams[85].

Table 25 provides an overview of these different models and their contents.

Type of Model		Knowledge of contents
Task related features of situations	**Equipment Model**	Equipment functioning Operating functioning Equipment limitations Likely failures
	Task Model	Task procedures Likely contingencies Likely scenarios Task strategies Environmental constraints
Team related aspects of situations	**Team Interaction Model**	Roles Information sources Interaction patterns Communication channels Role interdependencies
	Team Model	Team knowledge Team skills Team abilities Team tendencies

Table 25. Multiple Mental models of shared knowledge[74]

Shared knowledge is a critical element of mental models but it requires expectations for behaviours of team members to bring about task performance. The shared expectations allow a team to allocate resources, perform backup behaviour, coordinate actions and communicate effectively.

Finally, shared attitudes complete the components of mental models. Attitudes impact the way a team interacts and performs. Two attitudes that enhance performance are collective orientation and efficacy. Collective orientation is the capacity to take other team behaviours in account during team interactions. Efficacy is the assessment of the team's ability to perform required tasks.

3.4.6.2 The influence of input variables on Shared Mental Models.

To obtain shared relevant task knowledge team members must understand the technology or equipment with which they are interacting. The dynamics and control of the technology and how it interacts with the input of other team members is particularly crucial for team functioning. Second, team members must hold shared job or task models. Such models describe and organize knowledge about how the task is accomplished in terms of procedures, task strategies, likely contingencies or problems, and environmental conditions.

Input variables are task complexity and variety, individual knowledge and mental models, knowledge distribution and finally equipment complexities and variety[82,85]. Also time constraint impact the ability to asses the use of correct models[82].

Besides task knowledge team members must hold shared conceptions of how the team interacts. These models describe the roles and responsibilities of team members, interaction patterns and cohesion, information flow and communication channels, role interdependencies, and information sources. They also share an understanding on information that is specific to the member's knowledge, skills, attitudes, preferences, strengths and weaknesses.

The shared expectations and attitudes are strengthened through increased exposure of team members to each other, and therefore have a positive influence on the degree of overlap in mental models. Input variables that affect the amount of exposure are the interdependence, member proximity[72], communication modality[81], support and feedback[71], team size, organizational arrangements, team stability[38] and experience with teamwork[83].

Table 26 provides a summary to the elements, behaviours and determinants of shared mental models.

Cognitive Process	Influencing Factor	Input Variable
Understanding task and team requirements	Task clarity	Workload and time constraints
		Task variety
		Task complexity and uncertainty
		Task KSA
		Task mental models
		Equipment complexity
		Equipment variety
	Team Clarity	Interdependence
		Communication modality
		Knowledge and power distribution
		Team KSA
		Team cohesion
Creating Overlap	Exposure	Interdependence
		Team size
		Team stability
		Team KSA
		Member proximity
		Communication modality
		Support and feedback
		Organizational arrangements

Table 26. Input variables influencing shared mental models

In conclusion figure 13 and table 27 summarize the main cognitive processes, required behaviors and their influencing factors that determine the degree of shared mental models.

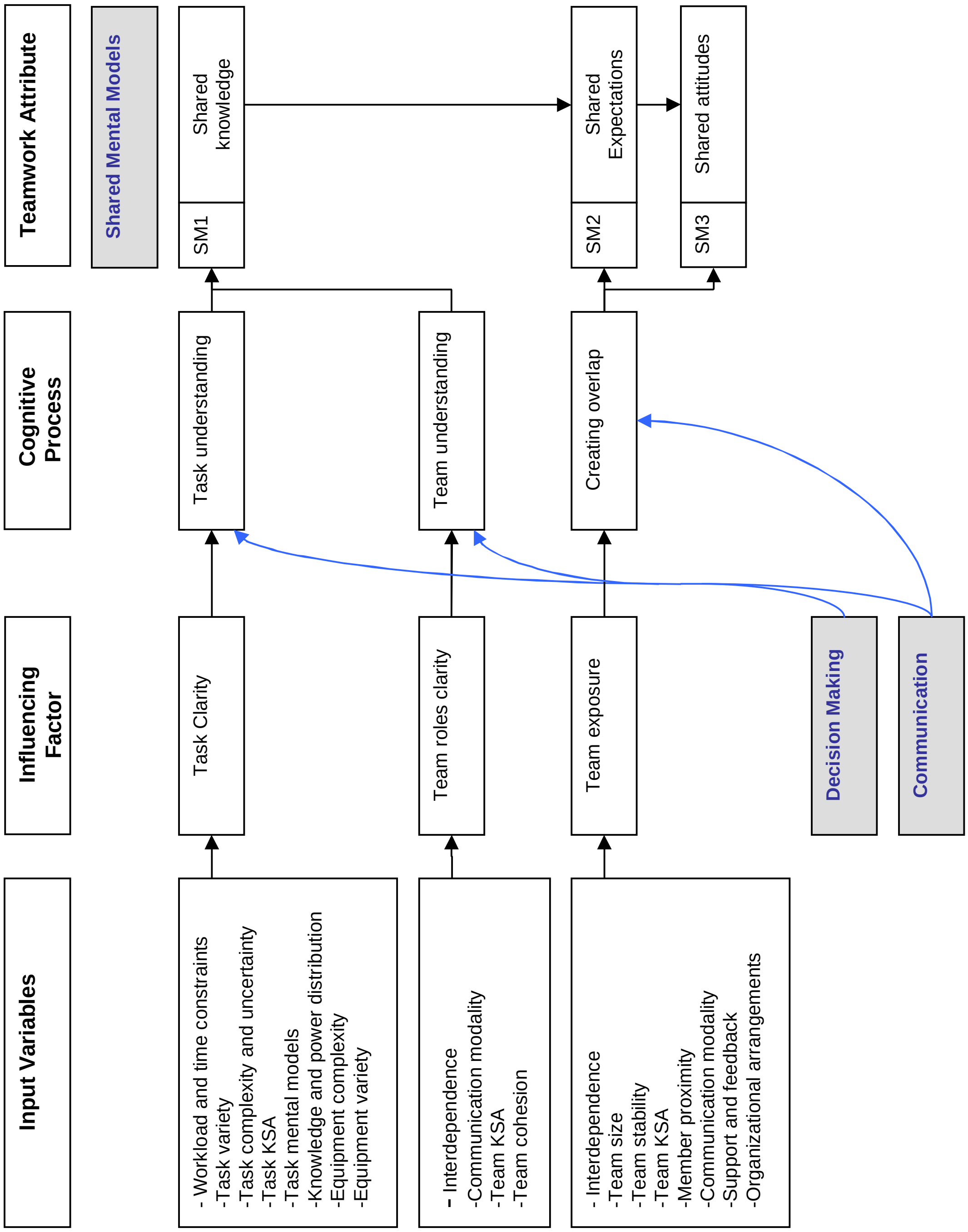

Figure 12. Variables and factors influencing Shared Mental Models

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Shared Mental Models

Shared mental models are knowledge structures, cognitive representations or mechanisms which humans use to organize new information, to describe, explain and predict events, as well as to guide their interactions with others.

Element	Definition	Process	Influencing factor	Input variables	Main behaviours
Shared knowledge	The manner in which members structure knowledge about each other's skills and task.	Task understanding	Task clarity Communication Decision making	**Task** • Task variety • Task complexity and uncertainty • Time constraints • Task KSA • Task mental models **Social** • Team Size • Team stability • Knowledge and power distribution • Member proximity • Interdependence • Communication modality • Support and feedback • Team cohesion • Team KSA **Environment** • Organizational arrangements • Equipment complexity • Equipment variety	Communicate equipment functioning Communicate procedures and contingencies Communicate interdependencies and roles Communicate abilities
		Team understanding	Team clarity Communication Decision making		
Shared expectations	Helping team members to compensate for one another, predicting each other's actions and provide information before being asked.	Creating overlap	Exposure Communication		Proactively provide information Proactively provide support Promote team initiative Communicate situational awareness
Shared attitudes	Team members poses compatible perceptions through similar attitudes about tasks to reach effective decisions.				Orientate on team behaviours Assess behaviours according to performance

Table 27. Elements, behaviours and influencing variables of Shared Mental Models

3.5 Theoretical framework of teamwork attributes

The six main attributes that comprise teamwork along with their elements are presented in table 28. In this table the influencing factors are presented for each attribute, these factors are impacted by the input variables of team effectiveness which in turn alter through the influence of a medical technology. To assess the impact these factors have on the effectiveness of teamwork performance requires the assumed moderator is also presented.

The central skill that leads the team performance is decision making. This skill sets up actions and goals that require coordination and collaboration through effective leadership and the requirements for situational awareness. The first stage of decision making determines the shared mental model of the team which in turn acts as the fundament for the situational awareness. These two attributes, SA and SMM, enable team members to recognize team performance and identify possible problems. The cognitive processes determine the coordination needs and styles of the team. Figure 13 shows the complex relationships between the teamwork attributes. The moderators of each relationship is assumed to be positive since improved teamwork skills will enhance the other attributes and therefore teamwork performance.

Beside these pivotal cognitive attributes the ability to support and coordinate all required behaviours through communication is a critical mechanism for effective performance. Communication is guided by effective leadership and correct shared mental models. Factors that influence the cognitive skills to attain shared mental models and the interpersonal skill of communication therefore posses a great ability to impact the effectiveness of teamwork performance.

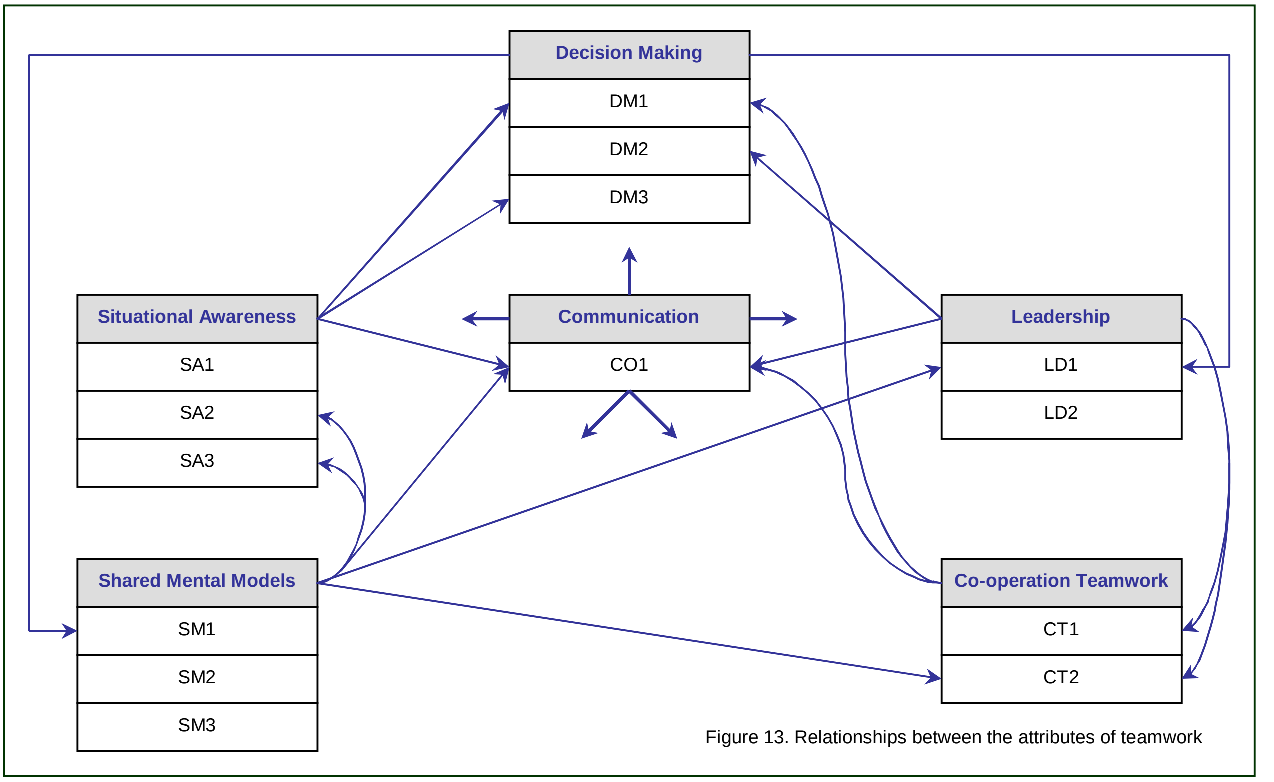


Figure 13. Relationships between the attributes of teamwork

Teamwork Attributes

Skills	Attribute	Definition	Element		Influencing Factors and moderator	
Cognitive Skills	**Decision Making**	The generation and selection of an alternative course of action based on available information, knowledge, prior experience, expectations, context and goals.	DM1 DM2 DM3	Option generation Option selection Implementation and assessment	Groupthink Collective memory Observability Authority Participation	- + + + +
Cognitive Skills	**Situational Awareness**	The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the future.	SA1 SA2 SA3	Perception Comprehension Projection	Workload Observability Distractions	- + -
Cognitive Skills	**Shared Mental Models**	Knowledge structures, cognitive representations or mechanisms which humans use to organize new information, to describe, explain and predict events, as well as to guide their interactions with each others.	SM1 SM2 SM3	Shared knowledge Shared expectations Shared attitudes	Task structure clarity Team roles clarity Team exposure	+ + +
Interpersonal Skills	**Leadership**	Leadership is the guidance of others in their collective pursuits, by organizing, directing, coordinating, supporting and motivating their efforts	LD1 LD2	Task maintenance Relational maintenance	Task structure clarity Authority and style	+ +
Interpersonal Skills	**Co-operation and Teamwork**	Co-operation is the ability to work effectively in a team.	CT1 CT2	Team-building and maintaining Back-up behaviour	Attraction Task structure clarity Observability	+ + +
Interpersonal Skills	**Communication**	The transfer of information, ideas and opinions among the members of a team.	CO1	Exchange information	Communication network Observability	- +

Table 28. Teamwork attributes, elements and influencing factors.

4 Theoretical Framework to Asses the Influence of Technology on Teamwork

4.1 Introduction

The foundations for the framework have been investigated and described in the previous chapter. Teamwork attributes and elements are impacted through different factors that are influenced directly by numerous input variables of team effectiveness. Table 26 provides a complete list of each attribute and factor. With these variables and factors established the framework for an assessment tool can be constructed. First a rough measure for each input variable needs to be determined. It lies not in the nature of this qualitative research to investigate in depth the correct range and level of influence of these variables. A rough indication of the unit of measure is, for the time being, sufficient. Then a framework needs to be constructed that links the variable to the influencing factors. This framework will provide a good reference to assess the impacts of medical technology on teamwork performance.

To assess the completeness of the framework a reference to measure teamwork needs to be developed. With this reference tool the quality or each teamwork attribute can be measured which will be an indication of the effects of altered influencing factors. In this chapter the following research questions will be discussed:

How to evaluate the feasibility of the framework in practice?

a How are the impacts of technology on teamwork measurable?
b How should the attributes and element of teamwork be measured?
c Are all relevant attributes and variables identified by the framework?

In the first paragraph the manner to measure the input variables will be discussed. After this the impact of the input variables on influencing factors of the different teamwork attributes and elements will be described. In this paragraph the general direction of this impact, positive or negative, will be provided. In paragraph 4 the different frameworks will be combined to create the theoretical assessment tool with which the impacts of medical technology on teamwork can be identified. The last sub question will be discussed in the next chapter on the case study.

4.2 What are the units of measure of the input variables?

To determine the direction and degree of change for each variables a Likert type rating scale will be used. The change in most of the variables can be observed empirically making this rating scale useful for the purpose of this thesis.

- Task Characteristics:

  The input variables that originate from the requirements of the tasks and influence the work characteristics can all be observed and rated using the 5-points scale. Task variety is described as a form of task enlargement. Variety can be measured by the number of task for each medical discipline that is added or removed will.

  Task complexity and uncertainty is constructed from three dimensions: component, coordinative and dynamic complexity[86]. Component complexity is the number of acts and related sub acts needed to execute and information cues needed to process in the performance of tasks. In this sense, the processing of information cues, component complexity is commonly referred to as information processing needs.

Coordinative complexity refers to the nature of the relationships between task input and task output. It is determined by the degree of sequencing in the task. Finally dynamic complexity is the degree in which individuals must adapt to changes in the tasks. It is determined by the degree to which a task is fixed or variable.

Task specialization and accuracy is, in contrast to task variety, a form of task enrichment. It can be measures using empirical statements on the required depth of knowledge and skills in task completion.

Workload an time constraints are the perceived amount of work required to perform in a given amount of time. This should not be confused with the influencing factor workload which relates to physical and mental capacity requirements. The variable workload and time constraints relate to the perceived time pressure. This variable the can be measured by observing the amount of time available to perform the work and tasks, since there is a direct relationship between the two concepts[38].

Finally, autonomy is the freedom and ability to control the timing, methods and decisions of work. The unit of measurement for this variable is therefore the ability to determine and execute work scheduling, work methods and initiate decisions.

- Social Characteristics:

Homogeneity and diversity can be measured along six different categories, these are social, knowledge, values, personality, status and finally along network ties[87]. The importance of team homogeneity is based on a informational perspective where less diverse team are unable to identify new strategies and ideas when they are faced with increased uncertainty. Although The need to be adaptive and therefore more diverse in composition can increase team performance it can reduces the social strengths of a team. The important characteristics to measure team performance should therefore be based on professional knowledge and skills and the differences in social ties and status.

Power and knowledge distribution are important variables in determining the degree to which team members possess the ability to lead the medical process. It closely follows other variables such as autonomy and homogeneity. Power of an individual member depends on the chance the member has on being critical to the success of a change in direction of the medical process. The power can be based on the position, abilities and persuasion of the team members and sub groups. Knowledge distribution is the degree to which the different team members share specific knowledge. For a medical team this distribution of power and knowledge is distinct and should be measured by the degree to which the ability to direct the medical process through knowledge and power is reduced or expanded among the team members of the different sub groups.

Team stability is an important variable since it indicates the capacities of a team over time. Team capacity is determined in large part by the individual skills of the different team members and therefore is greatly impacted by a high degree of turnover within teams[38]. Disruptions of the team capacities is determined by the rate of turnover and the changes in key or central positions. These two determinants should be measured to indicate changes in team stability.

Member proximity is made up of physical and psychological distance[38]. Physical distance is the actual distance in space and time between team members in which they interact with each other. The psychological distance is the perceived difference in status among members.

Closely connected to the proximity is the variable of communication modality. The mode of communication channel is strongly related to the distribution of the team. The manner in which team communicate has a direct influence on the quality of teamwork behaviours and teamwork performance through identification and the reduction in errors[88].

The main characteristics that determine the modality are the degree of co presence, visibility, audibility and contemporability or the time between sending and receiving the information[81]. The measures of the communication modality are therefore the degree to which team members communicate in each others presence, through technology and time.

Interdependence is the extend to which members are connected to others and is comprised from task, goal and outcome[42]. This connection is the extend of a work role to require the inputs of others. Task interdependence can be measured by the degree to which the performance of one members will affect other positions in the medical process.

One of the last variables from the social context is the amount of social support and feedback provided to others. This is influenced by the ability and the perception that members have on the opportunity to advice others on their performance. The awareness of each others performance and the possibilities within the team to address performance and provide advice should be measured to indicate the level of support and feedback.

Finally team and task cohesion is the last variable, besides individual variables, that needs to be measured. Task cohesion is the capacity to successfully perform as a coordinated group[41]. Team cohesion is the level of attraction among team members. Both variables are measured along the perception of the team members on the effectiveness of the team and the degree members find themselves attracted to the group.

- Environmental Characteristics:

  Organizational support is linked to factors facilitating team performance[42]. The rewards and training structure is mentioned in almost all team effectiveness models for increasing the individual capabilities required to act in a team. Through the increase of medical technologies within the operation room the need to train and keep members motivated to work to work with the technology in a team is becoming more important. Although this variable is important the effects of training and rewarding members are made operational through better individual capacities and therefore remain nearly invisible to the enhancement of team performance. The degree to which the organization provides members the ability to train and enhance their capabilities determines this variable.

  Information systems provide team members with relevant information on the medical process on areas of planning, resources and goals. This variable is measurable by determining the degree to which these systems are available and accessible to the team members.

Available resources necessary for performance should be measured by the degree to which members involved in a medical process can obtain all required resources. This is determined by the amount of resources required and the degree to which the supporting organization is able to provide them.

Procedures and regulations determine the manner in which members are required to adhere to acts in deciding a course of action. Being so it is a precursor to autonomy. It is the amount of actions that are enacted upon members to follow. For effective performance the amount and the complexity of the procedures are important.

Boundary spanning needs are the requirements of team members to interact with other area's within the organization. They focus on these needs are related to the flow of information and resources required for the planning and performance of the team. The need to communicate and cooperate with other departments for the planning, goal setting and performance of the team. This should be measured along the number of departments required to communicate with and the importance of other departments for the team's performance.

The physical environment are all factors that affect the conditions under which the team is operating. Factors are heat, noise, physical activity required and hazards to the health of the members[42].

The last variables of the environment that affect team effectiveness are related to the technological systems. The complexity of the equipments refers to the degree to understand the functioning of the components. This includes the operation, limitations and possible failures of the equipment. It is measured through the number of components, the technical knowledge required to operate the equipment and identify problems and the operational knowledge on the functions available. Equipment variety is the number of different equipments used in a medical procedure.

Ergonomics determine the extend to which the work allows for correct posture and movement to execute the task. A technology may be designed in such a way that the use of the equipment interferes with the medical procedure and forces the users to adapt a position that reduces the correct freedom of movement to perform the task. It can be measured by the degree to which it hinders or enhances correct execution of work by the user.

The interface design complexity determines the ability of the user to observe and retrieve the relevant information from[72]. The complexity of advanced systems interfaces is described to mainly arise from issues with software[89]. The amount of software and system modes that can be selected severely impact the cognitive abilities of users to maintain a good awareness of the situation. This confusion is enhanced through mode errors were commands are selected and input are provided in the incorrect mode. The interpretation of incorrect modes possess serious consequences.

Closely related to the design of the interface is the level of automation as a final variable. Automation is the shift of tasks allocated to humans to be carried out by systems or machines. The reduction in attention and workload required in performing these task is usually replaced by an increasing load on cognitive abilities[44].

Levels of automation designate the degree of human operator and computer control of dynamic tasks[44]. The functions that can be allocated are monitoring, generation options, selecting options and implementing options. Levels of automation can be measured along the range of full manual control of all tasks describe above to full automation. It describes the allocation of a higher level of tasks.

- Individual Characteristics:

  Task and team knowledge, skills and attitudes are the individual traits to perform the required tasks. The degree of change in the KSA's can be measured by investigating the needs of, and requirements placed on individuals to perform a task. The degree of individual traits that have to be acquired or reduced to perform in the team can be determined empirically.

  As with the requirements for task and team KSA's, requirements on personality characteristics may alter after the introduction of a technology. The level of experience, learning capacity and adaptability all are influenced by technology. To measure the changed requirements empirical observations on the demand on personality should be investigated.

  Finally, mental models alter when tasks and social constructs are changed. These individual knowledge structures must change alongside the new requirements for the tasks. Mental models are a critical component of the cognitive ability to be adaptable to the environment. Changes in the situation are better detected and interpreted using correct models which in turn facilitate more effective communications and decision making processes. Individual mental models are impacted by the knowledge requirements for task execution and technology demands.

Table 29 provides an overview of all the input variables along with their proposed unit of measure.

Units of measure for input variables of team effectiveness.		
Variables	**Definition**	**Unit of measure**
Task variety	The extend to which various skills are needed for task performance. This addresses the breadth of activities.	The number of tasks added or removed for each medical professional discipline.
Task complexity and uncertainty	The extend to which a job is multifaceted and difficult to perform.``	The number of acts to be executed.
		The degree of sequencing in a task.
		The degree to which a task is fixed.
Task specialization and accuracy	The degree to which specialized task are performed, or specialized knowledge and skill is required for task performance. This addresses the depth of knowledge and accuracy of performance.	The depth of knowledge required for task completion.
Workload and time constraints	The perceived amount of work required to perform the task in respect to the capacity of the individual team member.	Amount of available time to perform work.
Information processing needs	The degree to which a job necessitates an incumbent to focus on and manage information.	The number of information cues that need to be processed.

Table 29a. Units of measure for input variables of team effectiveness.

Units of measure for input variables of team effectiveness.		
Autonomy	The freedom an individual has in carrying out work.	Ability to set the work schedule.
		Ability to determine work methods.
		Ability to initiate decision making.
Team size	The number of individuals directly involved in the participating in the completion of the medical process.	Number of individual professionals directly involved in the medical process.
Team homogeneity	The extend to which members are similar or different to one another.	The number of different professional backgrounds involved with the medical process.
		The number of new members and subgroups introduced into the medical process.
Power and knowledge distribution	The degree to which different team members share specific knowledge and possess the ability to direct the medical process.	The amount of critical knowledge that is being shared by the different team members.
		The degree to which the power to direct the medical process is shared among the team members.
Team stability	The amount of disruptions in the capacities of the team over time.	The degree and amount to which team members are replaced.
		The amount of changes in key and central positions.
Member proximity	The physical and psychological distance between team members.	Distance in time and space between the interactions of individuals.
		The perceived level of equality among team members.
Communication modality	The manner through which members share information with each other.	The degree to which members are in each others presence for communications.
		The use of technology for communication.
		The time between sending and receiving information.
Interdependence	The extend to which members are connected to others.	The requirement of the inputs from other members to execute the work role.
		The degree to which the performance affects other positions in the medical process.
Support and feedback	The degree to which opportunities exist to support others and provide feedback on performance.	The degree to which members are aware of each others performance.
		The opportunity to advice others on their performance.
Task and team cohesion	The strength of the group's focus on a task and the level of attraction between team members	The perceived effectiveness of the team.
		The perceived attraction to the team.
Rewards and training	Organizational structures to increase the capabilities and motivation of individuals to act in a team.	The ability to increase individual skills and motivation required to act within the team.
Information systems	Systems that warehouse and distribute relevant knowledge.	The degree of access to sources of relevant information on the medical process.

Table 29b (continued). Units of measure for input variables of team effectiveness.

Units of measure for input variables of team effectiveness.		
Available resources	The availability of resources necessary for performance.	Amount of required resources.
		The ease to obtain resources throughout the medical process.
Procedures and regulations	Rules enacted upon members that determine the acts they must follow in task completion.	The number of procedures and regulations individuals must adhere to.
		The degree to which members can understand procedures.
Boundary spanning needs	Interactions within an organization, outside the team's department.	The number of departments outside the team that are required for the completion of the medical process.
		The importance of other departments availability of information and resources for the team's performance.
Physical environment	The actual conditions in which the work is performed	Degree to which the environment hinders the ability to perform.
Equipment complexity	The complexity of the equipments refers to the degree to understand the functioning of the components.	Number of components.
		Technical knowledge of the components required.
		Knowledge required to operate the equipment.
Equipment variety	The number of separate pieces of equipment involved with the medical procedure.	Number of separate pieces of equipment.
Interface design complexity	The ability to infer relevant information from the systems.	The ability to which relevant information can be obtained
		Number of software information modes available to the user.
Ergonomics	The extend to which work allows for correct posture and movement.	The degree to which a technology hinders the execution of the medical process.
Level of automation	The degree of allocating human tasks to systems and technologies.	The amount of tasks allocated to systems and machines.
Task KSA	Knowledge, skills and attitudes required for individual task performance.	The degree of additional or reduced KSA's required for task completion.
Team KSA	A set of interpersonal and self-management attributes essential for effective team performance.	The degree of additional or reduced KSA's required for effective teamwork performance.
Personality	Traits of individual team members that facilitate team interaction and functioning.	The change in demands on individual personalities to support teamwork behaviours.
Mental models	Knowledge structures that pertain to the task and team related aspect of situations.	The degree of required knowledge on tasks and technology.

Table 29c (continued). Units of measure for input variables of team effectiveness.

4.3 Influencing factors of the teamwork attributes.

From the previous chapter on teamwork 12 different factors were identified to influence the teamwork elements and attributes. These factors are: groupthink, collective memory, observability, authority, participation, workload, distraction, task structure clarity, team roles clarity, team exposure, attraction and communication network and distribution. For each factor the different variables are provided and the indication of how these variables affect the factor.

- Groupthink:
  The factor groupthink influences the information processing of the decision making process. Increased groupthink inhibits adaptive information seeking and therefore has a negative impact on this attribute. Five input variables are identified to determine the degree of groupthink. An increase in all variables will enhance groupthink and reduce decision making.

Influencing Factor	Attribute	Impact	Input Variable and Moderator	
Groupthink	Decision making	Negative	-Team cohesion	+
			-Member proximity (distance)	+
			-Communication modality	+
			-Information processing needs	+
			-Workload and time constraints	+

Table 30. Input variables that impact the factor Groupthink

- Collective memory:
  Information processing and information sharing involved with the decision making process depend for a large part on the available collective memory of the team. The use of collective memory benefits from the width and depth of available knowledge. Enhanced collective memory increases the adaptability and information generation of a team. Four input variables are identified to determine the use of collective memory, they all negatively impact the information sharing process.

Influencing Factor	Attribute	Impact	Input Variable and Moderator	
Collective memory	Decision making	Positive	-Team size	-
			-Homogeneity	-
			-Power & knowledge distribution	-
			-Autonomy	-

Table 31. Input variables that impact the factor Collective memory

- Observability:
  With teamwork it is critical to maintain good awareness of the situation. To be able to perceive cues from the environment and comprehend their meanings the workplace and technologies must be open to be observed by the team members. This factor is supportive for at least four teamwork attributes and addresses the ability to observe information, environment and the team members performance. The impact of good observability on all four attributes is positive.

Influencing Factor	Attribute	Impact	Input Variable and Moderator	
Observability	Decision making Situational awareness Co-operation and teamwork Communication	Positive	-Interface design complexity	-
			-Level of automation	-
			-Task KSA	-
			-Power and knowledge distribution	-
			-Member proximity	-
			-Communication modality	-
			-Interdependence	-
			-Support and feedback	+
			-Equipment variety	-
			-Equipment complexity	-

Table 32. Input variables that impact the factor Observability

- Authority:

  In performing a medical process within the OR decision making is the central attribute of teamwork that will lead all other teamwork skills to be used to attain, observe and correct the decision. For selection an option the person who actually makes the decision is the important factor. The authority has a positive influence on the decision making process when his/her position is stronger. The input variables that enhance the perceived power and capabilities of this person will influence this factor.

Influencing Factor	Attribute	Impact	Input Variable and Moderator	
Authority	Decision making Leadership	Positive	-Autonomy	+
			-KSA	+
			-Interdependence	-
			-Member proximity	-
			-Power and knowledge distribution	-
			-Information systems	+
			-Available resources	+
			-Procedures and regulations	-
			-Training and rewarding	+

Table 33. Input variables that impact the factor Authority

- Participation:

  The quality of the implementation and assessment of the selection option depend on the perceived fairness of the decision. Active participation reduces resistance to the implementation and has a positive influence on decision making.

Influencing Factor	Attribute	Impact	Input Variable and Moderator	
Participation	Decision making	Positive	-Autonomy	-
			-Team size	-
			-Team cohesion	+
			-Member proximity	+
			-Support and feedback	+
			-Power and knowledge distribution	-

Table 34. Input variables that impact the factor Participation

- Workload:

  The workload inhibits individuals to focus the correct amount of attention to the situation causing errors and mistakes to occur. Increased workload has a severe negative impact on situational awareness. The related input variables almost all increase the workload. Only an increase in task capabilities improves the ability to cope with the extra pressure on the attentional needs and the required memory capacity.

Influencing Factor	Attribute	Impact	Input Variable and Moderator	
Workload	Situational Awareness	Negative	-Task complexity and uncertainty	+
			-Information processing needs	+
			-Specialization and accuracy	+
			-Workload and time constraints	+
			-Task variety	+
			-Level of automation	+

Table 35. Input variables that impact the factor Workload

- Distraction:

  As with workload, an increase in distracting factors reduces the attention abilities of the team members. The variables draw away the required attention from the tasks necessary to complete the medical process.

Influencing Factor	Attribute	Impact	Input Variable and Moderator	
Distraction	Situational awareness	Negative	-Procedures and regulations	+
			-Physical environment	+
			-Ergonomics	-
			-Interface design complexity	+

Table 36. Input variables that impact the factor Distraction

- Task clarity:

  The construction of complete mental models by a team will be influenced for the most part by the correct understanding of the tasks performed by the team. The shared model will act as the foundation to coordinate and compare the performance of the team. Enhanced clarity on the task will contribute positively to the construction of the models and team work attributes. Input variables that reduce the uncertainty and comprehension of tasks will enhance this factor. The complexity of the task structure will furthermore enhance or inhibit the control on the team. Leadership is positively influenced by less complex task structures, therefore increased clarity will have a positive impact on leadership.

Influencing Factor	Attribute	Impact	Input Variable and Moderator	
Task clarity	Shared mental models Leadership Teamwork and co-operation	Positive	-Task variety	-
			-Task complexity and uncertainty	-
			-Workload and time constraints	-
			-Support and feedback	+
			-Task KSA	-
			-Task mental models	+
			-Interface design complexity	-
			-Equipment complexity	-
			-Equipment variety	-

Table 37. Input variables that impact the factor Task Clarity

- Team role clarity:

  Clarity on the roles of the team will, as with task clarity, enhance the construction of complete mental models among team members. Team clarity has a positive influence on this teamwork attribute and is impacted by variables that relate to the interpersonal ties among its members.

Influencing Factor	Attribute	Impact	Input Variable and Moderator	
Team clarity	Shared mental models	Positive	-Knowledge and power distribution	-
			-Interdependence	-
			-Communication modality	-
			-Team KSA	+
			-Team cohesion	+

Table 38. Input variables that impact the factor Team Clarity

- Team exposure:

  Team exposure is the ability of overlapping each individual mental model within the team creating a stronger and diverse shared mental models. The effect on the construction of shared mental models is positive.

Influencing Factor	Attribute	Impact	Input Variable and Moderator	
Team exposure	Shared mental models	Positive	-Interdependence	+
			-Team size	+
			-Team stability	+
			-Team KSA	-
			-Member proximity	-
			-Communication modality	-
			-Support and feedback	+
			-Boundary spanning needs	-
			-Task variety	-
			-Task KSA	+

Table 39. Input variables that impact the factor Team exposure

- Attraction:
  Attraction influences teamwork and co-operation through enhancing the cohesiveness of the team. Increased attraction has a positive influence on teamwork. The input variables are individual traits and perceptions on teamwork and the team.

Influencing Factor	Attribute	Impact	Input Variable and Moderator	
Attraction	Teamwork and co-operation	Positive	-Personality	+
			-Team KSA	+
			-Team and task cohesion	+

Table 40. Input variables that impact the factor Attraction

- Communication network and distribution:
  The last factor influences teamwork through the communication network and distribution within the team. Communication is essential in teamwork as it affects and enhances all the different attributes. The network depicts how the communication is distributed within the team. Increased distribution negatively affects the information sharing within the team. The input variables that increase the distribution and distances within the network positively impact this factor because the communication distribution will increased.

Influencing Factor	Attribute	Impact	Input Variable and Moderator	
Communication network and distribution	Communication	Negative	Task complexity	+
			Task variety	+
			Autonomy	-
			Information processing needs	+
			Time constraints	+
			Team size	+
			Member proximity	+
			Communication modality	+
			Interdependence	+
			Power and knowledge distribution	+

Table 41. Input variables that impact the factor Communication and network distribution

4.4 Framework to asses the impacts of medical technology on teamwork.

With the use of factors, the input variables are linked to the elements and attributes of teamwork. The variables, factors, elements and attributes together form the final framework to assess the impacts of technology on teamwork. The framework is presented in table 42a,b and c and consist of three parts. The first part is used to determine the degree and direction of change for each input variable. The units of measure to asses this change should be taken from table 29 and the questionnaire in appendix B.

The input variables are scored along the five points likert scale, these scores are converted into numbers for the use of further calculations. The scores are respectively -1. -1, 0, 1 and 2 for --, -, -/+, + and ++. The average scores of the units of measures are then used in the second part of the framework.

Part two of the framework assigns each variable to the influencing factors. The change for each variable along with the variable specific moderator for the assigned factor will provide an rough indication of the effect of the variable on that factor.

For example, a positive change in a variable together with a negative moderator will, according to logic, produce a negative effect for the factor (+ × – = –, + × + = +, – × – = +, 0 × + = 0 etc.). These indications combined determine the total average effect of the factor on the different elements of teamwork attributes.

The last part, finally links the influencing factors to the attributes that comprise teamwork in the same manner as in which the variables were assigned to the factors. The degree of change in the different factors along with the specific moderators can be combined to assess the eventual effect and change on the attributes of teamwork. To complete the framework, different elements are further linked to the teamwork attributes which are, as noted in paragraph 3.5 and figure 13, impacted by these attributes.

The framework follows a structured bottom up approach to trace the influence of a medical technology from generic variables to the difficult and complexly interrelated constructs of teamwork. Future effects, both positive and negative, can be identified that otherwise would remain unseen as latent causes of incidents. Once an effect is foreseen it can be traced down the opposite direction to the root causes and enable its users to act upon it in an early phase of adoption and implementation.

Framework to Assess the Indirect Effects on Teamwork Part I: Input Variables of Team Effectiveness

	Task Context								Social Context								Environment Context							
		Variable	--	-	0	+	++	Factor		Variable	--	-	0	+	++	Factor		Variable	--	-	0	-	++	Factor
Work characteristic	T01	Task variety						F06 F08 F10 F12		*Team Composition:*								*Organizational Support:*						
	T02	Task complexity and uncertainty						F06 F08 F12	S01	-Size						F02 F05 F10 F12	E01	-Rewards and training structure						F04
	T03	Task specialization and accuracy						F06	S02	-Homogeneity						F02	E02	-Information systems						F04
	T04	Information processing needs						F01 F06 F12	S03	-Power & knowledge distribution						F02 F03 F04 F05 F09 F12	E03	-Available resources						F04
	T05	Workload and time constraints						F01 F06 F08 F12	S04	Team stability						F10		*Organizational arrangements:*						
	T06	Autonomy						F02 F04 F05 F12		*Team architecture:*							E04	-Procedures and Regulations						F07 F04
									S05	-Member proximity						F01 F03 F04 F05 F10 F12	E05	-Boundary spanning needs						F10
									S06	-Communication modality						F01 F03 F09 F10 F12	E06	Physical environment						F07
									S07	-Interdependence						F03 F04 F09 F10 F12		*Technological systems*						
									S08	Support and feedback						F03 F05 F08 F10		*-Use of equipments*						
									S09	Task and team cohesion						F01 F05 F09 F11	E07	-Equipment complexity						F08 F03
																	E08	-Interface design complexity						F03 F07 F08
																	E09	-Equipment variety						F08 F03
																	E10	-Ergonomics						F07
																	E11	-Level of automation						F06 F03
Individual characteristic	T07	Task KSA						F03 F06 F08 F10	S10	Team KSA						F04 F09 F10 F11								
	T08	Task Mental models						F08	S11	Personality						F11								

Table 42a.Framework to measure impact of Input variables on team effectiveness Part I: Input variables of Team Effectiveness

Framework to Assess the Indirect Effects on Teamwork Part II: Influencing Factors of Teamwork Attributes

	Influencing Factor	Definition	Related input variable with moderator and change																					Total Effect	Impact on Element	Effected Attribute Element
				Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator			
F01	Groupthink	Errors of cognition in decision making that result in judgemental biases of the group and cause members to be reluctant to disagree on decisions.	Change	T04	+	T05	+	S05	+	S06	+	S09	+												Negative	DM1
F02	Collective memory	The shared reservoir of information held by two or more members of a group, and the shared mental models.	Change	T06	–	S01	–	S02	–	S03	–														Positive	DM1
F03	Observability	The ability to observe information, environment and team members performance.	Change	T07	–	S03	–	S05	–	S06	–	S07	–	S08	+	E07	–	E08	–	E09	–	E11	–		Positive	CO1 CT2 SA2 DM1
F04	Authority	The power to determine, adjudicate or otherwise settle issues or disputes and the right to control, command and determine the process.	Change	T06	+	S03	–	S05	–	S07	–	S10	+	E01	+	E02	+	E03	+	E04	–				Positive	LD2 LD1 DM2
F05	Participation	The degree to which leadership duties are shared and perceived fair among team members.	Change	T06	–	S01	–	S03	–	S05	+	S08	+	S09	+										Positive	DM3
F06	Workload	The amount of physical and mental capacity available and demanded to perform the task.	Change	T01	+	T02	+	T03	+	T04	+	T05	+	T07	–	E11	+								Negative	SA3 SA2 SA1
F07	Distractions	Factors that reduce and redirect attention away from the task.	Change	E04	+	E06	+	E08	+	E10	–														Negative	SA2 SA1
F08	Task structure clarity	The degree to which the task can be correctly understood by the team members.	Change	T01	–	T02	–	T05	–	T07	+	T08	+	S08	+	E07	–	E08	–	E09	–				Positive	SM1 CT1 LD2 LD1
F09	Team roles clarity	The degree to which the roles of other team members can be correctly understood.	Change	S03	–	S06	–	S07	–	S09	+	S10	+												Positive	SM1
F10	Team exposure	The ability of overlapping each individual mental model within the team to create a shared mental model.	Change	T01	–	T07	+	S01	+	S04	+	S05	–	S06	–	S07	+	S08	+	S10	+	E05	–		Positive	SM3 SM2
F11	Attraction	The degree to which members are draw n to committing themselves to the group.	Change	S09	+	S10	+	S11	+																Positive	CT1
F12	Communication network and distribution	The manner in which the exchange of information is distributed within the team.	Change	T01	+	T02	+	T04	+	T05	+	T06	–	S01	+	S03	+	S05	+	S06	+	S07	+		Negative	CO1

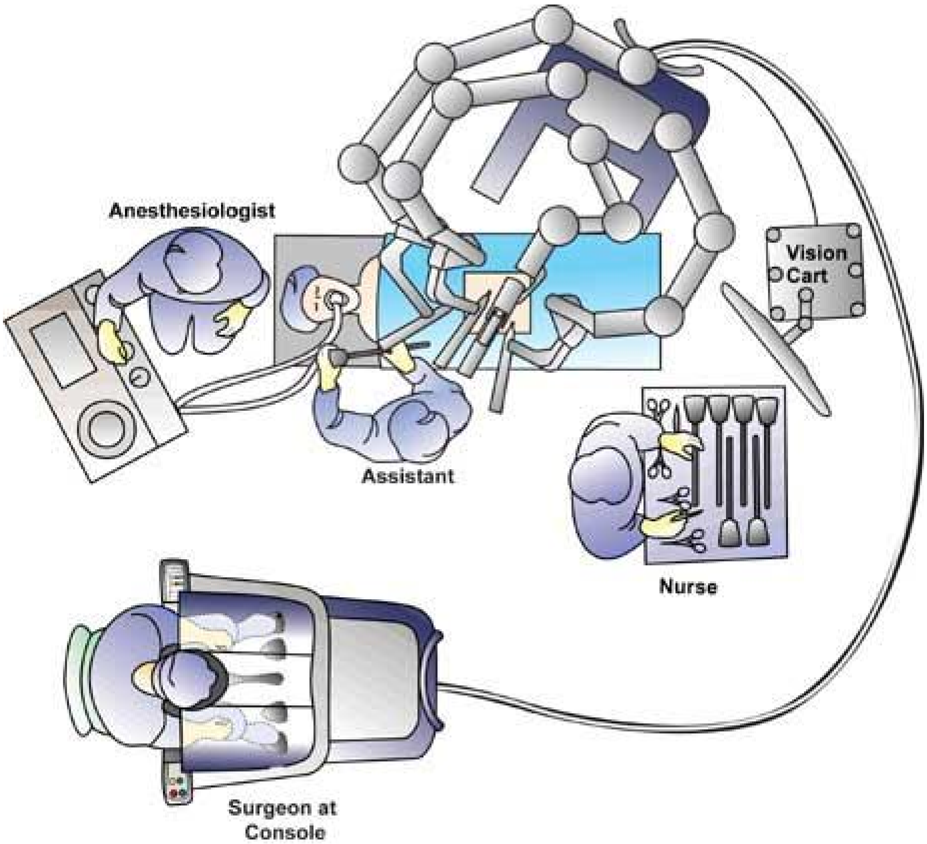
Table 42b. Framework to measure the impact of input variables on team effectiveness Part II: Influencing factors of teamwork attributes

Framework to Assess the Indirect Effects on Teamwork Part III: Teamwork Attributes

Attribute	Definition	code	Element	Definition		Related influencing factor						Total Effect	Affected Teamwork Elements
						Factor	Moderator	Factor	Moderator	Factor	Moderator		
Decision Making	The generation and selection of an alternative course of action based on available information, knowledge, prior experience, expectations, context and goals.	DM1	Option generation	Gathering and processing the information needed to make a decision.	Change	F01	-	F02	+	F03	+		LD1 SM1
		DM2	Option selection	Choosing a solution to a problem and inform relevant personnel.	Change	F04	+						
		DM3	Implementation and assessment	Undertaking the chosen option and continually reviewing its suitability in light of changes in the situation.	Change	F05	+						
Situational Awareness	The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the future.	SA1	Perception	The subconscious and intuitive perception of the environment. This is achieved through scanning for cues and patterns on the status and attributes relevant to the medical process.	Change	F06	-	F07	-				DM1 DM3 CO1
		SA2	Comprehension	The comprehension of the meaning of the information, which entails the creation of a mental model of the situation and the comparison with shared mental models.	Change	F03	+	F06	-	F07	-		
		SA3	Projection	The projection of events or actions in the future based on the comprehension of the mental model of the situation.	Change	F06	-						
Shared Mental Models	Knowledge structures, cognitive representations or mechanisms which humans use to organize new information, to describe, explain and predict events, as well as to guide their interactions with each others.	SM1	Shared knowledge	The manner in which members stucture knowledge about each other's skills and task.	Change	F08	+	F09	+				LD1 CT2 SA2 SA3 CO1
		SM2	Shared expectations	Helping team members to compensate for one another, predicting each other's actions and provide information before being asked.	Change	F10	+						
		SM3	Shared attitudes	Team members poses compatible perceptions through similar attitudes about tasks to reach effective decisions.	Change	F10	+						
Leadership	Leadership is the guidance of others in their collective pursuits, by organizing, directing, coordinating, supporting and motivating their efforts.	LD1	Task maintenance	Promoting task completion, regulating behaviour, monitoring communication and reducing goalambiguity to facilitate the achievement of group goals.	Change	F04	+	F08	+				CT1 CT2 CO1
		LD2	Relational maintenance	Maintaining and enhancing a positive team climate, mutual trust, openness and recognizing team member's performance.	Change	F04	+	F08	+				
Co-operation and teamwork	Co-operation is the ability to work effectively in a team.	CT1	Team-building and maintaining	The ability to establish positive interpersonal relation between team members and their active participation in fulfilling the task.	Change	F08	+	F11	+				DM1 CO1
		CT2	Back-up behaviour	Providing help to team members when they require assistance in demanding situations.	Change	F03	+						
Communication	The transfer of information, ideas and opinions among the members of a team.	CO1	Exchange information	Giving and receiving knowledge and information in a timely manner to aid establishment of shared understanding among team members.	Change	F03	+	F12	-				DM SA SM LD CT

Table 42c.Framework to measure impact of Input variables on team effectiveness Part III: Teamwork attributes

5 Validation of the framework



5.1 Introduction

The last question that remains unanswered is to assess and validate the completeness of the framework. To be able to validate the framework a measure needs to be developed that provides insights in the changed effects of teamwork within the operating room. An observational tool can provide discrepancies between the expected effects, based on the results of the questionnaire and the framework, and the actual changed situation.

In this master thesis the Da Vinci Surgical System is used to evaluate the completeness of the framework. The Da Vinci Surgical System is selected since it is introduced only a couple of years ago within the NKI-AVL, which allows for a good comparison of the effects on teamwork before the introduction and after the experiences of different physicians and assistants. In this chapter the following research question will be discussed:

How to evaluate the feasibility of the framework in practice?

c Are all relevant attributes and variables identified by the framework?

In the first paragraph a framework will be discussed to measure the different teamwork attributes through the use of observations. After this a background on the case study will be described. In the following paragraph the method and results are discussed.

5.2 Framework to measure the teamwork performance.

Behavioural marker systems are used to structure observation of the cognitive and interpersonal skills that make up the construct of teamwork. These systems are developed to enable observers to identify behaviours that contribute to superior or substandard performance[90]. Behavioural markers are behaviours of teams or individuals that are usually structured into a set of categories and elements. A framework that entails the behavioural markers for effective teamwork on the operation room is therefore a correct tool to assess any change in teamwork performance after the introduction of a new medical technology.

In health care a number of marker systems are derived from literature reviews of other industries and expert panel analysis. These systems are specifically developed for different groups of specialists. The structure of the NOTSS, non-technical skills for surgeons, and the ANTS, anaesthetists non-technical skills, marker systems are based on the Oxford NOTECH, non-technical skills, systems[6,91,92,93]. Validation of these behaviour rating systems has been conducted in several studies observing simulated operating room scenario's and medical teams performing real medical procedures[7,32,].

The basic structure of the rating systems comprises a three level hierarchy consisting of attributes or categories, elements and behaviours. Each behaviour is scored along a 4 point scale ranging from poor to good behaviours of performance in relation to patient safety.

The teamwork framework as presented in table 28 is in line with this basic structure and can therefore be applied to assess teamwork by means of observations. For each element a set of general desired behaviours of good clinical performance is constructed using the results of the literature study presented in chapter 3. Table 43 presents the modified framework to assess teamwork performance in the operation room and Appendix C provides an overview of the framework along with the set of desired behaviours.

Teamwork Attributes Rating System

Date: ……………………………………….. **Operation:** ……………………………………….. **Observation number:** ……………………….

Hospital: …………………………………….. **Phase of operation: Pre / Intra / Post** **Observer name:** …………………………….

	Attribute	Rating		Element	Rating	Feedback on Performance
Cognitive Skills	**Decision Making**		DM1	Option generation		
			DM2	Option selection		
			DM3	Implementation and assessment		
	Situational Awareness		SA1	Perception		
			SA2	Comprehension		
			SA3	Projection		
	Shared Mental Models		SM1	Shared knowledge		
			SM2	Shared expectations		
			SM3	Shared attitudes		
Interpersonal Skills	**Leadership**		LD1	Task maintenance		
			LD2	Relational maintenance		
	Co-operation and Teamwork		CT1	Team-building and maintaining		
			CT2	Back-up behaviour		
	Communication		CO1	Exchange information		

1	**poor**	Performance endangered or potentially endangered patient safety, serious remediation is required.
2	**marginal**	Performance indicated cause for concern, considerable improvement is needed.
3	**acceptable**	Performance was of a satisfactory standard but could be improved.
4	**good**	Performance was of a consistently high standard, enhancing patient safety.
n/a		Not applicable

Table 43. Framework tool for measuring teamwork performance in the operating room.

5.3 Background on the Da Vinci Surgical System.

Over the past 20 years a wide range of surgical robots has been developed and implemented clinically. A robot is defined as a reprogrammable, computer-controlled mechanical device equipped with sensors and actuators[94]. A classification of robotics is based on a role-based taxonomy and distinguishes three categories[94]:

- Passive: The role of the robot is limited in scope, or its involvement is largely low risk.
- Restricted: The robot is responsible for more invasive tasks with higher risk, but still restricted from essential portions of the procedure.
- Active: The robot is intimately involved in the procedure and carries high responsibility and risk.

Due to limitations in computing intelligence, the superiority of active role robots over more restricted roles is compromised. This limitation is a result of the trade-off between the role and autonomy of the technology. A progressively active robotic system requires a significant human interaction and thus possesses a reduces autonomy. Figure 14 displays this trade-off and illustrates a number of currently existing systems including the Da Vinci.

5.3.1 The Da Vinci Surgical System

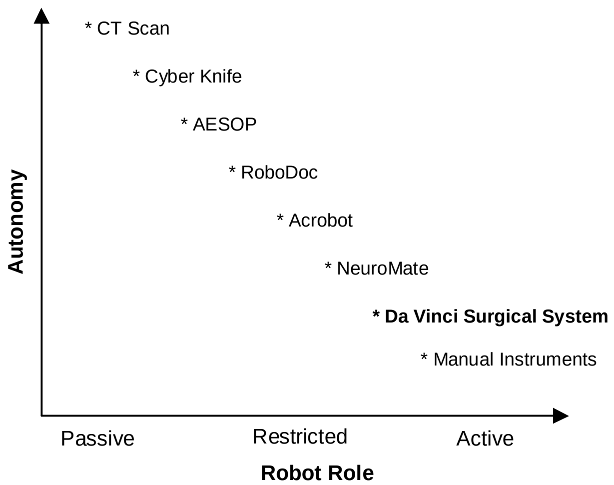


Figure 14. Trade-off between autonomy and procedural role[94]

The Da Vinci Surgical System is a tele-operated robotic system that assists the physician in the surgical procedure. Tele-presence in surgery refers to the remote operation of a robot to perform a surgical procedure. It was proposed as early as 1972 by the NASA as a method for providing remote surgical care to orbiting astronauts.

With the Da Vinci Surgical System tele-presence is accomplished by placing an electromechanical system between the surgeon and the patient to convert physical motion into electrical signals with the aid of a computer.

This signal is sent from the surgeon's master robot to the slave robot at the operating table in the form of a cart with four robotic manipulator arms. On each arm various instruments are connected, these include: a camera and light source that provides the surgeon with a 3D HD vision and instruments or end effectors that move under direction of the surgeon.

The instrument tips are a combination of standard surgical instruments and novel mechanism designs. These instruments provide haptic feedback to the surgeon which are limited to interaction with rigid structures and not with soft tissues. This restricts the surgeon to rely on visual feedback and attention to visual cues when handling bodily tissues. The instruments furthermore can be sterilized and interchanged during surgery.

A key component of the Da Vinci Surgical System is a small mechanical joint, the EndoWrist. This highly mobile joint provides the ability to exceed the natural range of the human hand. The EndoWrist can roll, pitch, yaw and grip providing a total of 7 degrees of freedom for each hand. This is illustrated in figure 15. The EndoWrist furthermore provides motion scaling and tremor reduction which combined allows for unparalleled precision and control by the surgeon[95].

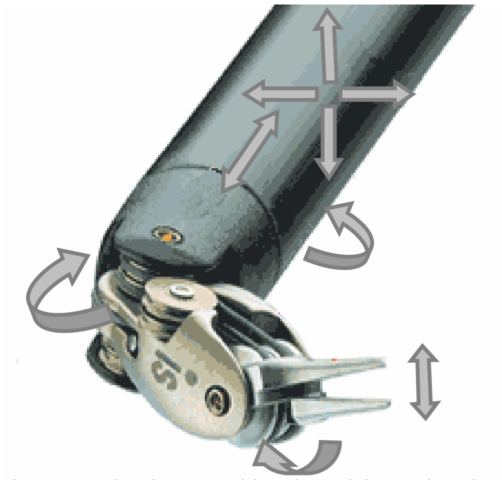


Figure 15. The degrees of freedom of the EndoWrist.

The Da Vinci Surgical System is used in several surgical specialties which include, urology, gynaecology, cardiothoracic, general surgery and colorectal. For this thesis the observations on the Da Vinci Surgical System were applied to the surgical specialty of urology and the treatment of prostate cancer.

The enhanced precision in minimal invasive surgery with the Da Vinci Surgical System offers patients with many potential benefits over the traditional open surgery. Table 44 presents that comparison between three types of surgery of prostate cancer.

Outcome	Measure	Da Vinci Surgery	Open Surgery	Laparoscopic Surgery
Cancer Control	T2 margin status	2,5	5,9	7,7
Complications	Length of hospital stay (days)	1,2	3	2,5
	Major (%)	1,7	6,7	3,7
	Minor (%)	3,7	12,6	14,6
Urinary Function	3 months (%)	92,9	54	62
	12 months (%)	97,4	93	83
Sexual Function	12 months (%)	86	71	76

Table 44. Surgery vs. Traditional Surgical Approaches to Prostate Cancer[96]

5.3.2 Robotic Prostatectomy Procedure

In general three phases of surgery can be identified, preoperative, operative and post operative.

In the preoperative phase the operation room is being set up by the assistants, who prepare the instruments and cover the slave robot in a sterile plastic cover. Then the patient is received by the team and a short checklist on the procedure is being exchanged between the surgeon and the patient. After this the anaesthetist is applying a sedative, both local and general, to the patient. In the last step in the pre-\operative phase the surgeon and assistants prepare the patient for surgery.

In the operative phase the robotic assisted laparoscopy is performed by filling the belly with carbon dioxide gas so that a working space can be created. For the prostatectomy 6 small incisions are then created through which the instruments are passed. The Da Vinci robot holds three instruments and the camera. Once the surgeon and the assistant properly set up the robot and calibrate the camera, the surgeon then takes place at the robotic console.

As a consequence, the surgeon is considered non-sterile for the procedure. A tableside assistants assists the surgeon by passing the instruments and aiding in the dissection with the removal of fluids and tissues. A second non-sterile assistant is present to prepare and pass the instruments and materials used for the procedure. After the removal and extraction of the instruments the incisions are sewn.

Finally in the post-operative phase the patient is being retrieved by the anaesthetists while the assistants remove all instruments and materials and sterile coverings.

The purpose of the procedure is to remove the prostate. The prostate and seminal vesicles normally produce fluids that are expelled during ejaculation. In order to remove the prostate it must be separated from the bladder above and the urethra below by cutting and sealing many blood vessels and soft tissues. On the back side of the prostate a bundle of nerves are located that required delicate movements from the surgeon. The seminal vesicles can also be removed along with the prostate. After the removal of the prostate the bladder is sewn to the urethra and a catheter is left in the bladder to aid the healing of the sewn area.

The whole procedure including the set up and cleaning of the operation room takes on average 2:30 hours to accomplish.

5.4 Methods.

A combination of questionnaires and a semi-structured interview on the changed input variables after the introduction of the Da Vinci Surgical System in the NKI-AVL hospital (see appendix B) is used to gather insights on the expected changes in the different teamwork determinants. These changes are determined by using the frameworks that are presented in paragraph 2.5.2.3 and 4.4. The questionnaires are taken by 2 surgeons and 2 assistants working with the Da Vinci Surgical Systems for an average of 4 years within the NKI-AVL hospital.

These result are then compared to the observations on the teamwork during prostatectomy procedures made within the operating room of the NKI-AVL hospital. The teamwork determinants are assessed by using the framework presented in paragraph 5.2. Since there was no possibility to perform observations on the situation before the implementation of the Da Vinci Surgical System a semi structured interview was held with a surgeon who had experience on working with both the open and the laparoscopic surgery within the NKI-AVL hospital.

5.5 Results.

In this paragraph the results of both the questionnaires and the observations will be discussed. First the assessment of the direct effects of the Da Vinci Surgical system is describe after which the indirect effects on teamwork are discussed. Finally a description of the results of the observations is made.

5.5.1 The direct impact of the Da Vinci Surgical System on Patient Safety

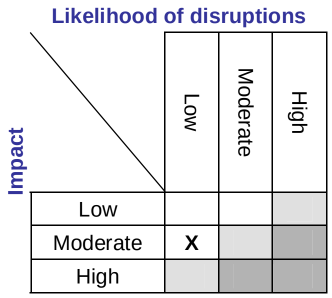


Figure 16. The assessed direct impact.

The results of the questionnaires on the direct impact of the introduction of the Da Vinci Surgical System on patient safety are presented in Appendix D. With the use of the frameworks of table 4a,b and c the indication of the expected direct impact is assessed. This expected impact is illustrated in figure 16.

The impact side of the framework is assessed to be moderate. Both the clinical risk as the ability to respond could be assessed and are moderate.

Although the duration of contact is long and it is considered to be an active device that is operated during the operative phase of surgery, the degree of invasiveness is moderate and furthermore the body systems affected are non critical systems with almost no energy is transmitted to the patient.

As with the ability to responds only moderate effects are indicated for the possibility to continue or initiate an alternate procedure and finally the degree to which the physical arrangements hinder any response to a disruption. For the other variables all effects are considered to be low and easy. These combined scores resulted in an assessed moderate impact.

The likelihood of a disruption is scored low on every variable except for the system integration, in house maintenance and received training on the use of the system. For these variables the difficulties are indicated to be moderate. The total score for on the likelihood of a disruption with the Da Vinci Surgical System is considered to be low.

When these two scores are combined, the result suggest only a low direct impact on patient safety.

5.5.2 The impact of the Da Vinci Surgical System on teamwork

The combined results of the questionnaires are presented in Appendix E. The inputs on the changed variables are used to determine the expected changes in the influencing factors and the eventual changes in the teamwork attributes and elements. With the use of the frameworks the outcomes for the different respondents, respectively the surgeons, assistants and a combined score of both, is presented in table 45 and table 46.

Factor		Impact on element	Change of Factor		
			Surgeons	Assistants	Combined
F01	Groupthink	Negative	+ 0.7	+ 0.7	+ 0.7
F02	Collective memory	Positive	- 0.5	- 0.38	- 0.38
F03	Observability	Positive	- 0.65	- 0.7	- 0.7
F04	Authority	Positive	+ 0.33	+ 0.22	+ 0.28
F05	Participation	Positive	+ 0.25	+ 0.33	+ 0.33
F06	Workload	Negative	+ 1.29	+ 1.29	+ 1.36
F07	Distractions	Negative	+ 0.38	0	+ 0.13
F08	Task structure clarity	Positive	- 0.65	- 0.78	- 0.7
F09	Team roles clarity	Positive	+ 0.4	+ 0.3	+ 0.4
F10	Team exposure	Positive	- 0.1	- 0.15	- 0.15
F11	Attraction	Positive	+ 1.17	+ 1.3	+ 1.3
F12	Communication network and distribution	Negative	+ 0.55	+ 0.7	+ 0.65

Table 45. Expected change in the influencing factors

Teamwork Attribute	Element		Surgeons	Assistants	Combined
Decision making	DM1	Option generation	- 0.62	- 0.6	- 0.6
	DM2	Option selection	+ 0.33	+ 0.22	+ 0.28
	DM3	Implementation and assessment	+ 0.25	+ 0.33	+ 0.33
Situational Awareness	SA1	Perception	- 0.84	- 0.65	- 0.62
	SA2	Comprehension	- 0.77	- 0.66	- 0.64
	SA3	Projection	- 1.29	- 1.29	- 1.36
Shared mental models	SM1	Shared knowledge	- 0.13	- 0.24	- 0.15
	SM2	Shared expectations	- 0.1	- 0.15	- 0.15
	SM3	Shared attitudes	- 0.1	- 0.15	- 0.15
Leadership	LD1	Task maintenance	- 0.16	- 0.28	- 0.21
	LD2	Relational maintenance	- 0.16	- 0.28	- 0.21
Co-operation and teamwork	CT1	Team-building and maintaining	+ 0.26	+ 0.26	+ 0.3
	CT2	Back-up behaviour	- 0.65	- 0.7	- 0.7
Communication	CO1	Exchange information	- 0.6	- 0.7	- 0.68

Table 46. Expected change in the teamwork attributes and elements

Table 46 indicates that six out of the fifteen elements are expected to contribute a moderate negative effect to teamwork in light of the changed input variables, these are highlighted in table 46. The other elements only have a slight positive or negative effect.

The combined effects on situational awareness are calculated to be higher then both effects for the surgeons and assistants. This is explained by the fact that both effects strengthen each others negative effects increasing the total effect.

The predominant negative impact of the introduction of the Da Vinci Surgical System on situational awareness is expected since an increase in the level of automation and the nature of the tasks can result in an increase of the physical and mental workload[44,71]. The reduction in the ability of each team member to observe the procedure and specific performance further contributes to this negative expectation.

The negative impact caused by a reduced observability also contributes strongly to the negative effects on option generation, back-up behaviour and the exchange of information. Additional to the negative influence of observability on the exchange of information is the contribution of a reduced communication network and distribution. This is expected because of the changed physical arrangement of the team structure.

For each of the different teamwork attributes the indicated changes will be discussed. And though the impact and changes on the teamwork attributes are similar for both the surgeon and the assistant a slightly higher negative effect for all three the elements of the situational awareness is expected for the surgeon.

- *Decision Making*

  On decision making a moderate decrease in the element of option generation is indicated, -0.6. For the other two elements only a slight positive increase is shown of respectively +0.28 and +0.33.

  Option generation is influenced by three factors that encompass the ability of the team to observe and check each others performance and to speak out within the group. All three factors poses a negative contribution to the element.

  The ability to speak up within the group and address the various options that are relevant to the surgical procedure, is impacted by the factors groupthink and collective memory. Groupthink is impacted by variables that address the physical arrangement of the team along with the processing demands of the task. The Da Vinci Surgical System has moderately increased the demands on information processing and time constraints. A third important variable that increases groupthink is the perceived higher task and team cohesion which in turn reduces the ability of the team to disagree on decisions.

  Collective memory deals with the degree to which the team possesses shared information. The variables that influence this factor address the team structure. Only slight increase of the variables was indicated.

  The last factor that impacts the element option generation is observability. This relates to the degree to which team members are able to observe each others performance during the procedure. This factor is constructed of a large number of variables that encompass in large part the team architecture and the use of equipment. With the introduction of the Da Vinci Surgical System the complexity and variation of the equipment is increased moderately to significantly which in turn has negatively impacted the observability for the team members. Another variable that contributed to this negative effect was a significant higher task skills and knowledge requirement for each team member.

  For the elements of option selection and implementation and assessment only a slight positive effect is expected. ***Option selection*** is positively related to the factor authority. The moderate increase in the variables of the social context that, for the most part, address the team architecture and decrease the ability to adjudicate or settle discussions are compensated by the variables of the environmental context that increase the support and skills of team members to contribute to the process of decision making. The overall effect only shows a slight increase in the factor of authority.

Implementation and assessment is impacted by the factor participation which addresses the degree to which the decision process is perceived to be fair among team members. The contribution of a moderate increase in the variables support and feedback and cohesion is reduced by reduced changes in the variables that address the power to initiate the decision process and a slight increase in the power distribution.

- *Situational Awareness*

The results of the questionnaire indicate that the introduction of the Da Vinci Surgical system has a moderate negative impact on the elements of situational awareness, respectively -0.62, -0.64 and -1.36.

For the three elements three factor are of importance. These are observability, workload and distractions. These factors combined determine the ability to observe the environment and to the attentional capacities available to the team members.
The factor observability and the related important input variables were discussed in the pervious discussion on the changed elements of decision making.

Perception of the environment is influenced by the factors workload and distractions. Workload is impacted mainly by task variables since they determine the amount of work required to accomplish the task. With the introduction of the Da Vinci Surgical System task variety and specialization have increased strongly while the other variables showed a moderate increase. The strong increase in task skills and knowledge has a positive impact on the factor workload.

Distractions do not contribute to the element of perception. The moderate increase of procedures and interface complexity is balanced by a better distraction free work environment and better ergonomics. The minimal increase of this factor reduces the overall impact on perception.

Comprehension is influenced by all three factors discussed above. The predominant negative impact of workload and observability reduces the effectiveness of this element.

Finally, ***projection*** is only impacted by the factor workload and thus has the largest negative effect of all three elements.

- *Shared Mental Models*

The introduction of the Da Vinci Surgical System has a limited impact on the teamwork attribute of shared mental models. The knowledge structures required to organize and structure information and expectations on performance seem to change little.

Shared knowledge is a construct of task clarity and team roles clarity. Although the indicated change for this element is 0.04, both factors do change to some degree in opposite direction. The clarity of the task structure is reduces due to a increased task variety and specialization, also the increased complexity and variety of the equipment contributes to the reduction of this factor.

This effects is compensated through acquired higher task skills and knowledge and the ability of the team to provide support and feedback on performance. The clarity of team roles has a positive contribution to the factor mostly due to the increased cohesion and acquired team skills.

Shared expectations and ***shared attitudes*** both poses the same effects since they are influenced through a single factor, team exposure. Team exposure is the degree to which mental models overlap within the team, variables that influence the factor are the amount of task and task knowledge that is required for the procedure by the team and the physical structure of the team. The slight increase of this factor is due to the increased cohesion and acquired team skills. The significant effects of the other variables seem to cancel each other out. The increase of task variety is compensated by higher task skills and knowledge.

- *Leadership*

  Both the task and relational maintenance are impacted by the same two factors, authority and task structure clarity. The impact of the introduction of the Da Vinci Surgical System on leadership is indicated to remain unchanged.

  Both factors have an opposite effect that is equally strong and therefore cancel each other out. The influence of the different input variables have been discussed with the elements option selection and shared knowledge.

- *Co-operation and Teamwork*

  The Da Vinci Surgical system has a moderate positive effect on ***team-building and maintaining*** which is caused by a large positive effect of the factor attraction. This effects counters the small negative effect of task structure clarity. Attraction is the about the commitment to the team. This commitment is influence by the variables cohesion, team skills and knowledge and a positive social personality. All three variables have increased moderately and highly with the introduction of the robot.

  Back-up behaviour is the ability to observe and assist team members when they require help. It is influence by the factor observability since it provides the team members with the ability to monitor each others performance. This factor has a moderate negative impact and is discussed above at the element option generation.

- *Communication*

  The ***exchange of information*** is impacted by the factors observability and the communication and network distribution. Both factors indicate a similar negative effect after the introduction of the Da Vinci Surgical system. The manner in which the exchange of information is distributed within the team is influenced by task input variables and the physical structure of the team itself. The biggest influence on this factor is attributed to the task input variables.

The importance of individual factors on teamwork attributes.

All relations of the framework have been assigned an equal weight in determining the effects on the teamwork elements. Therefore any claim on the importance of each individual factor on the impact on teamwork is reduced. However, the results of the framework indicate that three factors seem to play an important role in the contribution of the observed moderate effects on the impacted teamwork elements. These factors are the observability, the workload and the communication network and distribution.

The importance of these factors reflects the position of affected elements within the total construct of teamwork (see figure 13). In the analysis of the construct teamwork I concluded that a high level of situational awareness is critical for effective teamwork. Besides this important cognitive construct, effective communication is of crucial importance to the success of teamwork. Communication has the ability to direct and connect the different attributes and elements of teamwork.

In tables 47, 48 and 49 an overview is presented on the important input variables for each of the three factors.

Factor		Impact on element	Change of Factor		
			Surgeons	Assistants	Combined
F03	Observability	Positive	- 0.65	- 0.7	- 0.7
Most influential input variables			**Change of Variable**		
			Surgeons	Assistants	Combined
T07	Required task skills and knowledge		+ 1,5	+ 2	+ 2
S03	Power and knowledge distribution		+ 0,5	+ 0,5	+ 0,5
S05	Member proximity		+ 0,5	+ 0,5	+ 0,5
E07	Equipment complexity		+ 1,5	+ 2	+ 2
E08	Interface design complexity		+ 1	+ 1	+ 1
E09	Equipment variety		+ 1,5	+ 1	+ 1

Table 47. Most influential input variables for the factor Observability

Factor		Impact on element	Change of Factor		
			Surgeons	Assistants	Combined
F06	Workload	Negative	+ 1.29	+ 1.29	+ 1.36
Most influential input variables			**Change of Variable**		
			Surgeons	Assistants	Combined
T01	Task variety		+ 1,5	+ 2	+ 2
T02	Task complexity and uncertainty		+ 1,5	+ 1	+ 1
T03	Task specialization and accuracy		+ 1,5	+ 2	+ 2
T04	Information processing needs		+ 1,5	+ 1	+ 1
T05	Workload and time constraints		+ 0,5	+ 1	+ 1
T07	Required task skills and knowledge		+ 1,5	+ 2	+ 2
E11	Level of automation		+ 1	+ 0	+ 0,5

Table 48. Most influential input variables for the factor Workload

	Factor	Impact on element	Change of Factor		
			Surgeons	Assistants	Combined
F12	Communication network and distribution	Negative	+ 0.55	+ 0.7	+ 0.65
	Most influential input variables		Change of Variable		
			Surgeons	Assistants	Combined
T01	Task variety		+ 1,5	+ 2	+ 2
T02	Task complexity and uncertainty		+ 1,5	+ 1	+ 1
T04	Information processing needs		+ 1,5	+ 1	+ 1
T05	Workload and time constraints		+ 0,5	+ 1	+ 1
S03	Power and knowledge distribution		+ 0,5	+ 0,5	+ 0,5
S05	Member proximity		+ 0,5	+ 0,5	+ 0,5
S07	Interdependence		+ 0	+ 1	+ 0,5

Table 49. Most influential input variables for the factor Communication network and distribution

5.5.3 Observations results on the operation of the Da Vinci Surgical System

Observations were made in the operating room at the NKI-AVL hospital during standardized surgical procedures on robotic assisted radical prostatectomy. Four operations were observed by 1 observer using the framework presented in Appendix C.

The procedure is being performed using the Da Vinci Surgical System for over 5 years within the NKI-AVL and it is highly standardized. All four operations were divided in the pre operative phase, operative phase and the post operative phase.

The composition of the team has evolved over time to consist of a number of highly experienced surgeons and a small cluster of assistants that have acquired a high amount experience when compared to other procedures.

- ***Results of the semi structure interview:***

  From the semi structured interviews that were held, a number of changes in the teamwork attributes could be identified and observed.

  Decision making.
  A benefit of working with the Da Vinci Surgical System is the highly standardized procedure for both the surgeons and the assistants. This standardization has a positive impact on the selection and implementation of decisions since all team members are more aware of their own responsibilities.

  Situational awareness.
  On situational awareness the effects of working with the Da Vinci Surgical System have been indicated to require more effort to perceive visual cues from the environment by the surgeons on the performance of the assistants. Assistants indicate that they require more knowledge on the procedure and the technology used to perform the task. The required increase in task knowledge and skills have become more apparent and transparent for assistants, when compared to the laparoscopic and open surgery procedures. The new tasks for assistants demand an active participation in sharing their knowledge and opinions on the procedure and on the technical aspects of the Da Vinci Surgical System, which in the older procedures could be left dormant while performing their tasks. With respect to the projection of events all respondents indicated that the use highly standardized and analyzed procedures improved this aspect.

Shared mental models.
A benefit of the Da Vinci Surgical System is the ability to record all procedures and to use those recordings for training purposes. This additional training allows knowledge on the procedure to be shared by all members involved.

For the shared expectation positive effects are associated with the high degree of experience accumulated by the team members. This allows team members to be more predictive in their ability to provide advise to others.

The shared attitudes benefit from the standardized procedures which creates attitudes that are more alike on the perceptions about the tasks. Task and roles are more structured.

Leadership.
Task maintenance has become more difficult due to the increased task and step required to perform the procedure by the surgeon. The mental workload for the surgeons has increased to capture and structure a number of information cues that have disappeared from their direct field of vision.

The respondents indicate that the relational management has benefited form working with the Da Vinci Surgical System. The procedure is organized more visible which allow for each member to observe and understand the process which increases their ability to guide and consult each other.

Co-operation and teamwork.
As mentioned previously with the benefits for the relational management, the ability to understand the process better, increased the commitment to the team. The additional training both during and after completion of the procedure further contributes to this understanding and commitment.

Though commitment seems to be enhanced the ability to provide back-up behaviour to has reduced through a perceived increase in the spatial distance between team members.

Communication.
Surgeons indicate that the ability to exchange information has improved. On a side note, they do indicate that the ability to check if information is understood and acknowledged is reduced due to the limited field of vision for the surgeon.

- ***Results of the observations:***

Pre-operative phase.
The tasks and actions performed by the team during the pre-operative phases did not vary much for all the observed procedures. Before the surgeons arrive in the operating room the assistants perform the preparation of all instruments and materials.

During these activities communications and tasks are performed separately by the assistants. Experienced assistants provide explanations and share information to less experienced assistants on the manner to prepare the Da Vinci robot. Assistance is provided pro-actively. Once the operation room is prepared the experienced assistant inform the team to call the surgeon and ask for the patient to be sent.

The requested information is then acknowledged by the responsible team members. During these activities the adherence to strict protocols and procedures is limited which contributes to a relaxed atmosphere.

Once the surgeon arrives and the patient is brought in, the surgeon begins to check if all relevant information is available in the operating room. He then assembles the team around the patient and starts to run through the checklist and discusses any particulars with the entire team.

The next step was to administer the narcosis by the anaesthetist, during which he/she gave explanations about the procedure to the assistants. The surgeon and the assistant worked to prepare the patient for surgery, which was accomplished through simple semi structured routines that required little coordination. After the patient had been administered the narcosis by the anaesthetist, the surgeon is updated on the vitals and the situation of the patient.

No disruptions to the surgical process were experienced for all observations besides some minor problems with the sterility of the materials and instruments. The two back-up sets had their protective coverings punctured by the sharp edges of the containers. These problems did not disrupt or impact the procedure given the fact that there were just enough sterile sets available. Had the number of set been lower, the last procedure would have been postponed since it would take a couple of hours to get a new set sterile. The instrument set available in the hospital is limited due to the high costs of keeping them in inventory.

The performance of the team was good and could be observed without limitations. The average time to complete all tasks of the pre-operative phase was 38 minutes.

Operative phase.

During the first operation the team experienced a technical malfunction related to the light source for the Da Vinci 3D HD camera. During the calibration of the camera the surgeon noticed that the light source was inoperative. The assessment of the malfunction with the light source along with the decision process to resolve it, took 37 minutes to restore before the procedure could be resumed.

The surgeon requested information on the light source from the assistants who were instructed by the surgeon to inspect the front and back of the device. The technical department was contacted within a minute to assist with the malfunction. A number of possible causes were then opted by the surgeon along with the request to contact the manufacturer of the Da Vinci Surgical System, intuitive, before he left the operation room.

The assistants contacted intuitive and requested a back-up device to be delivered within a couple of hours.

11 minutes after the call to the technical department a technician arrived. The assistant informed him with the options that were presented to her from the helpdesk as on the other possible causes mentioned by the surgeon. The technician suggest using a mobile light source for the operation which is available in house. The assistant responds that this was not the preferred option of the surgeons due to the lower quality and power of the mobile light source.

Although the technician has examined the options presented by the assistant he explains their defaults and continues to inform them briefly on the workings of the light source. The technician explains that the only remaining option is to use the mobile light source. This was discussed with the surgeon over the phone after which he arrived on the operating room to continue with the procedure with the use of the mobile light source.

After 37 minutes the light sources was connected and calibrated by the surgeon and the surgical procedure could commence. Before the third operation of that day the back-up light source was delivered by intuitive.

The patient meanwhile had awakened slowly and this was noticed by the surgeon who instructed the anaesthetist to put the patient completely under again.

The surgical procedure is highly structured, the duration of the operative procedures all take 1:42 hours to accomplish. During the observations the different tasks and performance did not vary significantly between operations.

The surgeons instructs the table side assistant on instruments changes, the placement of clips, the degree of suction of fluids and the placement of instruments to increase the field vision within the patient. All instructions are acknowledged by the assistant and often reply by a request to check the performance of the assistant, which in turn will be acknowledged by the surgeon. During the procedure the surgeon also often provides explanation on the procedure or anatomy of the patient to the table side assistant and the non sterile assistant.

The procedure related communications from the surgeon are limited to a minimum and the surgeon continues to operate in silence.

Besides these communications, the surgeon undertakes inquiries into the status of the light source with the assistants. He furthermore inform the team on the progress of the procedure and he coordinates the planning from behind his console.

The assistants observe the procedure from the screens placed at the table. They often discuss the procedure and their tasks. The table side assistant furthermore provides their opinion on the procedure and asks for advice on her tasks. She even informed the surgeon when she was running behind with her tasks, which the surgeon had noticed.

The status of the robot can be easily observed by the surgeon from his station, but the assistant often updates the surgeon on this status. An alarm on a sudden movement of one arm was noticed by the assistant and acknowledge by the surgeon who explains the alarm and the consequences.

The performance of the team was could be observed without limitations. The teamwork performance was consistently of a high standard. On only a few occasions did the communication between the assistants and the surgeon result in a reduced performance. This reduced performance was quickly and easily identified and restored. In one case the vision of the field of operation was blurred due to a greasy lens. This hindered a clear vision on the application of a stitch of the urethra. Had the vision been clear the surgeon would have noticed that the tip of the needle was crooked and the tissue could not be punctured without rupture of the tissue. After two attempts and one small rupture the surgeon noticed the crooked tip en restored the instrument tip and continued the procedure with minimal delay and damage to the tissue. The assistant had observed and noticed the crooked tip but neglected to mention it to the surgeon.

It did not become clear why no action was taken to clear the lens or to inform the surgeon on the crooked needle tip. These miscommunications and active errors were rare. The separation of the surgeon from the operating table and speed of handling by the surgeon increase the autonomy of the surgeon which may result in a reduced participation of the assistant during slips and lapses of the surgeon.

The results for the scores on the teamwork attributes for the operative phase are presented in Table 50. The average time to complete all tasks of the operative phase was 1:42 hours.

Post-operative phase.

During the last phase of the procedure the assistants remove materials and instruments. The operating room is clean while the surgeon leave to prepare for the next patient. The tasks are as with the pre-operative phase initiated and executed mostly separately without any strong coordination. Communications address non procedural topics and assistance is provide ad hoc to each other. The duration of this phase is on average 15 minutes.

The teamwork score presented in table 50 are all satisfactory or consistently of high performance. This was expected since the team members have gained a lot of experience in working with the Da Vinci Surgical System. The procedures for the robotic assisted radical prostatectomy are furthermore highly standardized which streamlines the set of tasks and the ability of the team members to anticipate on the procedure these tasks.

Teamwork Attributes Rating System Scores

Skills	Attribute	Rating	Element		Rating	Feedback on Performance
Cognitive Skills	Decision Making		DM1	Option generation	3	The malfunction of the light source was recognized, but the formulation of the problem and options was ad hoc and the procedure to follow was left open to the assistants.
			DM2	Option selection	3	The communication of the decision could be improved.
			DM3	Implementation and assessment	4	The progress of the decision was updated regularly within the team.
	Situational Awareness		SA1	Perception	3	The environment to the surgeon is restricted to the view inside the patient and the audio information cues provided by a table side microphone.
			SA2	Comprehension	3	Regular Information on goals and expectations is shared sparsely.
			SA3	Projection	3	Due to the physical arrangement team workload can't be scanned with ease
	Shared Mental Models		SM1	Shared knowledge	4	During the procedure, information on the equipment is exchanged and assistants discuss each others performance. The surgeon provided comments on relevant discussions.
			SM2	Shared expectations	3	
			SM3	Shared attitudes	3	During the operative phase little discussion is provided on performance pro actively. Situational awareness isn't communicated often.
Interpersonal Skills	Leadership		LD1	Task maintenance	4	The surgeon manages and delegates tasks frequently. The instructions are communicated clearly.
			LD2	Relational maintenance	4	Team members often engage in discussions on procedures. Team members are guided and supported on their performance by each others.
	Co-operation and Teamwork		CT1	Team-building and maintaining	4	The team is highly committed and active participation is promoted through the ability to monitor the procedure.
			CT2	Back-up behaviour	3	The ability to recognize team members abilities and capacities is reduced.
	Communication		CO1	Exchange information	4	The use of closed loop communications between the surgeon and the assistant assures that information is received and understood.

1	**poor**	Performance endangered or potentially endangered patient safety, serious remediation is required.
2	**marginal**	Performance indicated cause for concern, considerable improvement is needed.
3	**acceptable**	Performance was of a satisfactory standard but could be improved.
4	**good**	Performance was of a consistently high standard, enhancing patient safety.
n/a		Not applicable

Table 50. Combined scores on the teamwork elements of robotic assisted prostatectomy at the NKI-AVL

5.5 Comparison between expectations and observations.

Although the observed teamwork performance is satisfactory there is still room for improvement. The teamwork elements can be compared to the expectations determined in paragraph 5.5.2.

Direct effects of the Da Vinci Surgical System on patient safety.

During the observations three minor incidents were observed that could potentially disrupt the surgical flow. An incident with the sterile coverings of the instrument sets was observed with the first operation. Because of the high costs of the instruments, the NKI-AVL only has a small number of instrument sets available. The time required to sterilize one set can take up to over one hour. During the first operation the assistants noticed that the sterile coverings of the two back-up sets were punctured. The punctures were probably causes by defects of the protective casings in which the instrument sets are transported. Had another set been used already or punctured then the operating team would have had an insufficient amount of set to complete all operations. This is an errors associated with re-use errors in sterilization as describe in the framework presented in table 4b.

A second incident was noticed when the tip of a needle, required for stitching the urethra to the bladder, was bent crooked. A combination of circumstances with blurred vision and ineffective teamwork eventually resulted in a minor active error and incident that was restored quickly. This incident is related to sensitive and delicate materials and lenses.

The last incident that was observed related to the malfunctioning of the lights source for the 3D HD camera. After a disruption of 37 minutes during the pre-operative a standby mobile light source was used while the back-up device was sent from a storage deposit in the Hague. Fortunately, the back-up device was available within short time by luck. The stand by light source could only provide half of the light intensity of the normal device. This error is related to inadequate storage of materials, since the device itself is robust and durable and another malfunction is not very likely.

The results of the framework as presented in appendix D have indicated possible negative effects on the likelihood of disruptions caused by the Da Vinci Surgical System with variables related to the system integration, in house maintenance and incomplete training on the use of technology. Table 51 presents the observed incidents versus the expected incidents.

Class	Observed Incident	vs.	Class	Expected Incident
Support	Insufficient sterile sets of instruments		Device	System integration difficulties
Device	Delicate instrument tips		Device	Inadequate maintenance
Device	In house maintenance capabilities are insufficient		Support	Lack of training

Table 51. Observed incidents with the Da Vinci Surgical Systems vs. expected incidents

The moderate impact of the observed incidents and the ability to respond with considerable ease seems to be concurrent to the assessed expectations of the framework. The inclusion of the ability to respond to a disruption to the framework to assess the impact of a medical technology strengthens the framework by providing complementary questions left unanswered by the assessment of the clinical risk alone. The assessment of a moderate impact classification of the Da Vinci Surgical Systems is inline with the observations of the different operations. The framework therefore seems to provide a complete scope of variables that need to be assessed.

The second part of the framework to identify any potential direct risk to patient safety captured only one of the observed incidents. Since the number of incidents was very low a definite answer on the completeness of this part of the framework is impacted. The fact that the Da Vinci Surgical Systems is proven to be a very durable and reliable technology contributed to the low occurrence of incidents during the observation of the surgical procedures.

The incidents with inadequate maintenance has been correctly assessed whereas the support error with insufficient set of instruments should have been assessed correctly since it has been mentioned to be of a concern to the surgeons and assistants during conversations after the observations were performed. The dependant relation to the supplier should be incorporated into the framework under the variable of inadequate maintenance because it was observed to be a viable potential source of error that had a direct impact on the surgical flow.

The other variables have been assessed correctly reflecting the high reliability and durability of the technology.

The framework adequately reflects the observed situation, the list of variables provide a complete collection of potential sources of errors, despite the relative low number of observed incidents.

Indirect effects of the Da Vinci Surgical System on teamwork and patient safety.
The results of the questionnaire indicated that six elements were negatively impacted after the introduction of the Da Vinci Surgical System. Table 52 presents an overview of the expected changes for each teamwork element and the teamwork ratings based on the observations.

Teamwork Attribute	Element		Surgeons	Assistants	Combined	Rating
Decision making	DM1	Option generation	- 0.62	- 0.6	- 0.6	3
	DM2	Option selection	+ 0.33	+ 0.22	+ 0.28	3
	DM3	Implementation and assessment	+ 0.25	+ 0.33	+ 0.33	4
Situational Awareness	SA1	Perception	- 0.84	- 0.65	- 0.62	3
	SA2	Comprehension	- 0.77	- 0.66	- 0.64	3
	SA3	Projection	- 1.29	- 1.29	- 1.36	3
Shared mental models	SM1	Shared knowledge	- 0.13	- 0.24	- 0.15	4
	SM2	Shared expectations	- 0.1	- 0.15	- 0.15	3
	SM3	Shared attitudes	- 0.1	- 0.15	- 0.15	3
Leadership	LD1	Task maintenance	- 0.16	- 0.28	- 0.21	4
	LD2	Relational maintenance	- 0.16	- 0.28	- 0.21	4
Co-operation and teamwork	CT1	Team-building and maintaining	+ 0.26	+ 0.26	+ 0.3	4
	CT2	Back-up behaviour	- 0.65	- 0.7	- 0.7	3
Communication	CO1	Exchange information	- 0.6	- 0.7	- 0.68	4

Table 52. Expected change in the teamwork attributes versus the observed teamwork ratings and the results of the interview.

The observations of the teamwork elements are impacted by the fact that the team members have worked together for a long period and have gained a lot of experience in working with the Da Vinci Surgical System. The team has narrowed to a highly skilled top-layer within the surgical department. They have been accustomed to the added and deepened tasks and increased equipment complexity. The increased standardization of the procedure has further increased the effectiveness of the teamwork. Finally, the Da Vinci Surgical System can be incorporated into know knowledge and task structures with considerable ease. The technology is a natural progression of previous and older surgical procedures, the open and laparoscopic surgery. The technology doesn't radically alter the task and knowledge requirements of the team members. This fact is further illustrated by mostly moderate increased in the tasks and technology input variables. The resulted observed teamwork performance of the entire team was therefore regarded as satisfactory or better.

Deficiencies with the teamwork elements could be observed when the team faced situations that required efforts outside the range of the standardized procedures, or in situations of high workload. Chances for improvements in teamwork elements could be observed in the decision making process, the achievement of good situational awareness, the creation of a set of shared expectations and attitudes and finally on the ability to provide back-up behaviours.

These deficiencies overlap with the expected negative result for most of these elements. The observed performance on two elements of shared mental models was rated as satisfactory and could be improved by communicating more often the performance and situational awareness to increase the overlap of expectations and attitudes. Although this behaviour was not observed during the procedure it was indicated in the semi structured interviews. The assistants and surgeons very often discuss the procedures that were recorded as part of recurrent training sessions. This explains the difference between the model and the observations.

The other noticeable difference between the results of the framework and the observations was that on the attribute of communication. In the model communication is impacted by the factor observability which in turn is impacted mostly by task related variables and increased equipment complexity. As mentioned above, this difference between the model and the observations can be explained by the fact that the team has accustomed themselves to the new technology over a significant period. The procedure furthermore requires a minimum of communication exchange between the surgeon and the assistants as a result of the increased standardization. The only time communication was less effective was during the incident with the light source. The decision making process was unclear and ambiguity was not clarified adequately.

Both the framework and the observations overlap on all elements of situational awareness. The negative effects that were mentioned related to the increased workload, especially for the surgeon, the increased requirements on task knowledge and skills and finally the reduced ability of the team to observe visual cues of each others performance due to the changed physical arrangements of the team structure. These negative effects impact the ability to achieve a high level of situational awareness.

6 Conclusion and recommendations

6.1 Introduction

The development of the two theoretical framework to assess both the direct and the indirect impact of a new medical technology on teamwork and patient safety is based on theories that originate from research on human errors related incidents and accidents in industries outside of healthcare. Those theories on human error are expanded into a list of variables that address the assessment of the ability to disrupt the surgical flow and the ability to impact factors which in turn influence the attributes that make up the concept of teamwork.

The proposed pathways of the direct and indirect impacts on teamwork performance and patient safety is presented in figure 5.

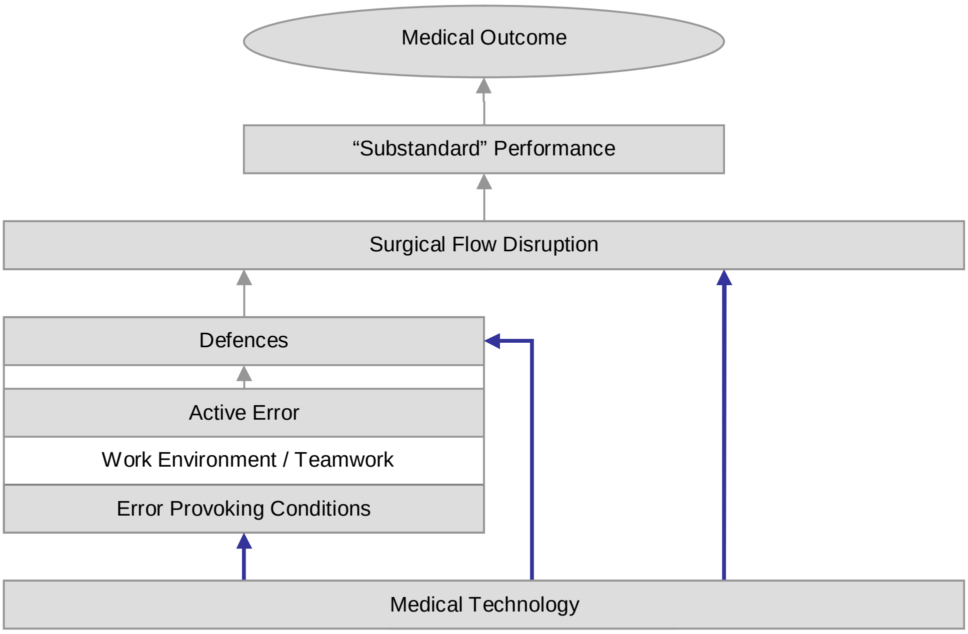


Figure 5. The direct and indirect influence of a medical technology on medical performance and outcome

In the young field of early health technology assessment little research has been done on the effects of a technology on teamwork and patient safety. The importance of creating a framework, to assess the possible implications for teamwork and patient safety as a consequence of the introduction of a new medical technology within the operating room, have been made visible in the past couple of years. Research in the past ten years has indicated that almost one in every 340 patients that are administered to a hospital dies as a result of a preventable adverse event[97]. 41% Of these preventable adverse events occur within the operating room. A further analysis on the types of preventable adverse events within the operating room show that roughly 55% of these events are related to the operation, procedure and diagnosis, and 8% can be traced to failures of the technological and supportive systems. These numbers summarized, indicate that roughly 1 in every 1.500 and 1 in 10.000 patients will die as results of a preventable adverse event within the operation room of a hospital relating to complications with respectively the surgical procedure and the supporting and technological systems.

To be able to construct a valid framework that can be used to asses the effects of a technology in an early phase of adoption, the following research question is formulated:

> ***How should the impact of the introduction of a new medical technology on teamwork and on patient safety within the OR be evaluated?***

This research question is subdivided into two sub-questions that address the relations between the dependent subjects of patient safety and teamwork and the independent variable of new medical technology. The last sub-question investigates the evaluation and validation for each constructed framework.

1. What is the influence of the introduction of technology on patient safety?
    a. What is Patient Safety?
    b. What are the types of classification of errors?
    c. How does the introduction of new technology directly affect patient safety?

2. How does technology affect teamwork and team performance?
    a. What is teamwork?
    b. Which attributes determine teamwork?
    c. What inputs have an effect on teamwork performance?
    d. What inputs of teamwork are affected by technology?

3. How to evaluate the feasibility of the framework in practice?
    a How are the impacts of technology on teamwork measurable?
    b How should the attributes and element of teamwork be measured?
    c Are all relevant attributes and variables identified by the framework?

6.2 The direct influence of a medical technology on patient safety.

Patient safety is a systematic approach to minimize the likelihood of errors and to maximize the likelihood to intercept them. The aim of patient safety systems and processes is to provide the patient with the freedom from accidental injury[1].

The errors related to patient safety are contributed to human failure. This human failure can be either a deliberate violation by the health care professional or a human error which can be a mistake or an active slip or lapse at the sharp end of the procedure.

These human errors can result in incidents which create a hazard to the patient. Normally incidents can be intercepted before they affect the outcome of the process. When an incident does affect the medical outcome it is considered an complication or adverse events.

The capacity of the health care professional to respond, adapt and compensate for complications is negatively impacted by disruptions of the surgical flow. The direct impact a medical technology has on patient safety is therefore the ability to disrupt the surgical procedure. The number of disruptions are negatively related to the capacity of the health care professionals to act upon and as a consequence, the amount of surgical errors is positively related to the amount of surgical flow disruptions[21].

The framework to asses the ability of a medical technology to disrupt the surgical flow is constructed of two parts. First, the impact of the disruption needs to be assessed. This impact is a combination of the clinical risk and the ability to respond to the disruption. The second part addresses the collection of errors that increase the likelihood of an disruption.

Both parts are then combined in a matrix to determine the potential risk of the direct effects of the medical technology on patient safety.

From observations on the Da Vinci Surgical System, the framework was validated. Both parts to assess the impact of a medical technology comprise of a complete set of variables. With this framework the impact of the Da Vinci Surgical Systems could be assessed that reflected the actual situations.

The variables that determine the clinical risk are based on the main factors that are used by governmental bodies in their assessment of risk classification[26], and could be assessed easily by medical professionals that were interviewed for this thesis research. The variables that comprises the ability to respond to a disruption did cover all aspects of the Da Vinci Surgical System. However, all variables were assigned an equal weight and thus an equal share in the determination of the impact.

The use of a matrix structure which combines both parts of the framework is a powerful and clear assessment tool which allows the user to directly observe a possible area of interest. Any score on moderate of high can then be traced back to identify variables on which adequate measures should be taken.

With the assessment of the potential sources of errors only a few incidents could be observed. These incidents could all be traced to a separate variable. The difference between expected sources of error and observed errors was little. Two of the three incidents should have been assessed correctly. The observed incidents and perceived reliability of the technology was adequately reflected by the outcomes of the framework. The framework did not incorporate the dependency of the surgical procedure on the maintenance support from external suppliers.

As conclusion on this framework I believe that it contains a complete set of variables for each separate part. The framework furthermore is user friendly and provides a clear visual representation of possible areas of interest to the assessor.

The two main concerns for this research are:

1 It should be investigated to what extend the different variables contribute to scores on each part of the framework.

2 This framework is in part validated by using observations on one technology. Two of the observed incidents were identified by using the framework. The other scores on both parts of the framework further adequately reflected the actual reliability and durability of the chosen technology To further improve the strength of the validations, the framework should be used on a number of different technologies.

6.3 The indirect influence of a medical technology on teamwork.

Teamwork is a collection of cognitive and interpersonal skills. Six main attributes have been identified from an extensive literature study on these teamwork skills. Three attribute are a collection of cognitive skills that are mental processes used for gaining and maintaining situational awareness for solving problems and taking decisions[38]. Two attributes are related to interpersonal skills that address the actual inter actions between team members to co-ordinate the decision made by the team. A last attribute deals with the transfer of information among the team. This communication attributes is essential to all other attributes for effective teamwork. These six attributes are comprised of a total of 15 different elements that addresses the different aspects and functions of each skills.

The collection of teamwork skills is tightly connected to each other since the outcome of on set of skills can influence the inputs of another. These complex relations are depicted in figure 13 below.

From literature I conclude that the cognitive skills of situational awareness perform a central and critical function on the effectiveness of teamwork. Any team that poses an effective awareness of their situation is able to act on the correct inputs. It is indicated that over 80% of all human related incidents are a result of ineffective situational awareness[63]. A second crucial attribute to the concept op teamwork is communication. As mentioned above, this attributes allows for effective coordination between the other attributes.

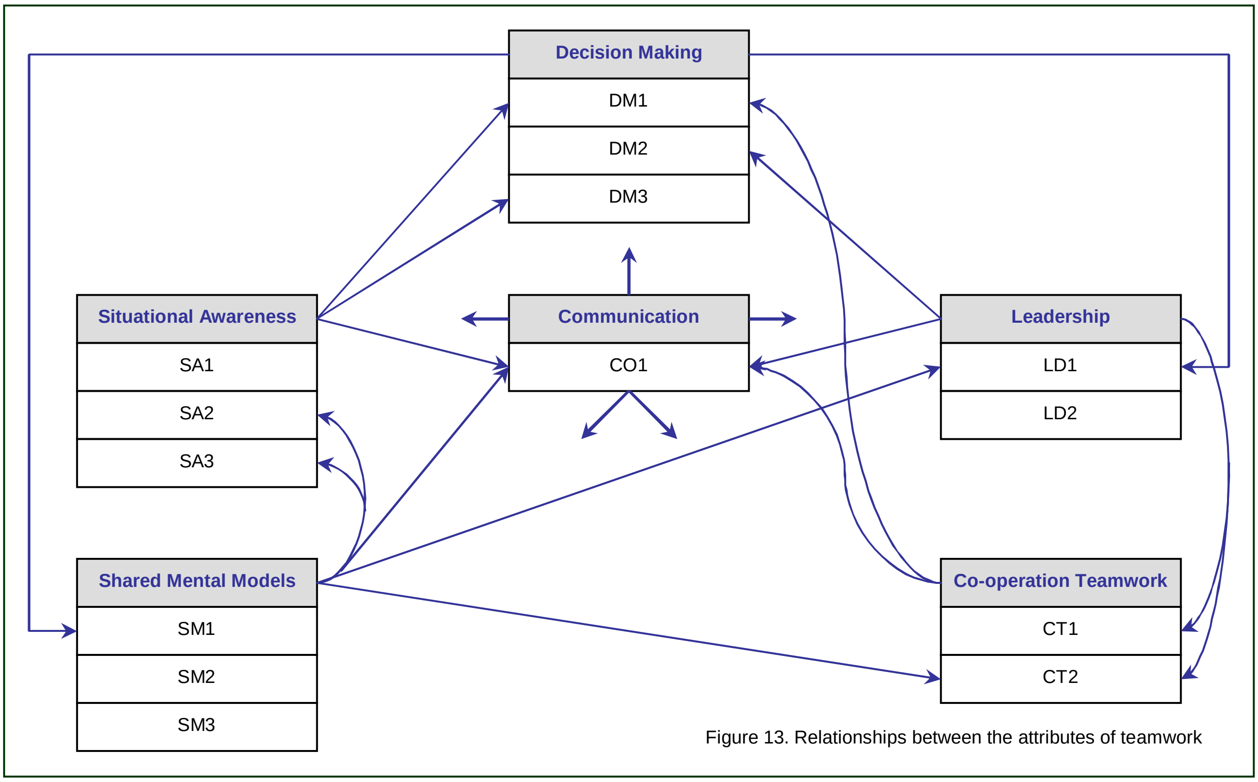


Figure 13. Relationships between the attributes of teamwork

To be able to assess the impacts of a medical technology on teamwork the construction of the framework is based on the basic Input-Process-Output models. A collection of variables have been identified as input variables that influence the teamwork processes. These variables are structured along the task, social and environmental contexts. The variables can be translated into a set of measures which are assessed according to a five point scale.

A direct relation between the variables and the teamwork elements and attributes could not be established since this would amount to an unworkable amount of relations. Therefore a moderator function was introduced to the I-P-O model, the Input-Moderator-Process-Output. These moderators bridge the gap between variables and the different processes that affect the teamwork elements in the form of influencing factors.

These factors are based on the active and cognitive processes that underlie each separate teamwork element.

12 factors were identified after a literature study:

- Groupthink;
- Collective memory;
- Observability;
- Authority;
- Participation;
- Workload;
- Distractions;
- Task structure clarity;
- Team roles clarity;
- Team exposure;
- Attraction to the team;
- Communication network and distribution.

The final framework is a three part construct in which the changes in the input variables are assessed and computed into a change of the influencing factors. For each teamwork element a combination or a single factor can used to determine the impact of a new medical technology on the different teamwork attributes.

For this research I focussed on including a complete and thorough set of variables and constructing a set of relationships that would identify and explain the different pathways along which aspects of a technology could manifestate themselves on effective teamwork. Given the limited amount of observations on a single technology, I did not perform a factor analysis to identify how much each variable or factor contributes to the proclaimed effects.

Each variable and factors was given an equal weight in the determination of the impacts on teamwork. The framework therefore provides a general indication of possible implications for the teamwork. The results of the calculations within the framework suggest an exactness that can not be validated by this research. The outcomes of the framework should rounded to the next whole number, e.g. the score of -0.62 on the element SA1 is considered to be a moderate increased negative effect.

Although it is not the purpose of this research it is recommended to perform an analysis of the possible weights for the different factors since they directly impact and contribute to the teamwork processes.

The observations on the teamwork performance with operations using the Da Vinci Surgical System were all rated as satisfactory or better, indicating that teamwork performance was of high standards and enhanced patient safety requiring only modest improvements. The technology is perceived as a natural progression on the previous and older procedures of open and laparoscopic surgery. It furthermore is a highly standardized procedure with which the team members have gained a considerable amount of experience. Since this technology was already introduced into the hospital the level of teamwork before the introduction could not be observed. The observations of expected effects of the framework were therefore reduced to some extend. However, these effects could be observed during high workloads and non-standard procedures.

As a conclusion, the results of the framework reflect the results of the observations to a considerable degree. The framework seems to poses a complete set of variables and factors.

The main concerns for this research are:

1 It should be investigated to what extend the different factors contribute to the determination of the effects on the teamwork elements.

2 The scores and results of the framework are, given the aforementioned concern, not exact representations of the actual expected effects. The suggested exactness should be used only as an indication of the degree and direction of the proposed effect.

2 This framework is validated by using observations on one technology. To further improve the strength of the validations, the framework should be used on a number of different technologies.

6.4 Recommendations.

I believe that these frameworks provide a good representation of the actual changes on the impacts of medical technology on teamwork and patient safety. The frameworks are an useful tool for healthcare professionals, since no other tool has been developed that allows the user to identify possible future problems with the difficult latent issues that have been identified to cause damage to patients and high costs to the health care institutions.

1. Future research on the influencing factors of the I-M-P-O model.

At the start of this thesis very little research had been published on this subject. The information that was available only discussed separate parts of teamwork and none could explain the precise process of how technology is able to transform and impact teamwork. The extension of the I-P-O model of effective teamwork with a moderator variable to explain the transformation of teamwork processes brought about by changed input variables is an important contribution to answer the research question. The factors are all grounded in theory on each separate teamwork attribute. I used research information that was spread out over a large number of topics and theories. Therefore the assumption can be made that the precise composition of the twelve factors might differ slightly from those that I have uncovered and constructed.

For instance, the factor observability is likely to be comprised from two or even three more specializes factors, such as observability of performance, observability of information and observability of the technology.

I recommend therefore that in further studies these factors should be thoroughly scrutinized on their completeness since they hold the key to bridge the effects of the input variable onto the teamwork elements.

Furthermore, as an addition to the strength of the framework, the actual weight of each separate factor should be investigated. With the identification of the contribution of each factor to the teamwork attributes a possible simplification of the framework can be established.

As a final recommendation, I suggest that the frameworks should be converted into an excel format to make it more user friendly and transform it into a quick tool that can be used for assessment.

2. Validation of the completeness of the frameworks on other medical technology.
A second recommendation is due to the fact that I only used one technology to validate the completeness of the frameworks. For a stronger and more valid result I would suggest to test the validity of the frameworks to a number of different medical technologies.

The frameworks have been developed to be used by health care professionals to assess the effects of existing or newly developed technologies.

However, I believe that the validity of the frameworks is reduced when they are used on technologies that are in a very early phase of development. Technologies that are being used in fundamental clinical research trials, in order to determine the usefulness and applicableness to current and future medical procedures, often are being tested next to and during normal operations. These tests, usually do not follow future established procedures. The framework is designed to measure effects of teamwork procedures and behaviours that usually are thus not fully established during this very early phase of technology application.

Furthermore, these technologies usually are not designed and incorporated into definite medical technologies and procedures. This would reduce the validity of the framework to assess the direct impacts of the actual medical technology on patient safety. This framework does however, provide technology developers with a rough indication of possible risks and areas of interest which can be used to guide the development.

A first recommendation would thus be to investigate if the framework to assess the direct effects of a medical technology on patient safety can be used to guide the development of technologies that are in a very early phase of development.

The second recommendation is to validate both frameworks on different types of technologies. First a distinction should be made between disruptive and non-disruptive technologies. Since the introduction and integration of the Da Vinci Surgical System was very much a natural progression of existing procedures and technologies, I only observed minor effects. Technologies should further be divided according to the degree of interactions and interdependencies with other medical specialists, such as image fusion and image guided technologies. And the last distinction between technologies should be on the degree of automation of the technology.

Finally, I would recommend that the observations should be performed by at least two persons to test the inter-reliability of the observations. These persons should be fully competent in understanding each medical procedure that is observed. Furthermore, each observer should be trained on assessing and identifying the different relevant teamwork behaviours.

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Appendix A: Search term used for the literature review

Human Error Classification and Patient Safety

Inclusion criteria:

- Articles that describe a human error classification systems in health and contain the terms human error, incidents, adverse events.
- Articles that provide a description of the causes of adverse events based on the review of large number of patient records, interviews with health care professionals and observations during medical procedures within the OR.

Search terms:

Research Question 1:	Human Error Classification and Patient Safety	Results
Search Engine:	PubMed, National Library of Medicine	
Limits:	Human, English, 1998-2011, Reviews	
Key search terms:	Patient Safety, Adverse Events, Incident, Human Error, Classification.	
Search outcomes:	Patient safety AND Human Error	63
	With review set as a limit	19
	Patient safety AND Classification AND Incident	22
	With review set as a limit	4
	Adverse events AND Human Error	32
	With review set s a limit	5

Teamwork and Team performance

Inclusion criteria:

- Articles that provide a literature review of teamwork, teamwork performance and patient safety within health care.
- Articles that outline the different taxonomies of teamwork and definitions of non-technical skills within health care and aviation.
- Empirical studies that focus on the validation of non-technical skills of health care teams.
- Empirical studies that discuss the measurement of non-technical skills and teamwork performance through observations during simulated and non-simulated medical procedures.

Search terms:

Research Question 2:	Teamwork and Team Performance	Results
Search Engine:	PubMed, National Library of Medicine	
Key search terms:	Teamwork; Team Performance; Non-technical Skills; Measurement; Effective; Technology.	
Limits:	Human, English, 1998-2011, Reviews	
Search outcomes:	Teamwork AND Performance AND effective	76
	With review set s a limit	19
	Teamwork AND Measurement	36
	With review set s a limit	4
	Teamwork AND Technology	86
	With review set s a limit	21
	Teamwork AND Non-technical skills	17
	With review set s a limit	4

Human Error Classification and Patient Safety

Inclusion criteria:

- Articles that describe a human error classification systems in health and contain the terms human error, incidents, adverse events.
- Articles that provide a description of the causes of adverse events based on the review of large number of patient records, interviews with health care professionals and observations during medical procedures within the OR.

Search terms:

Research Question 1:	Human Error Classification and Patient Safety	Results
Search Engine:	PubMed, National Library of Medicine	
Limits:	Human, English, 1998-2011, Reviews	
Key search terms:	Patient Safety, Adverse Events, Incident, Human Error, Classification.	
Search outcomes:	Patient safety AND Human Error	63
	With review set as a limit	19
	Patient safety AND Classification AND Incident	22
	With review set as a limit	4
	Adverse events AND Human Error	32
	With review set s a limit	5

Appendix B: The interview/Questionnaire protocol

Questionnaire Technology Assessment on Teamwork and Patient Safety

Dear Sir or Madam,

This questionnaire is used to determine the changes and impacts of working with a new medical technology on teamwork and patient safety within the operating room. The technology chosen to observe for this research is the Da Vinci Surgical System (DVSS). The information of this questionnaire will be used exclusively to scientific purposes. The time to fill in the questionnaire will be approximately 20 minutes.

Your information will be processed anonymously.

Date:	
Place:	
Name:	
Function:	
Organization:	

Instructions for completing the questionnaire.

You are asked to tick the appropriate box for each question concerning the impact of the medical technology (DVSS) on the different input variables for effective team performance. For this research a rough indication of the perceived change is sufficient. If you have any remarks on the questions or relevant information, please use the empty boxes at the end of each part of the questionnaire along with the correct coding for each question.

You can return the questionnaire in the return-envelope provided to you, or send it to

G.H.Kleinsmit
Derde Oosterparkstraat 82-e
1091 KB Amsterdam
ghkleinsmit@hotmail.com

Thank you for your cooperation!

coding	Task Context of Input Variables	significant decrease	moderate decrease	unchanged	moderate increase	significant increased
T01	The variety of skills and tasks needed for task performance	O	O	O	O	O
T02.1	The number of acts and sub acts needed to execute the task	O	O	O	O	O
T02.2	The degree of sequencing between tasks	O	O	O	O	O
T02.3	The degree to which the task is fixed and changes in the task do not occur often	O	O	O	O	O
T03	Depth of specialized knowledge and accuracy required for task completion	O	O	O	O	O
T04	The number of information cues that needs to be processed	O	O	O	O	O
T05	Amount of available time to perform the tasks	O	O	O	O	O
T06.1	Ability to set the work schedule	O	O	O	O	O
T06.2	Ability to determine the work method	O	O	O	O	O
T06.3	Ability to initiate decision making	O	O	O	O	O
T07	The level of basic knowledge, skills and attitudes required for task completion	O	O	O	O	O
T08	The degree of required knowledge on the technology use and requirements	O	O	O	O	O

Remarks

coding	Social Context of Input Variables	significant decrease	moderate decrease	unchanged	moderate increase	significant increased
S01	Number of individual professionals directly involved in the medical process	O	O	O	O	O
S02.1	The number of different professional backgrounds involved with the medical process	O	O	O	O	O
S02.2	The number of new members and subgroups introduced into the medical process	O	O	O	O	O
S03.1	The amount of critical knowledge that is being shared by the different team members	O	O	O	O	O
S03.2	The degree to which the power to direct the medical process is shared among the team members	O	O	O	O	O
S04.1	The degree and amount to which team members are replaced	O	O	O	O	O
S04.2	The amount of changes in key and central positions	O	O	O	O	O
S05.1	Distance in time and/or space between the interactions of individuals	O	O	O	O	O

coding	Social Context of Input Variables (continued)	significant decrease	moderate decrease	unchanged	moderate increase	significant increased
S05.2	The perceived level of equality among team members	O	O	O	O	O
S06.1	The degree to which members are in each others presence for communicating	O	O	O	O	O
S06.2	The use of technology for communication (video, audio, mobile, computer)	O	O	O	O	O
S06.3	The time between sending and receiving information	O	O	O	O	O
S07.1	The requirement of the inputs from other members to execute the work role	O	O	O	O	O
S07.2	The degree to which the performance affects other positions in the medical process	O	O	O	O	O
S08.1	The degree to which members are aware of each others performance	O	O	O	O	O
S08.2	The opportunity to advice others on their performance	O	O	O	O	O
S09.1	The perceived effectiveness of the team	O	O	O	O	O
S09.2	The perceived attraction to the team	O	O	O	O	O
S10	The amount of additional interpersonal and self-management skills and knowledge required for effective team performance	O	O	O	O	O
S11	The change in demands on individual personalities to support teamwork behaviours	O	O	O	O	O

Remarks

coding	Environmental Context of Input Variables	significant decrease	moderate decrease	unchanged	moderate increase	significant increased
E01	The ability to increase individual skills and motivation required to act within the team	O	O	O	O	O
E02	The degree of access to sources of relevant information on the organization of the medical process	O	O	O	O	O
E03.1	Amount of required resources	O	O	O	O	O
E03.2	The ease to obtain resources throughout the medical process	O	O	O	O	O
E04.1	The number of procedures and regulations individuals must adhere to	O	O	O	O	O
E04.2	The degree to which members can understand procedures	O	O	O	O	O
E05.1	The number of departments outside the team that are required for the completion of the medical process	O	O	O	O	O
E05.2	The importance of other departments availability of information and resources for the team's performance	O	O	O	O	O

coding	Environmental Context of Input Variables (continued)	significant decrease	moderate decrease	unchanged	moderate increase	significant increased
E06	Degree to which the environment hinders and distracts the ability to perform	O	O	O	O	O
E07.1	Number of components	O	O	O	O	O
E07.2	Degree of required technical knowledge of the components	O	O	O	O	O
E07.3	Knowledge required to operate the equipment	O	O	O	O	O
E08.1	Number of software information modes available to the user	O	O	O	O	O
E08.2	The ability to which relevant information can be obtained	O	O	O	O	O
E09	The number of separate pieces of equipment involved with the medical procedure	O	O	O	O	O
E10	The degree to which a technology hinders the for correct posture and movement required for execution of the medical process	O	O	O	O	O
E11	The amount of human tasks allocated to systems and machines	O	O	O	O	O

Remarks

Experience with working with the Da Vinci Surgical System (DVSS)	
How long have you been working with the DVSS?	
Have you worked on the same medical process using a different technology other than the DVSS? If yes, which?	
Comment brief on what **positive** and **negative** changes with working with the DVSS, if any, you experienced that were related to teamwork on the following dimensions: **1) Decision Making,**	
1.a) Option generation: Gathering and processing the information needed to make a decision	
1.b) Option selection: Choosing a solution to a problem and inform relevant personnel	
1.c) Implementation and assessment: Undertaking the chosen option and continually reviewing its suitability in light of changes in the situation	

2) Situational Awareness	
2.a) Perception: The perception of the environment, through scanning for cues and patterns on the status and attributes relevant to the medical process	
2.b) Comprehension: The comprehension of the meaning of the information, which entails the creation of a mental model of the situation and the comparison with existing shared mental models	
2.c) Projection: The projection of events or actions in the future	
3) Shared Mental Models	
3.a) Shared Knowledge: The manner in which members structure knowledge about each other's skills and task	
3.b) Shared Expectations: Predicting each other's actions and provide information before being asked	
3.c) Shared Attitudes: Team members poses compatible perceptions through similar attitudes about tasks	
4) Leadership	
4.a) Task Maintenance: Promoting task completion, regulating behaviour, monitoring communication and reducing ambiguity	
4.b) Relational Maintenance: Enhancing a positive climate, trust, openness and recognizing team member's performance	
5) Co-operation and teamwork	
5.a) Team-building and Maintaining: The ability to establish positive interpersonal relations and active participation	
5.b) Back-up Behaviour: Providing help to team members when they require assistance in demanding situations	
6) Communication	
6.a) Exchange Information: Exchanging knowledge and information in a timely manner to establishment of shared understanding	

Additional comments

Appendix C: Observation form of teamwork attributes

Teamwork Attributes Rating System

Date: ……………………………………….. **Operation:** ……………………………………. **Observation number:** ……………………….

Hospital: ………………………………….. **Phase of operation: Pre / Intra / Post** **Observer name:** ……………………………..

	Attribute	Rating		Element	Rating	Feedback on Performance
Cognitive Skills	Decision Making		DM1	Option generation		
			DM2	Option selection		
			DM3	Implementation and assessment		
	Situational Awareness		SA1	Perception		
			SA2	Comprehension		
			SA3	Projection		
	Shared Mental Models		SM1	Shared knowledge		
			SM2	Shared expectations		
			SM3	Shared attitudes		
Interpersonal Skills	Leadership		LD1	Task maintenance		
			LD2	Relational maintenance		
	Co-operation and Teamwork		CT1	Team-building and maintaining		
			CT2	Back-up behaviour		
	Communication		CO1	Exchange information		

1	**poor**	Performance endangered or potentially endangered patient safety, serious remediation is required.
2	**marginal**	Performance indicated cause for concern, considerable improvement is needed.
3	**acceptable**	Performance was of a satisfactory standard but could be improved.
4	**good**	Performance was of a consistently high standard, enhancing patient safety.
n/a		Not applicable

Decision Making

The generation and selection of an alternative course of action based on available information, knowledge, prior experience, expectations, context and goals.

Element	Definition	Cognitive process	Main behaviours
Option generation	Gathering and processing the information needed to make a decision.	Information processing	Share information Recognize problem Formulate problem Discuss and formulate options Use opinions from the team
Option selection	Choosing a solution to a problem and inform relevant personnel.	Selecting	Asses risk Communicate decisions Provide alternate options
Implementation and Assessment	Undertaking the chosen option and continually reviewing its suitability in light of changes in the situation.	Assessing	Confirm selected course Update team on progress Discuss progress

Situational Awareness

The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the future.

Element	Definition	Cognitive process	Main behaviours
Perception	The subconscious and intuitive perception of the environment. This is achieved through scanning for cues and patterns on the status and attributes relevant to the medical process.	Attention	Review goals Monitor environment Share information Acknowledge changes
Comprehension	The comprehension of the meaning of the information, which entails the creation of a mental model of the situation and the comparison with shared mental models.	Pattern Matching	Discuss information Request updates Inform on situation and goals Describe cues
Projection	The projection of events or actions in the future based on the comprehension of the mental model of the situation.	Dynamic switching	Assess future environment Describe expectations Communicate plans Scan team workload

Shared Mental Models Shared mental models are knowledge structures, cognitive representations or mechanisms which humans use to organize new information, to describe, explain and predict events, as well as to guide their interactions with others.			
Element	**Definition**	**Process**	**Main behaviours**
Shared knowledge	The manner in which members structure knowledge about each other's skills and task.	Task understanding Team understanding	Communicate equipment functioning Communicate procedures and contingencies Communicate interdependencies and roles Communicate abilities
Shared expectations	Helping team members to compensate for one another, predicting each other's actions and provide information before being asked.	Creating overlap	Proactively provide information Proactively provide support Promote team initiative Communicate situational awareness
Shared attitudes	Team members poses compatible perceptions through similar attitudes about tasks to reach effective decisions.		Orientate on team behaviours Assess behaviours according to performance

Leadership Leadership is the guidance of others in their collective pursuits, by organizing, directing, coordinating, supporting and motivating their efforts.			
Element	**Definition**	**Process**	**Main behaviours**
Task maintenance	Promoting task completion, regulating behaviour, monitoring communication and reducing goal ambiguity to facilitate the achievement of group goals.	Control Leading	Maintain standards Manage and delegate tasks Delegate workload Manage resources Scan boundaries Utilize and plan resources
Relational maintenance	Maintaining and enhancing a positive team climate, mutual trust, openness and recognizing team member's performance.		Direct and enable team Use authority and assertiveness Guide and support team Consult with team Coaches member behaviours

Co-operation and Teamwork Co-operation is the ability to work effectively in a team.			
Element	**Definition**	**Process**	**Main behaviours**
Team building	The ability to establish positive interpersonal relation between team members and their active participation in fulfilling the task.	Creating team cohesion	Establish open communications Establish participation Maintain positive atmosphere Avoid hostilities, resolve conflicts Provide feedback, suggestions
Back-up behaviour	Providing help to team members when they require assistance in demanding situations.	Supporting	Assists others Recognize abilities of team Allocate workload State team responsibilities

Communication The transfer of information, ideas and opinions among the members of a team.			
Element	**Definition**	**Process**	**Main behaviours**
Exchange Information	Giving and receiving knowledge and information in a timely manner to aid establishment of shared understanding among team members.	Expectation Exchange context	Exchange information clearly Exchange information timely Acknowledge information Check information is understood Clarify ambiguity Use of information cues

Appendix D: Questionnaire results of the indirect impact.

Scores of Surgeons on Input Variables of Team Effectiveness

	Task Context								Social Context								Environment Context							
		Variable	--	-	0	+	++	Factor		Variable	--	-	0	+	++	Factor		Variable	--	-	0	+	++	Factor
Work characteristic	T01	Task variety				■	■	F06 F08 F10 F12		*Team Composition:*								*Organizational Support:*						
	T02	Task complexity and uncertainty				■	■	F06 F08 F12	S01	-Size			■			F02 F05 F10 F12	E01	-Rewards and training structure				■		F04
	T03	Task specialization and accuracy				■	■	F06	S02	-Homogeneity				■		F02	E02	-Information systems				■		F04
	T04	Information processing needs				■	■	F01 F06 F12	S03	-Power & knowledge distribution			■	■		F02 F03 F04 F05 F09 F12	E03	-Available resources				■		F04
	T05	Workload and time constraints			■	■		F01 F06 F08 F12	S04	Team stability				■		F10		*Organizational arrangements:*						
	T06	Autonomy			■	■		F02 F04 F05 F12		*Team architecture:*							E04	-Procedures and Regulations				■		F07 F04
									S05	-Member proximity			■	■		F01 F03 F04 F05 F10 F12	E05	-Boundary spanning needs				■		F10
									S06	-Communication modality			■			F01 F03 F09 F10 F12	E06	Physical environment		■	■			F07
									S07	-Interdependence			■			F03 F04 F09 F10 F12		*Technological systems*						
									S08	Support and feedback				■		F03 F05 F08 F10		*-Use of equipments*						
									S09	Task and team cohesion				■		F01 F05 F09 F11	E07	-Equipment complexity				■	■	F08 F03
																	E08	-Interface design complexity				■		F03 F07 F08
																	E09	-Equipment variety				■	■	F08 F03
																	E10	-Ergonomics			■			F07
																	E11	-Level of automation				■		F06 F03
Individual characteristic	T07	Task KSA				■	■	F03 F06 F08 F10	S10	Team KSA				■	■	F04 F09 F10 F11								
	T08	Task Mental models				■	■	F08	S11	Personality				■		F11								

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Scores of Nurses on Input Variables of Team Effectiveness

	Task Context								Social Context								Environment Context							
		Variable	--	-	0	+	++	Factor		Variable	--	-	0	+	++	Factor		Variable	--	-	0	+	++	Factor
Work characteristic	T01	Task variety					X	F06 F08 F10 F12		*Team Composition:*								*Organizational Support:*						
	T02	Task complexity and uncertainty				X		F06 F08 F12	S01	-Size		|	X			F02 F05 F10 F12	E01	-Rewards and training structure				X		F04
	T03	Task specialization and accuracy					X	F06	S02	-Homogeneity				X		F02	E02	-Information systems				X		F04
	T04	Information processing needs				X		F01 F06 F12	S03	-Power & knowledge distribution			X	X		F02 F03 F04 F05 F09 F12	E03	-Available resources				X		F04
	T05	Workload and time constraints				X		F01 F06 F08 F12	S04	Team stability			X			F10		*Organizational arrangements:*						
	T06	Autonomy			X			F02 F04 F05 F12		*Team architecture:*							E04	-Procedures and Regulations				X		F07 F04
									S05	-Member proximity			X	X		F01 F03 F04 F05 F10 F12	E05	-Boundary spanning needs				X		F10
									S06	-Communication modality			X			F01 F03 F09 F10 F12	E06	Physical environment	X					F07
									S07	-Interdependence				X		F03 F04 F09 F10 F12		*Technological systems*						
									S08	Support and feedback				X		F03 F05 F08 F10		*-Use of equipments*						
									S09	Task and team cohesion				X		F01 F05 F09 F11	E07	-Equipment complexity					X	F08 F03
																	E08	-Interface design complexity				X		F03 F07 F08
																	E09	-Equipment variety				X		F08 F03
																	E10	-Ergonomics				X		F07
																	E11	-Level of automation			X			F06 F03
Individual characteristic	T07	Task KSA					X	F03 F06 F08 F10	S10	Team KSA				X		F04 F09 F10 F11								
	T08	Task Mental models					X	F08	S11	Personality				X		F11								

Scores of Surgeons on Influencing Factors of Teamwork Attributes

Coding	Influencing Factor		Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Total Effect	Impact on Element	Effected Attribute Element
		Related input variable with moderator and change																							
F01	Groupthink		T04	+	T05	+	S05	+	S06	+	S09	+											+0,7	Negative	DM1
		Change	1,5		0,5		0,5		0		1														
F02	Collective memory		T06	-	S01	-	S02	-	S03	-													-0,5	Positive	DM1
		Change	0,5		0		1		0,5																
F03	Observability		T07	-	S03	-	S05	-	S06	-	S07	-	S08	+	E07	-	E08	-	E09	-	E11	-	-0,65	Positive	DM1 SA2 CT2 CO1
		Change	1,5		0,5		0,5		0		0		1		1,5		1		1,5		1				
F04	Authority		T06	+	S03	-	S05	-	S07	-	S10	+	E01	+	E02	+	E03	+	E04	-			+0,33	Positive	DM2 LD1 LD2
		Change	0,5		0,5		0,5		0		1,5		1		1		1		1						
F05	Participation		T06	-	S01	-	S03	-	S05	+	S08	+	S09	+									+0,25	Positive	DM3
		Change	0,5		0		0,5		0,5		1		1												
F06	Workload		T01	+	T02	+	T03	+	T04	+	T05	+	T07	+	E11	+							+1,29	Negative	SA1 SA2 SA3
		Change	1,5		1,5		1,5		1,5		0,5		1,5		1										
F07	Distractions		E04	+	E06	+	E08	+	E10	-													+0,38	Negative	SA1 SA2
		Change	1		-,05		1		0																
F08	Task structure clarity		T01	-	T02	-	T05	-	T07	-	T08	+	S08	+	E07	-	E08	-	E09	-			-0,65	Positive	LD1 LD2 CT1 SM1
		Change	1,5		1,5		0,5		1,5		1,5		1		1,5		1		1,5						
F09	Team roles clarity		S03	-	S06	-	S07	-	S09	+	S10	+											+0,4	Positive	SM1
		Change	0,5		0		0		1		1,5														
F10	Team exposure		T01	-	T07	-	S01	+	S04	+	S05	-	S06	-	S07	+	S08	+	S10	+	E05	-	-0,1	Positive	SM2 SM3
		Change	1,5		1,5		0		1		0,5		0		0		1		1,5		1				
F11	Attraction		S09	+	S10	+	S11	+															+1,17	Positive	CT1
		Change	1		1,5		1																		
F12	Communication network and distribution		T01	+	T02	+	T04	+	T05	+	T06	-	S01	+	S03	+	S05	+	S06	+	S07	+	+0,55	Negative	CO1
		Change	1,5		1,5		1,5		0,5		0,5		0		0,5		0,5		0		0				

Table 28b. Framework to measure the impact of input variables on team effectiveness Part II: Influencing factors of teamwork attributes

Scores of Nurses on Influencing Factors of Teamwork Attributes

Coding	Influencing Factor	Related input variable with moderator and change	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Total Effect	Impact on Element	Effected Attribute Element			
F01	Groupthink		T04	+	T05	+	S05	+	S06	+	S09	+											+0,7	Negative	DM1			
		Change	1		1		0,5		0		1																	
F02	Collective memory		T06	-	S01	-	S02	-	S03	-													-0,38	Positive	DM1			
		Change	0		0		1		0,5																			
F03	Observability		T07	-	S03	-	S05	-	S06	-	S07	-	S08	+	E07	-	E08	-	E09	-	E11	-	-0,7	Positive	DM1	SA2	CT2	CO1
		Change	2		0,5		0,5		0		1		1		2		1		1		0							
F04	Authority		T06	+	S03	-	S05	-	S07	-	S10	+	E01	+	E02	+	E03	+	E04	-			+0,22	Positive	DM2	LD1	LD2	
		Change	0		0,5		0,5		1		2		1		1		1		1									
F05	Participation		T06	-	S01	-	S03	-	S05	+	S08	+	S09	+									+0,33	Positive	DM3			
		Change	0		0		0,5		0,5		1		1															
F06	Workload		T01	+	T02	+	T03	+	T04	+	T05	+	T07	+	E11	+							+1,29	Negative	SA1	SA2	SA3	
		Change	2		1		2		1		1		2		0													
F07	Distractions		E04	+	E06	+	E08	+	E10	-													0	Negative	SA1	SA2		
		Change	1		-1		1		1																			
F08	Task structure clarity		T01	-	T02	-	T05	-	T07	-	T08	+	S08	+	E07	-	E08	-	E09	-			--0,78	Positive	LD1	LD2	CT1	SM1
		Change	2		1		1		2		2		1		2		1		1									
F09	Team roles clarity		S03	-	S06	-	S07	-	S09	+	S10	+											+0,3	Positive	SM1			
		Change	0,5		0		1		1		2																	
F10	Team exposure		T01	-	T07	-	S01	+	S04	+	S05	-	S06	-	S07	+	S08	+	S10	+	E05	-	-0,15	Positive	SM2	SM3		
		Change	2		2		0		0		0,5		0		1		1		2		1							
F11	Attraction		S09	+	S10	+	S11	+															+1,3	Positive	CT1			
		Change	1		2		1																					
F12	Communication network and distribution		T01	+	T02	+	T04	+	T05	+	T06	-	S01	+	S03	+	S05	+	S06	+	S07	+	+0,7	Negative	CO1			
		Change	2		1		1		1		0		0		0,5		0,5		0		1							

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Combined Scores on Influencing Factors of Teamwork Attributes																													
Coding	Influencing Factor		Related input variable with moderator and change																				Total Effect	Impact on Element	Effected Attribute Element			
			Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator	Variable	Moderator						
F01	Groupthink		T04	+	T05	+	S05	+	S06	+	S09	+											+0,7	Negative	DM1			
		Change	1		1		0,5		0		1																	
F02	Collective memory		T06	-	S01	-	S02	-	S03	-													-0,38	Positive	DM1			
		Change	0		0		1		0,5																			
F03	Observability		T07	-	S03	-	S05	-	S06	-	S07	-	S08	+	E07	-	E08	-	E09	-	E11	-	-0,7	Positive	DM1	SA2	CT2	CO1
		Change	2		0,5		0,5		0		0,5		1		2		1		1		0,5							
F04	Authority		T06	+	S03	-	S05	-	S07	-	S10	+	E01	+	E02	+	E03	+	E04	-			+0,28	Positive	DM2	LD1	LD2	
		Change	0		0,5		0,5		0,5		2		1		1		1		1									
F05	Participation		T06	-	S01	-	S03	-	S05	+	S08	+	S09	+									+0,33	Positive	DM3			
		Change	0		0		0,5		0,5		1		1															
F06	Workload		T01	+	T02	+	T03	+	T04	+	T05	+	T07	+	E11	+							+1,36	Negative	SA1	SA2	SA3	
		Change	2		1		2		1		1		2		0,5													
F07	Distractions		E04	+	E06	+	E08	+	E10	-													0,13	Negative	SA1	SA2		
		Change	1		-1		1		0,5																			
F08	Task structure clarity		T01	-	T02	-	T05	-	T07	-	T08	+	S08	+	E07	-	E08	-	E09	-			-0,7	Positive	LD1	LD2	CT1	SM1
		Change	2		1		1		2		2		1		2		1		1									
F09	Team roles clarity		S03	-	S06	-	S07	-	S09	+	S10	+											+0,4	Positive	SM1			
		Change	0,5		0		0,5		1		2																	
F10	Team exposure		T01	-	T07	-	S01	+	S04	+	S05	-	S06	-	S07	+	S08	+	S10	+	E05	-	-0,15	Positive	SM2	SM3		
		Change	2		2		0		0,5		0,5		0		0,5		1		2		1							
F11	Attraction		S09	+	S10	+	S11	+															+1,3	Positive	CT1			
		Change	1		2		1																					
F12	Communication network and distribution		T01	+	T02	+	T04	+	T05	+	T06	-	S01	+	S03	+	S05	+	S06	+	S07	+	+0,65	Negative	CO1			
		Change	2		1		1		1		0		0		0,5		0,5		0		0,5							

Framework Part III: Teamwork Attributes Scores Surgeons											
Coding	Element	Definition	Related influencing factor							Total Effect	Affected Teamwork Elements
DM1	Option generation	Gathering and processing the information needed to make a decision.		F01	-	F02	+	F03	+	-0,62	LD1 SM1
			Change	0,7		-0,6		-0,65			
DM2	Option selection	Choosing a solution to a problem and inform relevant personnel.		F04	+					+0,33	
			Change	0,35							
DM3	Implementation and assessment	Undertaking the chosen option and continually reviewing its suitability in light of changes in the situation.		F05	+					+0,25	
			Change	0,25							
SA1	Perception	The subconscious and intuitive perception of the environment. This is achieved through scanning for cues and patterns on the status and attributes relevant to the medical process.		F06	-	F07	-			-0,62	DM1 DM3 CO1
			Change	0,86		0,38					
SA2	Comprehension	The comprehension of the meaning of the information, which entails the creation of a mental model of the situation and the comparison with shared mental models.		F03	+	F06	-	F07	-	-0,63	
			Change	-0,65		0,86		0,38			
SA3	Projection	The projection of events or actions in the future based on the comprehension of the mental model of the situation.		F06	-					-0,86	
			Change	0,86							
SM1	Shared knowledge	The manner in which members structure knowledge about each other's skills and task.		F08	+	F09	+			+0,01	LD1 CT2 SA2 SA3 CO1
			Change	-0,39		0,4					
SM2	Shared expectations	Helping team members to compensate for one another, predicting each other's actions and provide information before being asked.		F10	+					+0,2	
			Change	0,2							
SM3	Shared attitudes	Team members poses compatible perceptions through similar attitudes about tasks to reach effective decisions.		F10	+					+0,2	
			Change	0,2							
LD1	Task maintenance	Promoting task completion, regulating behaviour, monitoring communication and reducing goal ambiguity to facilitate the achievement of group goals.		F04	+	F08	+			-0,03	CT1 CT2 CO1
			Change	0,33		-0,39					
LD2	Relational maintenance	Maintaining and enhancing a positive team climate, mutual trust, openness and recognizing team member's performance.		F04	+	F08	+			-0,03	
			Change	0,33		-0,39					
CT1	Team-building and maintaining	The ability to establish positive interpersonal relation between team members and their active participation in fulfilling the task.		F08	+	F11	+			+0,39	DM1 CO1
			Change	-0,39		1,17					
CT2	Back-up behaviour	Providing help to team members when they require assistance in demanding situations.		F03	+					-0,65	
			Change	-0,65							
CO1	Exchange information	Giving and receiving knowledge and information in a timely manner to aid establishment of shared understanding among team members.		F03	+	F12	-			-0,6	DM SA SM LD CT
				-0,65		0,65					

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Framework Part III: Teamwork Attributes Scores Nurses

Coding	Element	Definition	Related influencing factor										Total Effect	Affected Teamwork Elements
				Factor	Sign	Change	Factor	Sign	Change	Factor	Sign	Change		
DM1	Option generation	Gathering and processing the information needed to make a decision.	Change	F01	-	0,7	F02	+	-0,38	F03	+	-0,7	-0,6	LD1 SM1
DM2	Option selection	Choosing a solution to a problem and inform relevant personnel.	Change	F04	+	0,22							+0,22	
DM3	Implementation and assessment	Undertaking the chosen option and continually reviewing its suitability in light of changes in the situation.	Change	F05	+	0,33							+0,33	
SA1	Perception	The subconscious and intuitive perception of the environment. This is achieved through scanning for cues and patterns on the status and attributes relevant to the medical process.	Change	F06	-	0,71	F07	-	0				-0,36	DM1 DM3 CO1
SA2	Comprehension	The comprehension of the meaning of the information, which entails the creation of a mental model of the situation and the comparison with shared mental models.	Change	F03	+	-0,7	F06	-	0,71	F07	-	0	-0,47	
SA3	Projection	The projection of events or actions in the future based on the comprehension of the mental model of the situation.	Change	F06	-	0,33							-0,33	
SM1	Shared knowledge	The manner in which members structure knowledge about each other's skills and task.	Change	F08	+	-0,33	F09	+	0,3				-0,03	LD1 CT2 SA2 SA3 CO1
SM2	Shared expectations	Helping team members to compensate for one another, predicting each other's actions and provide information before being asked.	Change	F10	+	0,25							+0,25	
SM3	Shared attitudes	Team members poses compatible perceptions through similar attitudes about tasks to reach effective decisions.	Change	F10	+	0,25							+0,25	
LD1	Task maintenance	Promoting task completion, regulating behaviour, monitoring communication and reducing goal ambiguity to facilitate the achievement of group goals.	Change	F04	+	0,22	F08	+	-0,33				-0,06	CT1 CT2 CO1
LD2	Relational maintenance	Maintaining and enhancing a positive team climate, mutual trust, openness and recognizing team member's performance.	Change	F04	+	0,22	F08	+	-0,33				-0,06	
CT1	Team-building and maintaining	The ability to establish positive interpersonal relation between team members and their active participation in fulfilling the task.	Change	F08	+	-0,33	F11	+	1,3				0,49	DM1 CO1
CT2	Back-up behaviour	Providing help to team members when they require assistance in demanding situations.	Change	F03	+	-0,7							-0,7	
CO1	Exchange information	Giving and receiving knowledge and information in a timely manner to aid establishment of shared understanding among team members.		F03	+	-0,7	F12	-	0,7				-0,7	DM SA SM LD CT

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Framework Part III: Teamwork Attributes combined scores											
Coding	Element	Definition	Related influencing factor							Total Effect	Affected Teamwork Elements
DM1	Option generation	Gathering and processing the information needed to make a decision.		F01	-	F02	+	F03	+	-0,59	LD1 SM1
			Change	0,7		-0,38		-0,7			
DM2	Option selection	Choosing a solution to a problem and inform relevant personnel.		F04	+					+0,28	
			Change	0,28							
DM3	Implementation and assessment	Undertaking the chosen option and continually reviewing its suitability in light of changes in the situation.		F05	+					+0,33	
			Change	0,33							
SA1	Perception	The subconscious and intuitive perception of the environment. This is achieved through scanning for cues and patterns on the status and attributes relevant to the medical process.		F06	-	F07	-			-0,46	DM1 DM3 CO1
			Change	0,79		0,13					
SA2	Comprehension	The comprehension of the meaning of the information, which entails the creation of a mental model of the situation and the comparison with shared mental models.		F03	+	F06	-	F07	-	-0,54	
			Change	-0,7		0,79		0,13			
SA3	Projection	The projection of events or actions in the future based on the comprehension of the mental model of the situation.		F06	-					-0,79	
			Change	0,79							
SM1	Shared knowledge	The manner in which members structure knowledge about each other's skills and task.		F08	+	F09	+			+0,04	LD1 CT2 SA2 SA3 CO1
			Change	-0,33		0,4					
SM2	Shared expectations	Helping team members to compensate for one another, predicting each other's actions and provide information before being asked.		F10	+					+0,25	
			Change	0,25							
SM3	Shared attitudes	Team members poses compatible perceptions through similar attitudes about tasks to reach effective decisions.		F10	+					+0,25	
			Change	0,25							
LD1	Task maintenance	Promoting task completion, regulating behaviour, monitoring communication and reducing goal ambiguity to facilitate the achievement of group goals.		F04	+	F08	+			-0,03	CT1 CT2 CO1
			Change	0,28		-0,33					
LD2	Relational maintenance	Maintaining and enhancing a positive team climate, mutual trust, openness and recognizing team member's performance.		F04	+	F08	+			-0,03	
			Change	0,28		-0,33					
CT1	Team-building and maintaining	The ability to establish positive interpersonal relation between team members and their active participation in fulfilling the task.		F08	+	F11	+			0,49	DM1 CO1
			Change	-0,33		1,3					
CT2	Back-up behaviour	Providing help to team members when they require assistance in demanding situations.		F03	+					-0,7	
			Change	-0,7							
CO1	Exchange information	Giving and receiving knowledge and information in a timely manner to aid establishment of shared understanding among team members.		F03	+	F12	-			-0,68	DM SA SM LD CT
				-0,7		0,66					

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