Causal Loop Based Change Propagation and Risk Assessment

Andreas Rasmussen
Kongsberg Maritime
Eikeveien 17
3120 Nøtterøy, Norway
E-mail: rasmussen83@gmail.com

Gerrit Muller
Buskerud University College
Kongsberg, Norway

Michael Pennotti
Stevens Institute of Technology
Hoboken, NJ, USA

Abstract

The implications of initiating a new project or making changes on an already existing system can potentially have substantial influence on the system itself, other conflicting systems, or more non-technology oriented aspects.

This paper addresses how systemigrams and causal loop diagrams (CLD) can be used for communicating holistic and common system models to different segments of an organization. These models have been found useful in order to make sure all the involved parts have the same understanding of the project as well as following how the initiation of a new project will propagate in respect of four aspects: technology, organization, business, and finance. It is further described how the mapped propagation can be used as a basis for risk assessment where the risk is defined as the product of impact and probability.

The method described in this paper provides a new and more lucid approach of risk assessment based on what the project want to achieve.

Introduction

Changes are usual in systems today. Companies frequently experience how changes affect their systems. The changes can originate in different parts of the system lifecycle. Some changes may occur already in the concept or design phase, while others emerge during the production phase. Feedback from customers in the systems operational lifetime is also a source of changes that often affects the system. These are the most common phases to address changes, which mean that most of the proposed methods of handling change impact are related to these phases. Especially within the area of software (SW) engineering we can find several proposed methods to handle changes. Many of these methods address change impact analysis in respect of requirements traceability. Goknil et al. (Goknil, Kurtev, and van den Berg) propose to trace requirements through a meta-model describing the requirement relations for a SW product. This is a sufficient approach if the meta-model is in place, but the number of requirements for more complex systems can be quite large in which it will result in a quite complex requirement model. However, as Heindl and Biffl propose, a full requirements tracing model can be effective in respect of re-testing the affected test cases. When just focusing on updating the test cases based on the changed requirements the situation will be more lucid. A weakness of these models is the lack of ability to detect affected elements not described by the requirements, such as economical, business, and organizational aspects, as well as how other products and technologies will be affected.

To get a full overview of all the affected elements related to changes the propagation should be mapped. The importance of mapping the change propagation is an issue that Rutka et al. (Rutka, Guenov, Lemmens, Schmidt-Schäffer, Coleman, and Rivière) emphasize. They propose a change impact and propagation analysis method, based on dependency matrices describing the reliance between the affected elements in the system. Each of the affected dependencies in the matrices is supported by unique tables that describe the different properties related to a change, e.g. the level of change. This method, however, is designed to be implemented in a software system and is therefore not intended for use as an easy to follow communication model. That is, the dependency matrices have the potential to be relatively large in cases of large and complex systems as one element can be affected by several other elements and each element can affect many other elements.

The chains of interactions between the different elements in a system, which can also be seen as root causes (Rushing), may be difficult to see in a dependency matrix. These relations can be very useful in terms of reducing defects and improve a system (Rahal) by following how e.g. a change of one of the elements will propagate. A good way of displaying these root causes, or mapping the propagation, is by using causal loop diagrams (CLD) (Rushing) because this type of diagrams has the unique ability to illustrate the system dynamics and mechanisms (Binder, Vox, Belyazid, Haraldsson, and Svensson).

Another aspect of the dependency matrix method described by Rutka et al. (Rutka, Guenov, Lemmens, Schmidt-Schäffer, Coleman, and Rivière) is the ability to provide risk levels related to the affected elements. This is a useful property when it comes to decision making. A concern here, however, is that the risk levels provided by the dependency matrix only represent the downside, or negative, risks. The handbook for the Australian standard AS/NZS 4360 (Standards Australia International Ltd) defines risk as "*the chance of something happening that will have an impact on objectives*", meaning that Risk = Probability x Impact. The handbook further points out that "*Risk may have a positive or negative impact*" and emphasizes that "*it is recognized that activities involving risk can have positive as well as negative outcomes*". The negative risks are easy to imagine, but the positive risks are not that common to consider in risk management and is thus harder to see. TenStep Inc describes positive risk as "*…risk that we initiate ourselves because we see a potential opportunity…*", which is in conformity with SWOT analysis principles (BHP Information Solutions Ltd) (Lee). SWOT is an acronym for Strengths, Weaknesses, Opportunities, and Threats. This type of analysis provides a way to analyze these four aspects in order to maximize the potential of strengths and opportunities and minimize the impact of the weaknesses and threats. This relation between risk and SWOT analysis is also described by New South Wales (NSW) Department of State and Regional Development that claim "*The strengths and opportunities can be viewed as positive risks and the threats and weaknesses as negative risks*".

In the following sections of this paper, a methodology describing how CLDs can be used for mapping the propagation effect when a new project is initiated or a change is requested will be addressed. This method also includes risk assessments, both positive and negative risks, based on the propagation mapped in the CLDs.

Proposed Method

When initiating a new project one of the first things to do, after eliciting stakeholder requirements, is to make all the involved parts to agree on the acceptance criteria for the project. There should be no more than five criteria addressing the expectations of the stakeholders, forming the foundation of the key factors for success. These criteria are based on the stakeholder requirements and define how to appraise the success of the project (Verma and Pennotti, 2005). The success can often be measured in form of e.g. money or time, but sometimes quantified measuring does not apply to the acceptance criteria. In these situations the conclusion whether the specific acceptance criteria is met or not must be based on demonstrations, tests, or expert assessments.

In terms of change impact analysis (CIA) acceptance criteria can be useful for analyzing the impacts caused by a project. When a new project is initiated it will affect several different factors in an organization or system. Also, when the project is finished and the new product or system is released it may affect already existing systems. In order to get an overview of what such risks may be, an analysis should be executed.

Many projects carried out today are of very complex nature and therefore affecting many factors in the surrounding systems or organizations. Due to the complexity it is often difficult to see the full picture and get a complete overview of which factors may be affected. Even if a good indication of affected factors is achieved the number of affected elements in a system or an organization will probably be quite high. Taking all the affected elements into consideration will be a comprehensive and time consuming task. To cope with this problem the use of acceptance criteria can filter out the most important parts of the system.

The identification of acceptance criteria is not a method for studying changes itself. It is more a way of narrowing down the scope; what to focus on and a method of splitting a project into simple and more manageable elements. To get an overview of how the project is organized it is useful to make a top-level diagram containing all the acceptance criteria. The diagram should be arranged in such a way that it clearly communicates which elements will be affected by each of the acceptance criteria. One type of diagram suited for this purpose is systemigrams.

Systemigrams, described by Professor John Boardman and Dr Brian Sauser in *Systems Thinking: Coping with 21st Century Problems,* are diagrams that structure prose in graphical representation also known as systemic diagrams. It consists of nodes, expressed with nouns or noun phrases, and arrows linking the nodes together, which are expressed by verbs or prepositional phrases. The strength of systemigrams is the ability to unite all aspects of a system in the same diagram in a holistic way of thinking.

In order to map which factors that may be affected in respect of each of the acceptance criteria it is useful to make a more detailed lower level diagram. At this point it is not only important to map the relationships between the affected factors but is also important to describe the dynamics. If e.g. the two elements, *Labor hours* and *System cost*, affect the same element, *Profit*, in opposite ways the *Profit* node will affect another node, *Investment in R&D*, in different ways relative to whether we look at the *Labor hours* or *System cost* element. For purposes like this causal loop diagrams (CLD) are well suited.

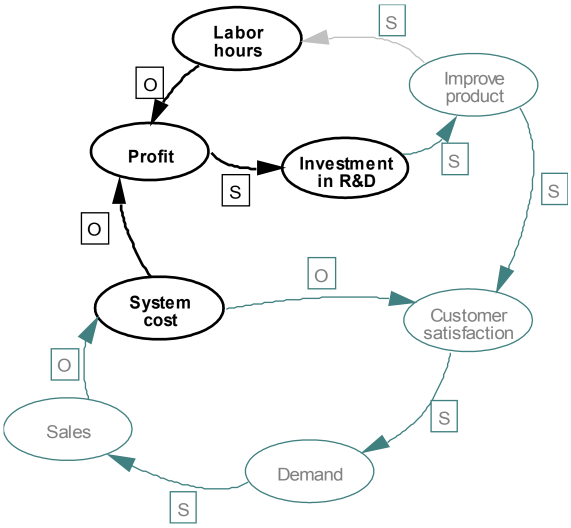

Figure 1: Example of Causal Loop Diagram

Figure 1 illustrates an example of a CLD. The elements highlighted are the elements described above. However, all the elements in the diagram are important in order to understand the dynamics. These diagrams describe how the different elements in a system interrelate and behave due to the influence of each specific element. The elements in the diagram are linked together by arrows describing which direction the connection is heading. Each of these arrows is labeled either S or O. The S label means that the relationship between two elements is the same. That is, if the link between element A and C is labeled S, element C will be affected in the same way as element A. If element A increases it means that element C will increase as well. If the link is labeled O, on the other hand, it means that the relationship between A and C is opposite. Accordingly, if element A increases element C will decrease (Boardman and Sauser).

When looking at the impacts of introducing a new project in a system perspective, it is relatively easy to map it by the use of causal loop diagrams. However, the projects are often quite big and complex resulting in rather large and complex diagrams. In order to reduce complexity and size of the CLDs they should be based on the acceptance criteria of the project. The problem statement on which to base the CLD will then be: how will the introduction of the project in respect of the specific acceptance criterion propagate? The demand of one of the acceptance criterion will be one of the elements in the CLD. The rest of the nodes in the diagram are all the elements in terms of components, economy, manpower, time to market, creation of documents, etc, that will be affected by the project. When the CLD is read and the information is extracted the starting point should be at the acceptance criterion node in the diagram. The number of CLDs to be made depends on the number of acceptance criteria. By zooming in on each of the acceptance criteria the system of interest complexity will be filtered out which make it easier to get an overview of and understand.

The graphical representation in the causal loops provides a propagation overview of which elements that may be affected by the project and how but does not say anything about the severity of the impacts. To find the impact severity of each affected element in the beginning of the project is not an exact science because it is something that has to be applied prior to the project start-up. Nevertheless, the results will be more exact later in the project when more insight and understanding of the project reveals more information, which means that the diagrams and risk assessments should be iterated. The causal loops give a good indication of which elements or factors that have to be investigated further. However, the number of elements highlighted by the causal loops is usually quite high, and due to time constraints, which often appear in projects, not all of the affected elements can be further investigated. Thus it is important to emphasize the elements that may cause the most important impact, or risk, to the organization. Each of the nodes in the CLD should for that reason be assigned an impact rating number (IR) in accordance to relative to the four risk categories: technology, organization, business, and finances. These four categories are based on the five prevailing categories used in Kongsberg Maritime's (KM) risk assessment as a part of the phase II report delivered by KM projects today. Four of the five prevailing categories are the same as described above while the fifth category is *market* (Kongsberg Maritime, 2005). In this paper the market risk is seen as the same as the business risk. The technology risks are the risks related to the architecture of the system or product itself, such as e.g. the risk of the system to fail. The organizational risks are the risks concerning logistic issues, human resource matters, training etc. When it comes to the business risks these are the risks concerning more political issues such as customer relations and business development. The last category, financial risks, includes all the economical aspects.

The impact value assigned to each of the categories for each of the affected nodes reaches from 0 to 3, where 0 means no impact, 1 means minor impact and 3 means major impact. An impact, or consequence, rating between 1 and 3 is in conformity with table 4.3.1 in (AIRMIC, ALARM, IRM, 2002) which also considers both positive and negative risks. In this paper a positive or negative sign of operation should be assigned each of the IRs in order to distinguish between positive and negative impact. This scale will provide the engineers with a common basis when assigning the IRs which is important for the reliability of the results.

Table 1: Impact Rating

Impact Rating	
IR	**Description**
3	Major impact
2	Medium impact
1	Minor impact
0	Has no impact

However, it is important to assess the probability of the impact to occur as well as the impact itself. A way of handling this issue is to assign each of the impacts a probability number (P) in accordance to Table 2. This rating table is a modified version of the occurrence rating table that Nordgård describes in his Robust Engineering lecture. The scale that quantifies the probability reaches from 1 to 5 where 1 means that the probability of the impact to occur is almost never and 5 represents that the impact almost certain will occur.

Table 2: Probability Rating

Probability Rating	
P	**Probability**
5	Almost certain
4	High
3	Medium
2	Low
1	Almost never

Table 3 gives an illustration of how to fill in the information gained from the CLD and the impact and probability rating process. There should be made one table for each CLD, which means one table for each acceptance criterion. This information is filled in at the top row of the table in order to distinguish the tables from each other. In the *Link 1*, *Node 1*, *Link 2* and *Node 2* columns the description from the CLD shall be filled in. The column named *Link 1* holds the relationship describing how *Node 1* will react when affected. The column named *Node 1* describes the nodes that have a relationship arrow pointing out towards another node. This node affects the nodes described in the *Node 2* column which are the nodes with arrows pointing inwards from another node. The *Link 2* column holds the relationship describing how *Node 1* will affect *Node 2*. All the nodes in the CLD must be filled in to this table. The columns in Table 3 that are split are assigned to the IR values at the top row according to . Further, the lower row of the split columns is assigned to the probability rating (P) according to Table 2. The characters T, O, B, and F represent the four risk categories technology, organization, business, and finances respectively.

When all the nodes in the causal loops have been impact and probability rated the risk related to each of the element groups for each of the affected elements can be calculated and filled in to the same table. These numbers, located in the *Risk Values* rows, are the product of IR and P which highlights the affected elements that should be investigated further in respect of the element groups. The last column in Table 3 called *PRI* represents the priority numbers. Each element shall be prioritized in accordance to its risk values as well as the project plan. Some of the elements with high risk values may not be possible to work on before other elements or tasks, with e.g. lower risk values, have been completed. In such situations the priority of the high-risk elements will be lower than the priority of other elements that must be solved first.

Table 3: Template of risk and priority assessment table

Acceptance criterion								
Link1	**Node 1**	**Link 2**	**Node 2**	T_{IR}	O_{IR}	B_{IR}	F_{IR}	**PRI**
				T_P	O_P	B_P	F_P	
Risk Values								
Risk Values								
Risk Values								

Each of the risk values found in Table 3 can be compared to Table 4 which is a product of and Table 2. If the value is 0 there is no risk. Risk values from 1 through 5 represent a minor risk, from 6 through 10 means medium risk, and a number from 11 through 15 represents a major risk.

Table 4: Risk Rating

Risk Rating	
Rating	**Description**
11 - 15	Major risk
6 - 10	Medium risk
1 - 5	Minor risk
0	No risk

Introduction to Case Study

Dynamic positioning (DP) and process control systems for ships and offshore installations are some of the market segments where KM has developed and delivered solutions for the past three decades. The DP system is designed to keep the vessel within a specified position and heading limits when needed. The system is implemented on a variety of ships from drill ships, Floating Production, Storage and Offloading (FPSO) ships, cable-laying and crane vessels to mega yachts and cruise ships, among others. DP is a very important market for KM. In order to maintain and improve their position within a competitive market and adapt to new markets, they need to cope with the increasing technological development and new regulations as well as creating a differentiation in the mind of the customers. The majority of this development is managed by the Innovation Department (former Technology Base (TB)) which is base technology centric for the common frameworks and components suitable for the major wide product portfolio. Today the Innovation Department maintains and manages further development of several common Firmware (FW), SW and HW components integrated in a variety of systems delivered by other departments. In addition they also hold the responsibility for the process control system Advanced Integrated Multifunctions (AIM).

In 2005 the project New RIO Hardware Line was initiated on demand from the DP department. One of the project objective was to develop a new system for stand alone DP. Before this project was initiated the DP deliveries depended on delivering all the equipment that was related to the DP system. A problem with this solution was that many ships had thruster control systems from other suppliers competing with KM and such equipment was not compatible with the old DP system provided by KM. If the customers wanted to use the DP system delivered from KM they had to replace the existing thruster control system with KM's thruster control system. This was an expensive solution which contributed to weaken KM's ability to compete within this market segment. To solve this concern KM introduced new HW modules for I/O processing, a new real time redundancy concept, and a new synchronous I/O BUS called RBUS (Kongsberg Maritime).

Another objective in this project was to increase the efficiency of producing and assembling the systems. Prior to the project all the deliveries were custom-made. The cabinets were designed and manufactured specially for each delivery and the HW had to be installed with different configurations in most of the cases. Concerns regarding time to market and high production cost implied that serial production had to be initiated. One of the aspects that had to be improved to meet this requirement was the plug and play functionality of the HW modules. In the old system several thrusters was connected to 32 channel I/O modules. In some cases it had to be redundancy in the I/O modules to minimize the risk of potential drift-off from the wanted position if some of the modules failed. With this solution all the cabling from the thruster to the I/O module had to be done manually for each case. This was a factor that contributed to slow down the production speed of each delivery. To meet this challenge the New RIO HW Line project developed new HW modules that had good plug and play ability. These new components are designed to be plugged onto a rail system that provides the modules with both power and data. The I/O models (RMP 200-8) has 8 channels to be connected to one thruster each. Since each I/O module is dedicated to one thruster and the Mean Time Between Failures (MTBF) is shorter for the thrusters than for the I/O modules there is no need for redundancy in the I/O modules. This reduced the need for components in the deliveries. However, to apply the plug and play functionality the cabinets had to be pre-wired from the cabinet supplier. Today KM delivers two different types of pre-wired cabinets, for different redundancy solutions, that suit the main stream of customers.

The initial intention was to involve several product departments in a joint project benefiting all the involved parts. However, all the product departments, except DP, left the project leaving DP as the only stakeholder and TB as the developer. Having only one product area as stakeholder resulted in more DP oriented solutions. This was a concern for TB due to their role in developing base technology for common frameworks and components to be used in several product areas. Accordingly, TB adapted the system architecture and design during the project to easier apply to other products at a later time.

The Case

As described in the introduction to the case study section the acceptance criteria for the New RIO HW Line project is to make a stand alone DP system and to make serial production of the DP systems possible. A top level diagram for the project is illustrated in Figure 2. This means that to succeed with the project the aforementioned two criteria must be fulfilled. The following example will focus on the affected elements related to serial production of the DP systems.

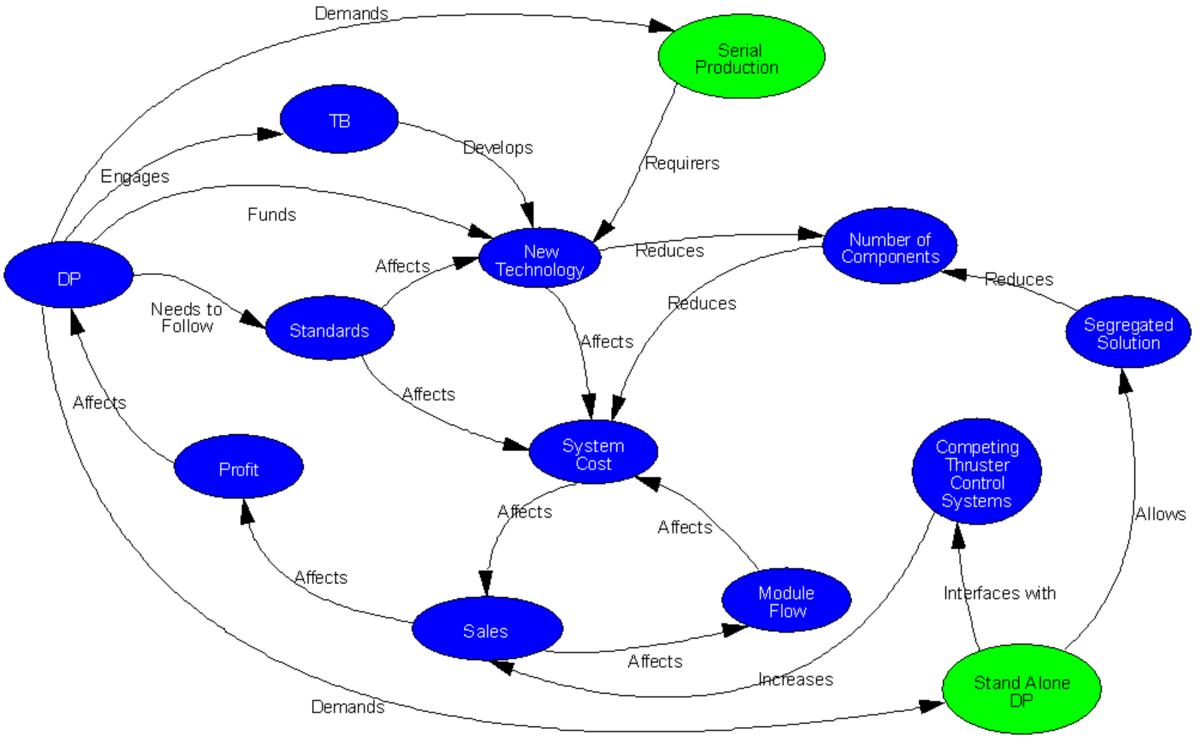

Figure 2: Top-level diagram of initiation of New RIO HW Line

The CLD shown in Figure 3 illustrates which elements may get affected as a result of initiating the New RIO HW Line project in respect to achieving serial production. As we can see there are several elements that affect the system cost which will influence the number of deliveries. One of the elements is the decreased number of different HW modules to be produced. Since the modules developed are more common-functionality modules the variety of modules required in the new generation DP system will be reduced. Consequently, the number of different modules to be produced will decrease which results in a reduced total production cost. This will result in a lower system cost. Thus will again resulting in a decreased system cost. Other important relationships in the CLD are that new pre-fabricated cabinets together with plug and play capabilities for the HW modules will reduce the production time of each system which will increase the possible number of system deliveries. The two most important aspects of the serial production are prefabricated cabinets and the plug and play capabilities for the HW modules. The cabinets are pre-wired from the supplier and suit the delivery projects for the main stream of the customers. The plug and play modules are designed to be used in KM's thruster control system suited for DP deliveries of the main stream of the customers. As a result of the pre-fabricated and pre-wired cabinets, as well as the HW modules plug and play capabilities a decreased production time for each system is gained. In retrospect it turned out that the reduced production time was crucial to KM in order to cope with the increased demand for deliveries in the market. The reduced system cost as a consequence of a reduced number of different HW modules to be produced, and the decreased production time due to pre-fabricated cabinets and plug and play capabilities are candidates for further investigation. At this point the CLD it does not say anything about the risk related to each link and is therefore investigated further in Table 5.

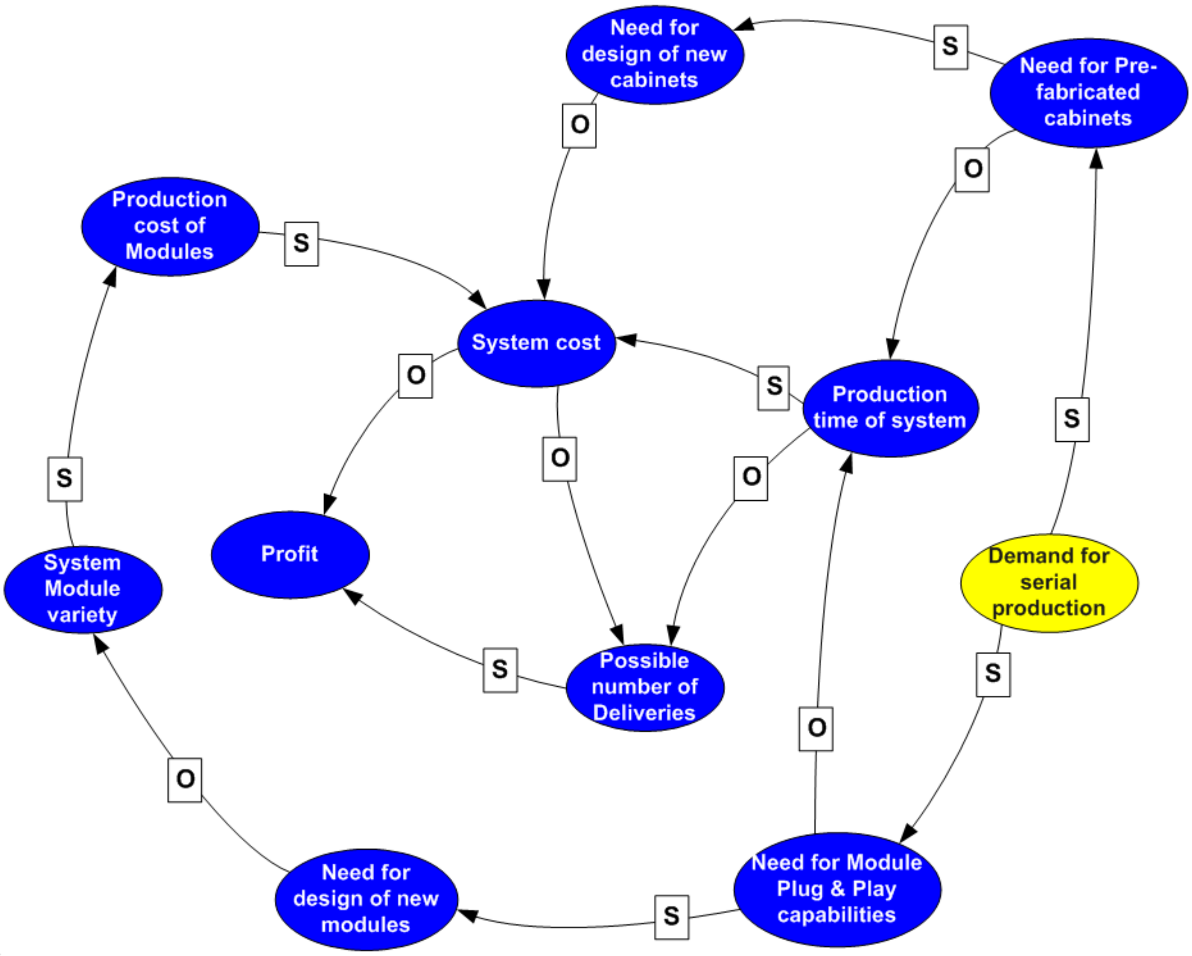

Figure 3: CLD describing affected elements in respect of Demand for serial Production

Table 5 allows filling in the assessments of impact and probability as well as the calculated risk factor. The table provides an overview of the impact, probability, and risk related to technology, organization, business, and finances. Since the CLD is more like a communication model describing the relations in a system it is important to use a table in addition to the CLD for providing an overview of the risk assessments which should be used for documentation. In order to demonstrate the method the example provided in Table 5 is just an extraction of the full table that should be made for a project.

Table 5: Risk and priority assessment table for Serial Production

Serial Production								
Link1	**Node 1**	**Link 2**	**Node 2**	T_{IR}	O_{IR}	B_{IR}	F_{IR}	**PRI**
				T_P	O_P	B_P	F_P	
Increased	Need for design of new modules	Decreases	Module variety	2	1	2	1	
				5	4	4	3	
			Risk Values	**10**	**4**	**8**	**3**	**4**
Decreased	Module variety	Decreases	Production cost of modules	1	0	1	2	
				2	-	3	4	
			Risk Values	**2**	**0**	**3**	**8**	**4**
Decreased	Production cost of modules	Decreases	System cost	1	0	2	2	
				3	-	5	4	
			Risk Values	**3**	**0**	**10**	**8**	**3**
Decreased	System cost	Increases	Possible number of deliveries	1	1	2	3	
				3	2	4	5	
			Risk Values	**3**	**2**	**8**	**15**	**2**
Decreased	System cost	Increases	Profit	1	1	1	2	
				3	3	3	4	
			Risk Values	**3**	**3**	**3**	**8**	**3**
Increased	Possible number of deliveries	Increases	Profit	1	1	1	3	
				2	3	3	5	
			Risk Values	**2**	**3**	**3**	**15**	**2**
Increased	Need for pre-fabricated cabinets	Decreases	Production time of system	0	1	3	2	
				-	3	4	4	
			Risk Values	**0**	**3**	**12**	**8**	**1**
Increased	Need for module plug and play capabilities	Decreases	Production time of system	0	1	3	2	
				-	3	4	4	
			Risk Values	**0**	**3**	**12**	**8**	**1**
Decreased	Production time of system	Increases	Possible number of deliveries	1	2	3	3	
				3	4	4	5	
			Risk Values	**3**	**8**	**12**	**15**	**1**

When Table 5 has been filled out a better indication of where the largest risks may be has been attained. The risk can then be categorized in accordance with Table 4 indicating whether the potential risks are minor, medium, or major. In order to make the CLD even more informative it can be updated with illustrations of the risk assessments. This may be done by vary the thickness of the link arrow lines. The line thickness should represent the three different risk categories plus the cases where no risk is involved. Hence the arrows should have three different line thicknesses plus e.g. dotted lines illustrating no risk. The thinnest line will represent minor risk, while the thickest line will represent a major risk. However, for each sets of links and nodes, four risk values representing each of the four risk dimensions; technology, organization, business, and finances are assessed. But only one of the risk dimensions should be represented in the CLD. For a general use the highest of the risk values should be represented, while in other situations where e.g. the diagram should be used to communicate with economists the risks represented should mainly be economical. In order to show what kind of risks that is represented in the diagram on of the characters T, O, B, and F representing technology, organization, business, and finances respectively, should be shown for each link. For the chosen character the related risk number should also be shown.

In addition to the risk values and the thickness coding of the links the diagram should provide information regarding the priority of each of the instances according to Table 5. The priority numbers can be presented in the same way as the risk numbers, by the prefix PRI followed by the priority number.

Another dimension that should be illustrated in the CLD is whether the risk is positive or negative. A way to show this in the diagram is color coding. Red is widely used as a color representing e.g. danger, stop, or bad, and will consequently be well suited to represent a negative risk in the diagram. When it comes to the positive risk it should be illustrated by a color that communicates positive relations. A color that most people associate with something positive is green. Other colors can be used instead, but these are probably the most commonly used colors for such representations.

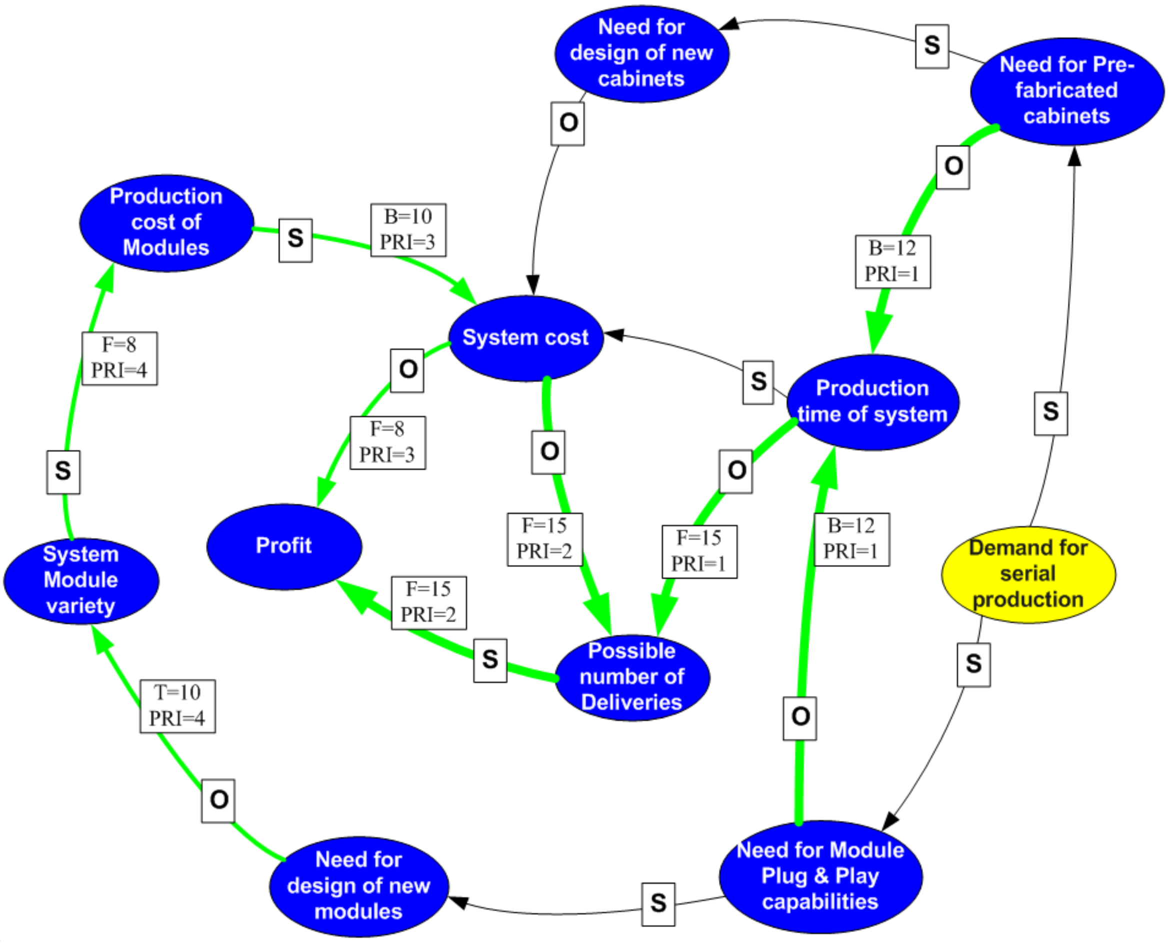

Figure 4: Risk and priority numbers embedded in a CLD.

The example provided by the diagram in Figure 4 highlights the largest risk values irrespective of the four categories from Table 5 as a more general view. As we can see from the color of the links in the diagram and the risk numbers, there are only positive risks identified as the most important risks from the table. One of the links that is especially important to investigate further is the link between the *Production time of system* node and the *Possible number of deliveries* node. This link is the only link that has a positive risk value of 15 and a priority 1. This is the largest positive risk value and the highest priority possible according to Table 4 and the common way of assigning priority numbers, respectively.

Evaluation

As we can see from the CLD in Figure 4 the diagram can be a quick and easy way of communicating possible positive and negative risks in a holistic propagation view with e.g. management and control boards. The model also applies to the participants in the project to gain a common basis for understanding the project and its objectives. As described earlier Table 5 incorporates risk numbers for technology, organization, business, and finances. These values can be used to present the respective CLD in different ways. The project control board will probably be most interested in the risks related to finances while representatives from business development will probably want to see an overview of the risks concerning the business. This can be achieved by representing the risk numbers concerning finances or business provided by Table 5 in a CLD in the same way as illustrated in Figure 4. The values presented in the CLD should change depending on the receiver of the message.

However, the chance that the impact and probability numbers filled into Table 5 can be influenced by the personal interests and opinions of each person is impending. When running projects the personnel involved will usually have different opinions about the different technical solutions and what is most important to focus on. This can be a potential problem when assessing impact and probability. This is why it is important to sit in groups when filling out the table. Such groups should consist of representatives from several different fields to obtain a broader evaluation during the rating process.

Another issue is that the use of this method must be considered for each project. In small projects where it is easy to see the full picture the effort of using the method might be too high compared to what the project will gain. In large complex projects on the other hand, the method can be very useful in order to get an overview of all the affected elements as well as the dynamics in the system. However, an important lesson learned from working with this paper is the importance of that the method must be easy to understand and use as well as easy to communicate to others. Methods that are hard to use and understand will probably not be used in projects because the project resources will focus on carrying out the project.

The above sections describe a snapshot of the project in an early phase. Projects, in real life, will change continuously during the entire project life time. The project plan will usually be updated with a fixed frequency and the knowledge about the system to be developed in addition to the factors affected by the system will change. Accordingly the numbers describing impact, probability, risk, and priority as well as the diagrams should be dynamically updated during the lifetime of the project at the same incidence as the project plan. Some of the nodes can be deleted from the CLD while others can be added to describe new information in the project. The respective table will therefore be updated as well.

In the case of updating the data and figures during the entire life time of the project a lot of information will be produced. The handling of this data should be a subject for further study. A way to cope with this issue can be to develop a SW tool to edit and manage the data and diagrams. This way it would be easy to study and analyze the changes during the project life cycle. This would open up the possibility for e.g. conducting regression analyses on the risk numbers in order to look for trends.

Another issue for further studying that should be considered in respect of augmenting the functionality of the method is the possibility of describing the actions to be taken in order to cope with the different risks.

Conclusion

The method presented in this paper shows how causal loop diagrams (CLD) can be used to map the propagation effect when initiating a new project. These diagrams provide a basis for conducting risk assessments based on impact and probability. Further it is demonstrated the value of using the CLDs as a quick and easy way of communicating possible positive and negative risks, found by the risk assessment, in a holistic propagation view. The graphical representation provided by the CLDs will assure all involved actors in the project to gain a common basis of understanding the project and its objectives.

The focus in this paper has been to apply the method in the initial phase of a project in order to explain the principle, but the method should be applied through the entire life cycle of the project. The information about the system will change during the project lifetime due to better insight in the system as well as changes based on testing and new or changed requirements from the stakeholders.

References

1AIRMIC, ALARM, IRM, 2002. A Risk Management Standard.

BHP Information Solutions Ltd. SWOT analysis.

Binder, T., Vox, A., Belyazid, S., Haraldsson, H., Svensson, M. Developing System Dynamic Models from Causal Loop Diagrams.

Boardman, John and Sauser, Brian, 2008. *Systems Thinking; Coping with 21st Century Problems*.

Goknil, A., Kurtev, I., van den Berg, K. Change Impact Analysis based on Formalization of Trace Relations for Requirements. Software Engineering Group, University of Twente, the Netherlands.

Heindl, M., Biffl, S. Requirements Tracing Strategies for Change Impact Analysis and Re-Testing - An Initial Tracing Activity Model and Industry Feasibility Study.

Kongsberg Maritime. Phase II Report

Kongsberg Maritime. Phase III Report RIO200.

Lee, D. Conducting a SWOT Analysis. Futurscope Ltd

Nordgård, Knut. Exercise Failure Mode and effect analysis: Robust Engineering: Buskerud University College.

NSW Department of State and Regional Development. Risk management tools and activities.

Rahal, F. Enhancing Six-Sigma with Root Cause Analysis. Apollo Associated Services, LLC

Rushing, W. M. Causal Loop Diagrams: Little Known Analytical Tool. iSixSigma LLC

Rutka, Guenov, Lemmens, Schmidt-Schäffer, Coleman, Rivière. Methods for Engineering Change Propagation Analysis. Airbus, Cranfield University, EADS Germany, EADS CRC France.

Standards Australia International Ltd. Handbook: Risk Management Guidelines - Companion to AS/NZS 4360:2004.

TenStep Inc. Should You Factor Positive Risk into Project Planning?

Verma, Denish and Pennotti, Mike, 2005. Fundamentals of Systems Engineering: Systems Operational Effectiveness and Life Cycle Analysis (SDOE 625): Stevens Institute of Technology.

BIOGRAPHY

Andreas Rasmussen received his BSc in Cybernetics from Buskerud University College in 2003 and in 2009 he received his MSc in Systems Engineering from Stevens Institute of Technology. He is currently employed as a Systems Engineer in the R&D Department at Kongsberg Maritime.

Gerrit Muller received his Master's degree in physics from the University of Amsterdam in 1979. He worked from 1980 until 1997 at Philips Medical Systems as a system architect, followed by two years at ASML as a manager of systems engineering, returning to Philips (Research) in 1999. Since 2003 he has worked as a senior research fellow at the Embedded Systems Institute in Eindhoven, focusing on developing system architecture methods and the education of new system architects, receiving his doctorate in 2004. In January 2008 he became a full professor of systems engineering at Buskerud University College in Kongsberg, Norway.

Dr. Michael Pennotti is Associate Dean for Academics and Distinguished Service Professor in the School of Systems and Enterprises at Stevens Institute of Technology. A systems engineering leader for more than thirty years, Dr. Pennotti has broad experience with both technical and organizational systems. He spent twenty years at Bell Laboratories designing, analyzing, and improving the performance of three generations of anti-submarine warfare systems for the United States Navy. In 1990, he shifted his focus to business management, and over the next ten years, served on the senior leadership teams of three different businesses as Quality Director for AT&T Business Communications Systems, Human Resources Vice President for Lucent Technologies' Enterprise Networks Group, and VP Quality for Avaya. Since joining Stevens in 2001, Dr. Pennotti has helped develop the SDOE Program into the largest graduate program in systems engineering in the world. He is a member of the International Council on Systems Engineering and a senior member of both the IEEE and the American Society for Quality. He holds Ph.D. and MS degrees in Electrical Engineering from the Polytechnic Institute of New York, a BEE from Manhattan College, and is a graduate of the AEA/Stanford Executive Institute for Technology Executives.