The Value of Systems Engineering Tools for Understanding and Optimizing the Flow and Storage of Finished Products in a Manganese Production Facility

Marianne I. Drotninghaug
Vale
Hestgjerdet 22 A
8618 Mo I Rana, Norway
Marianne.drotninghaug@rdmeuro.com

Gerrit Muller
Buskerud University College
Kongsberg, Norway

Michael Pennotti
Stevens Institute of Technology
Hoboken, NJ, USA

Abstract

This paper investigates the value of specific Systems Engineering tools applied to the flow and storage of finished products inside a Manganese Production Facility. The tools are evaluated according to the value they provided for a systems engineer working in manufacturing industries and the value they provided for non-Systems Engineering personnel. The tools include context diagram, physical architecture, IDEF0 diagrams, Use Case Scenarios, Scenario Tracing and a geographical model.

The selected systems engineering tools provided different value for the systems engineer and the other employees. For the systems engineer the most valuable tool was the IDEF0 diagrams and the scenario tracing, in terms of adding to the understanding of the flow and storage of finished products, while for the other employees the geographical model proved to be the most valuable in terms of the number of comments it triggered and the number of improvements that were related to it.

Introduction

Application of Systems Engineering in Manganese Production Facility. The techniques related to Systems Engineering have traditionally been used for the development of complex systems, such as airplanes, air shuttles and weaponry systems. But while Systems Engineering has grown as a profession, so have the contexts in which it may be applied. This paper analyzes the value of common Systems Engineering tools in a company that produces manganese alloys. Vale is one of the world's largest mining companies (www.vale.com) and its headquarters are located in Brazil. One of their manganese producing plants is however located far from the tropical environment of Brazil. Rio Doce Manganese Norway (RDMN) is located in the North of Norway in the small town of Mo I Rana. The authors have chosen to focus on the flow and storage of finished products from ladle to ship inside RDMN. The Systems Engineering tools have been chosen on the basis of their expected ability to depict the Flow and Storage of Finished Products System at RDMN. The tools that were applied are: Context Diagram, Physical Architecture, IDEF0 Diagrams, Use Case Scenarios, and Scenario Tracing.

In addition a physical layout of the plant was used to communicate the findings of the application of the Systems Engineering tools to other RDMN employees without Systems Engineering backgrounds. The value of the Systems Engineering tools was analyzed from two separate perspectives:

- What is the value of the selected Systems Engineering tools for a Systems Engineer working in the manufacturing industry?
- What is the value of the selected Systems Engineering tools for employees of a manganese alloy plant, without Systems Engineering background?

Motivation for Application of Systems Engineering in RDMN. Since the beginning of RDMN in 2003 the company has seen a steady rise in demand for their products. They therefore wish to optimize their system for product handling from ladle to ship that is from the time the metal is tapped from the furnaces to the time it leaves port ready for sale. This paper focuses on the Flow and Storage of Finished Products from ladle to ship, hereby referred to as the FSFP System.

RDMN management wishes to optimize every part of the system including cooling, crushing, storing, monitoring, evaluating and reporting. The main goal of the company is to simplify the process while gaining maximum yield and maintaining sufficient process control. One of the focus areas of the owner company Vale is PPC or Production Planning and Control. The PPC process aims to design a production system which will enable the company to meet delivery dates with minimal cost, achieve effective utilization of production facilities and ensure a smooth flow of materials.

This paper investigates the application of common Systems Engineering tools to the FSFP System in order to determine if these methods may help PPC reach some of the goals of Vale and move closer to RDMN's overall goal of achieving maximum yield while maintaining sufficient control over the process from ladle to ship. It also responds to a request from RDMN managers to gain a better understanding of the flow and storage of the materials.

A more general motivation of the authors is to provide further research in the area of the value of Systems Engineering in different areas, as this is requested by the Systems Engineering community in several contexts.

The value of Systems Engineering in Manufacturing Industries. Systems Engineering has traditionally been used for developing highly complex products such as weaponry systems and airplanes. This paper investigates the value of Systems Engineering in a less conventional application, where the system in question is not the finished product but rather the processes that produce a product. Research suggests a similar level of applicability of Systems Engineering and Architecting (SE&A) across multiple domains, geographic, project or program size and system service complexity (INCOSE Systems Engineering Handbook 2007). Following an Airforce/LAI workshop in June 2004, Honour (2004) presents seven studies that provide some indication in terms of quantifying the value of Systems Engineering. The research collected have many common traits in that they state that there is not sufficient research conducted to make absolute conclusions. However most of the authors indicate that there is a strong case to be made for providing sufficient Systems Engineering efforts in projects or programs. More in depth research is presented in the background section of this paper. By applying well-known tools to a real life situation the authors wishes to gain a clearer understanding of how Systems Engineering can be utilized in other areas than the originally intended ones. This may also help clarify the role of a system engineer or system architect in other industries than those that develop complex systems. Case studies are often the best mean to study application of theoretical principles to real life situations. One main drawback of case studies is that they are difficult to generalize. However, when several case studies are performed in the same area valuable information is provided, and with the growing number of studies, the results become more suitable for making generalizations.

Applying Systems Engineering in Manganese Production Facility. Following interviews with managers it became clear that the top-level understanding of the flow of the finished products at RDMN was lacking. The Systems Engineering tools applied are selected from the wide variety of methods that has been presented during the three years of master study at Buskerud University College in Kongsberg (Hibu). The courses that have been offered are a mix of courses offered by Stevens Institute of Technology (www.stevens.edu/sse) and by Professor Gerrit Muller in cooperation with the Gaudi Project (http://www.gaudisite.nl/).
The first step of the process was to gain a clear understanding of the flow and storage of finished products from the systems engineer perspective. This was done using a variety of Systems Engineering tools to depict the FSFP System. The discoveries and lessons learned through this process are documented and discussed in the results section. The next step was to create an effective model to be used to communicate the results from the Systems Engineering tools application to other RDMN employees with non-Systems Engineering background. The findings from the results of the application of Systems Engineering tools were then communicated to RDMN employees during a two hour presentation. The results from this presentation and additional feedback from RDMN employees are also discussed in the result section.

Background

The Value of Systems Engineering. In this paper the authors wishes to explore to value of Systems Engineering in the manufacturing industry. Most of the previous research is related to the development of complex systems. However many of the findings from these studies are assumed to have some validity in the manufacturing industry as well. The authors also suspects that the infinite number of different naming conventions for what can ultimately be considered Systems Engineering tools makes the process of gaining an overview of the field a very challenging task. The focus of the searches has therefore been studies that deal directly with the term Systems Engineering. In section 1.3 the results from an Airforce/LAI workshop in June 2004 is briefly mentioned. The participants of this workshop found seven research projects that deal directly with the issue of determining the value of Systems Engineering (Honour 2004). A study performed at NASA discovered a correlation between early investments in project definition and fewer cost overruns during project development. However the results are only loosely connected to Systems Engineering efforts (Gruhl 1992). Miller et al. (2000) found that a well-developed organizational structure was vital for project success. Sufficient Systems Engineering effort seem to have a positive effect on development time (Franz 1995). When combined with project management and test processes Systems Engineering seems to improve project productivity (Barker 2003). A study performed among INCOSE members and NASA employees show that both groups believe Systems Engineering has moderate to significant impact on complex systems projects (Kludze 2004). However members of INCOSE were generally more positive than NASA employees. Optimum Systems Engineering effort has been suggested as 15-20%, however the quality of the Systems Engineering effort matters. Sufficient Systems Engineering effort seems to improve cost compliance, schedule compliance and subjective quality (Mar & Honour 2002). The release of Ibm.com's Interactive Solution Marketplace applied SE&A techniques and found that this had a positive effect on the project. The project delivered according to stakeholder expectation, on schedule, five percent under budget and with greatly reduced need for re-work (Hole et al.2004). Systems Engineering is correlated to the process of making a system robust (Rhodes 2004) which is part of the overall goals of RDMN and Vale. It is suspected that the reason why some do not see the need for

Systems Engineering is that requirements managements is viewed as sufficient for starting up a project(Ring 2006). Most of the available research concludes that Systems Engineering provide value to projects. The society of Systems Engineering emphasises the need for further research on the subject so as to make the findings more reliable. This case study may hopefully contributed in that respect.

The Systems Engineering Process. Forsberg and Mooz (1992) view the development process of systems engineering as a decomposition process followed by recomposition or integration process. Since the FSFP system at RDMN has been in place for many years this paper focuses mostly on the recomposition part of systems engineering. For re-engineering efforts the goal of the modelling of the system should be an objective and quantifiable starting point for investigating why we do things the way we do. The System architecture should provide a basis for understanding our system and asking questions why the different solutions are selected (Willoch 1994). Systems Engineering processes are often defined according to different viewpoints (Muller 2004, Karangeleng & Hoang 1994). In this paper the focus has been on what can be considered the functional view (Muller 2004). While research regarding the value of Systems Engineering in general can be found in vast amounts, research related to each specific tool has proven to be more difficult to locate. Since the tools are quite specific this was not surprising. For IDEF0 methodology there are some studies available. For the context diagrams, the physical architecture, use cases and the scenario tracing we have not been able to track down any specific studies. The available literature mostly provides explanations, pros and cons related to the tool. Cheng-Leong et al. (1999) make a case for using a common IDEF0-based methodology for describing manufacturing systems. According to the authors this will among other things help reduce time-consumption, incompatibility between models and difficulties in model maintenance. Long (2006) states that IDEF0 diagrams are among the most commonly used tools for graphical representations to communicate a systems functional and data requirements. He concludes that the IDEF0 has a lot in common with the N2 charts although the IDEF0 diagram provides the capability to indicate the allocation of functions to systems components. This allocation of functions to systems components helped in communicating the results of the IDEF0 to the rest of the RDMN employees. One drawback of the IDEF0 is that the specification of controls is incomplete. Based on these findings it is assumed that IDEF0 diagrams are best suited for depicting the functional flow of the FSFP system. The Use Case Scenario and the scenario tracing are useful for providing additional value to the IDEF0 diagrams. Use Cases are often applied for the understanding of entities interaction especially in software systems (Stokes 2001). However the authors' hypothesis is that this tool may provide relevant information for hardware systems as well. It is expected that the physical architecture and the context diagram will help clarify how the system actually work. The goal of the development of the geographical model is to provide a mean that will enable communication and help with decision making regarding possible improvements.

General Background Information RDMN. RDMN has two furnaces producing about 120 000 metric ton of manganese alloys each year. In addition the plant has its own sintering plant which processes the raw fines material received into larger fractions of materials, called sinter, to be used in production. The two main products at RDMN is High Carbon Ferromanganese (FeMn) and Silicomanganese (SiMn), which are further divided into Standard SiMn and Low boron SiMn. The finished products are sold in the following fractions; 0-3 mm, 3-10 mm, 10-50 mm and 50-80 mm. The production of metal produces by-products, some of these are also a focus area of this paper. RDMN sells CO gas as energy and slag, which is the waste, created through the melting process, and used for land filling. Sculls, a mix of metal and slag, is mainly use as remelt for own furnaces. Fines are the smallest fraction of metal (0-3 mm) and this is mainly used for remelt on furnaces and for refining. In certain situations fines is also sold. The FSFP System at RDMN is defined as all components and processes involved in handling both main products and by-products from ladle to ship. Most of the transportation performed in this system is outsourced to a company called MIT (Mo Industri Transport). The contributions of MIT are viewed as a direct part of RDMN's FSFP System.

Body of Work

A Case Study of the Value of Systems Engineering in Manufacturing Industry. The main goal of this paper is to analyze the value of specific Systems Engineering tools in a manganese alloys plant. Through several iterations the research questions and goals of this paper have been made explicit. Extra care has been taken to make sure the facts and analysis are kept as objective and true to real life situations as possible. In addition several considerations have been made to validate the results of the research. One aspect of case studies that should be considered is the risk of researcher bias. The final report has been reviewed by RDMN employees that attended the two hour presentation. The content of the paper has been regularly reviewed by a faculty advisor from Buskerud University College. The paper has also been reviewed by a RDMN employee with a Phd degree. In addition the authors has been cautious when making any conclusions regarding cause and effect. Other possible causes that could explain the observed effects have been commented. The authors have tried to analyze the effects as objectively as possible, keeping in mind that one author is an RDMN employee. When applying the Systems Engineering tool the authors made an effort to be true to the tool as it has explained in the master degree courses. It is therefore concluded that anyone with the same knowledge about the Systems Engineering tools would apply the tools in a similar matter as the authors.

The Process of the Case Study of the FSFP system. During the early phases of the master project process interviews with RDMN managers were conducted. The interviews were informal and with only one research question: "What area inside RDMN do you think is most important to clarify and possibly improve. Although other areas were also listed, the FSFP system was ranked as their highest priority. This is probably related to the fact that there is an identified need of re-designing the tapping and casting area layout. In-depth knowledge of the flow is expected to have significant impact on the process of designing an optimum layout.

After clarifying what area inside RDMN was going to be the focus of the paper, Systems Engineering tools were chosen based on their expected ability to provide value to the focus area. It was also necessary to consider the available amount of time for applying these tools to the focus area. After a lot of research of the different tools presented during the master courses, five SE tools were selected. The five tools are; context diagram, physical architecture, IDEF0 diagrams, Use Case Scenarios and Scenario tracing. In addition a model linking the knowledge extracted from the SE tools to the geographical landscape of RDMN was developed. This was done in order to communicate the findings of the Systems Engineering process more effectively to RDMN employees without Systems Engineering background. The geographical model was developed using techniques discussed during Professor Gerrit Muller's course: MA611 Systems Modelling and Analysis.

The next step was to apply the selected tools to the focus area. The information about the FSFP system was collected with assistance from RDMN's database and experienced colleagues. Knowledge of the Systems Engineering tools was acquired through the available master syllabuses and internet based searches. The process of applying these tools and the result of the process forms the basis for the analysis of the first research question. What is the value of the selected tools for a systems engineer working in the manufacturing industry? The results from the application of the Systems Engineering tools to the FSFP system can be found in the technical report; Flow and Storage of Finished Products at RDMN. This report contains company sensitive information and is therefore limited for internal use.

After the tools had been applied the results of the process was illustrated in a PowerPoint presentation. 10 RDMN employees were invited to a two hour session in November 2008, where the findings from the Systems Engineering process were presented. The audience consisted of managers, engineers, production employees and administrative personnel. The outcome of this meeting formed the basis for the analysis of the second research question; what is the value of the selected Systems Engineering tools for employees at a manganese alloy plant without Systems Engineering background?

The last step in the process was to evaluate the process of applying the tools, the results of the application and the outcome of the presentation. This exercise was in danger of becoming quite qualitative and based on the authors personal interpretation of the results. In order to quantify and make the analysis as objective as possible the results have been given specific ranked values, which in turn are presented graphically. The value of the Systems Engineering tools has been measured in terms of the added knowledge it gave to the systems engineer, the degree of activity it triggered from the audience of the two hour presentation and the number of suggested improvements they contributed. No activity or added knowledge was interpreted as a negative find while any added knowledge or activity was interpreted as a positive find. The amount of added knowledge and activity has been ranked according to a scale from 0 to 5. A rank of 0 means no amount of added knowledge or activity and 5 is the most amount of added knowledge or activity in relationships to the contributions of other tools. The numbers of improvements are shown with the actual number of suggestions provided.

Results

In this section examples from the application of each of the Systems Engineering tools will be presented. The examples are explained and implications of the results are discussed. Any modifications that were made to the tools as a result of the presentation are discussed. The more general findings related to the two research questions is presented towards the end of this section.

The context diagram shows the systems that have direct or indirect relationships with our system in the customer context (Muller 2004). The final context diagram showed 6 systems directly related to FSFP, 5 more remote systems, and 4 infrastructure systems. When developing the context diagram the authors gained knowledge regarding several systems that were not quite obvious at the start up of the process. The process also helped the system engineer define the scope for the FSFP system. During the presentation many new related systems were suggested. A debate took place whether some of the systems in the diagram were a part of the actual FSFP system or an outside system. RDMN have significant amount of outsourced services. The boundaries between the FSFP system of RDMN and the outsourced services are not crystal clear. This adds to the challenge of defining the system scope. It seems the context diagram helped clarify the boundaries of the FSFP system both to the audience and the systems engineer. After the two hour presentations Molab, Ventilation Systems and Refractory were added to the diagram.

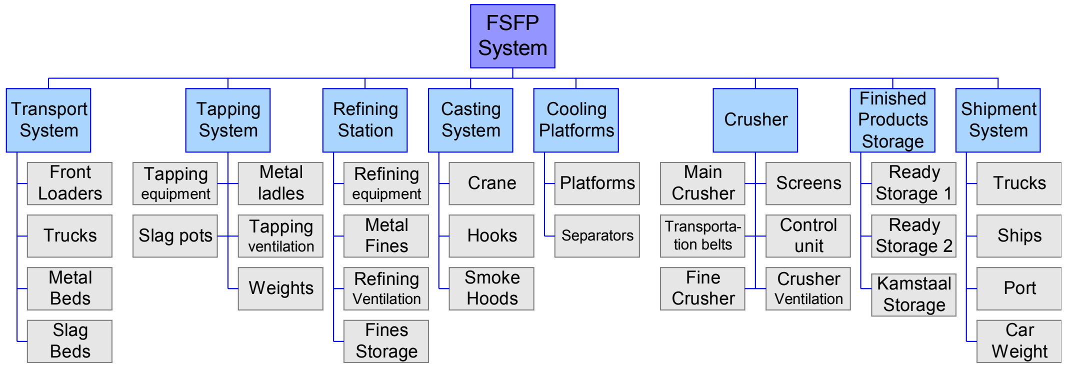

Figure 1: Physical Architecture of the FSFP System

Figure 1 displays the physical architecture of the FSFP System. The development of this diagram did not require a lot of time, however during the presentation we spent a lot of time on this specific tool. It became clear to the authors that the actual physical architecture was not as straight forward as initially perceived. During the presentation it became difficult keeping the discussion on a high enough level. The physical architecture was decomposed three levels. A physical architecture should contain a satisfactory level, in terms of detail, quantity and quality of components, to work as a basis for the development of an operational architecture (Buede 2000). The architecture in this example is not decomposed down to the lowest level of the Configuration Items. More effort should therefore be made to ensure that the physical architecture is complete before using this architecture as a basis for the operational architecture. However the architecture triggered a lot of comments from the audience which indicated that this tool has important value as a communication tool. As mentioned it proved to be a challenge keeping the audience from going directly to the lowest systems components. It also proved to be difficult separating the different areas from each other. For instance many of the participants mentioned that trucks should be included in several of the different second level components. The authors initial thought when making the architecture was to try and separate the different areas so that the same component would not have to be included in several areas. The authors' opinion as a systems engineer was that trucks should only be included in the area defined as the transport system. It seems that this tool highlighted the difference in mindset of a systems engineer and the other employees with non-SE education backgrounds. Decomposition is a useful method of gaining the overview of a system and avoid having an incomplete or in this case repetitive list of components (Buede 2000). The physical architecture gave the authors as a systems engineer a better overview of the physical components of the FSFP system. We believe that the RDMN employees had some difficulties adapting to the abstract way of thinking and therefore wanted to create a list of the components instead of a decomposition of the system. Since the physical components of a system are something that is familiar and real to the employees the tool worked efficiently as an enabler for discussion. This discussion provided the systems engineer with extended knowledge of the actual physical system. Following the representation several components were added to the third level of the architecture. These include front loaders, car weight, smoke hoods and ventilation systems.

The next applied tool, the IDEF0 diagrams, proved to be the most time-consuming. Figure 2 shows an example of the IDEF0 diagrams at the second level of the decomposition. This diagram shows a breakdown of the first level function; Liquid metal and slag processing. The refining function is placed outside the rest of the functions since this is an alternative function that is not used for all the products. The audience expressed that their initial reaction was that this tool seemed quite complex. After explaining the tool and comparing them to other functional models, such as N2 charts and Functional Flow Block Diagrams, many of the participants seemed more familiar with the way of thinking. As a systems engineer the most challenging part of the application of this tool was finding the most sensible way of decomposing and separating the functions. For example we decided to start all over again with the first level architecture after several attempts to decompose to the second level. During the process the authors discovered many new functional requirements to the system. It also became clear that we did not yet fully understand how the system operates. As expected the participants had some difficulty understanding the difference between controls and inputs. This is also a known challenge related to IDEF0 diagrams (Buede 2000).

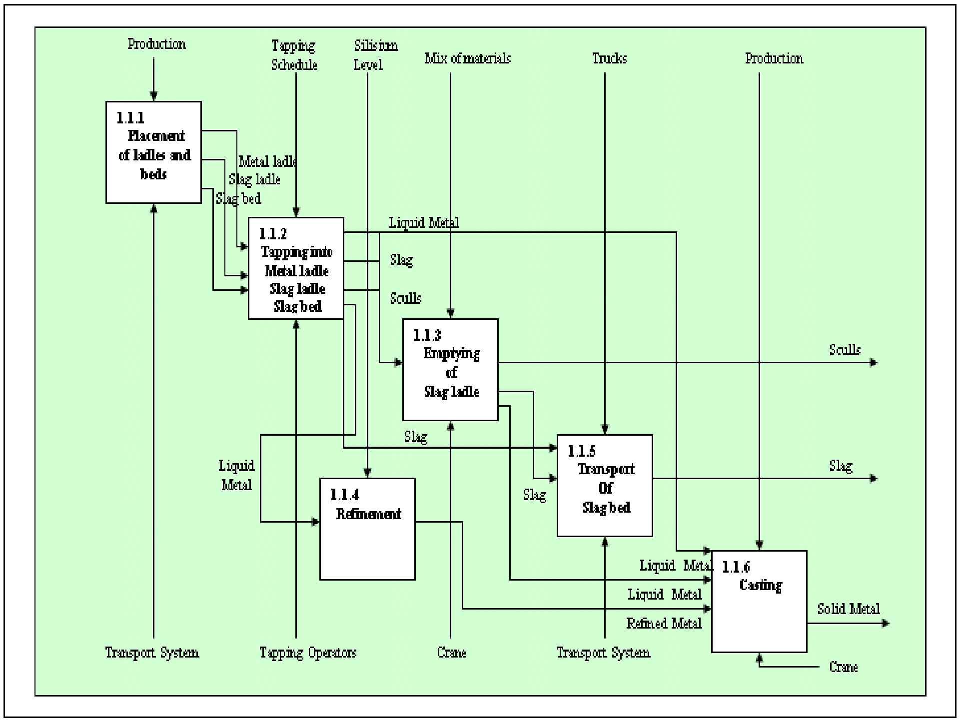

Figure 2: Example of IDEF0 diagram of FSFP system

Due to the somewhat abstract and complex nature of the diagrams the conclusion based on the level of involvement from the audience is that this tool has most value for Systems Engineering educated personnel. On the other hand many of the participants indicated that they would like to see this tool applied to the design of a new FSFP system. One of the participants has actually used this tool for gaining in depth knowledge to his process area, gas-and water treatment. This indicates that the IDEF0 diagrams have appeal, but they require more effort before they are understood by personnel both with and without Systems Engineering education.

The modification made to the IDEF0 diagrams following the presentation were mainly related to definitions. E.g. tapping plan was changed to tapping schedule, refinement was changed to refining.

However it is suspected that if there had been more time available for presentation and explanation of the entire set of diagrams the feedback would have increased significantly. The decision not to spend more time on the IDEF0 diagrams was related to the fact that this would have required the two hour presentation to be expanded with a significant amount of time. In order to ensure that the amount of participants became as high as possible the presentation was set to last a maximum of two hours.

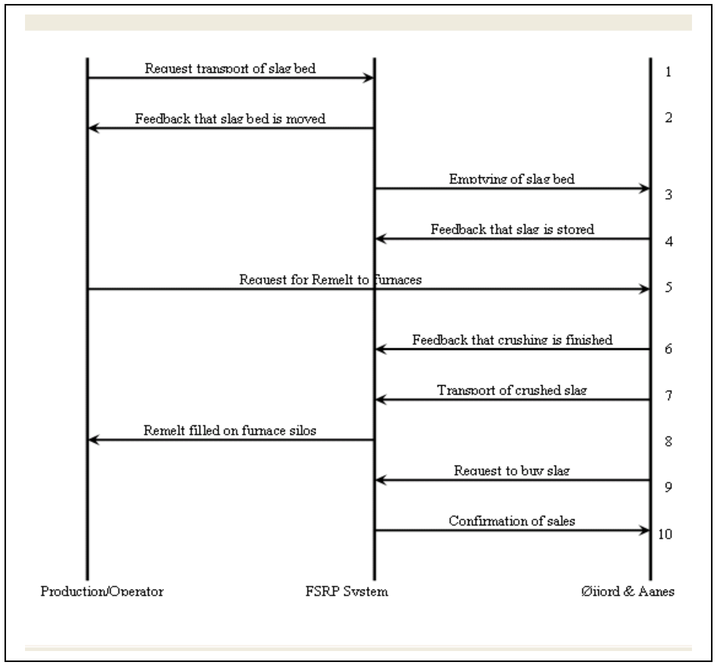

Figure 3: Example of Use Case Scenario for the FSFP system

Use Case Scenarios were developed for what was considered the main functions of the system. In order to time-box the exercise only the "sun-shine" scenarios were depicted. The layout of the Use Case Scenarios was copied from the layout suggested by Stevens Institute of Technology. Figure 3 shows a Use Case Scenario for the transport and storage of slag. Use Since this tools forces the systems engineer to think in terms of input and output it proved to be challenging to apply Use Case Scenarios to the FSFP system. The specific Use Case Scenario method applied in this paper may be more suited for software systems. However Stevens uses this method for a system which consist of both software and hardware components. The FSFP is a hardware intensive system and this may explain the difficulties during application. This required a certain level of abstraction in order to be able to develop the Use Case Scenarios. It was also difficult to make a clear separating of the systems that operates with the FSFP. Several systems/operators are included in what is ultimately one process. During the presentation the abstraction level was mentioned. However it was pointed out by the participants that this was actually positive as it highlighted need for certain function, especially feedback. The participants said that they found themselves asking; why do we not have a feedback function for this step? The Use Case Scenarios triggered a good deal of discussions and it is expected that with more available time for presentations of several Use Case Scenarios the comments and discussions would have been more extensive. The tool was easily understood by the participants. Suggestions were made to add systems to some of the Use Case Scenarios. For instance for the Use Case Scenario in the example it was suggested to add MIT as a third interacting system. These modifications will be made in the technical report for use in RDMN.

After developing the Use Case Scenarios a tracing of the use cases through the functional architecture was performed. Figure 4 shows an example of the tapping and casting of HC FeMn through the second level of the IDEF0 diagrams. Tracing is often performed to clarify how the system meets input and output requirements (Muller 2008).This process step was also quite time consuming, but as a systems engineer the authors felt it provided a lot of information to the study. Several modifications had to be made to the IDEF0 diagrams after discovering that not all functions were included or that functions were misinterpreted. During the presentation of this tool the audience became quiet. It is the authors understanding after talking to the participants after the presentation that this tool seemed abstract and complex. Initially it seems that this step was most valuable for the systems engineer for validating the functional architecture and ensuring requirements completeness. However, we do suspect that with more time available to explain the process, the amount of participant activity would increase. With the limited presentation time available it was very difficult to present the tool and its results in significant level of detail. The results from the two hour presentation are therefore somewhat misleading with regards to the degree of audience activity. As mentioned earlier this is also true for the IDEF0 diagrams and the Use Case Scenarios. However the findings from the application of the SE tools are made available for RDMN employees in the previous mentioned technical report. Any feedback that comes as a result of this report has also been considered during analysis of the value of the tools for non Systems Engineering educated personnel.

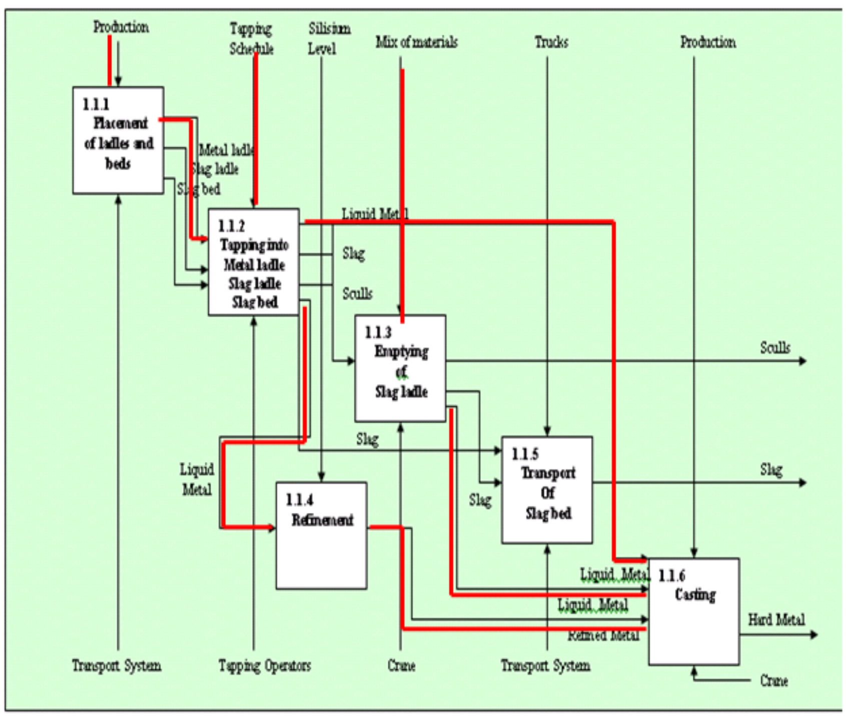

Figure 4: Example of Scenario Tracing of the FSFP system

The main focus of the geographical model (figure 5) was to make it easily accessible for every RDMN employee no matter their background. This was achieved by focusing on the actual geographical layout of the RDMN plant and keeping the level of detail to a minimum. Multicoloured arrows were used to illustrate the flow of products. The model triggered a lot of discussions during the presentation. As a systems engineer the process seemed more time-consuming than contributing to the understanding of the system. However it seemed to be a very valuable communication tool between the systems engineer and the non-Systems Engineering colleagues. Most of the possible improvements were discovered via this model. The geographical model contains 33 different routes of products. By implementing the suggested improvements the number of flows could be reduced with 6 routes, in other words a reduction in number of transport routes of 18% (X = (100x6)/33 = 18.18 %) During the presentations some additional flows were discovered. It was pointed out that the metal goes to a pre-cooling area before it is moved on to the cooling platforms. It was also suggested to add a route from the crusher to the silos to illustrate the bags of metal dust that are taken from the crusher ventilation system to the furnaces for remelt.

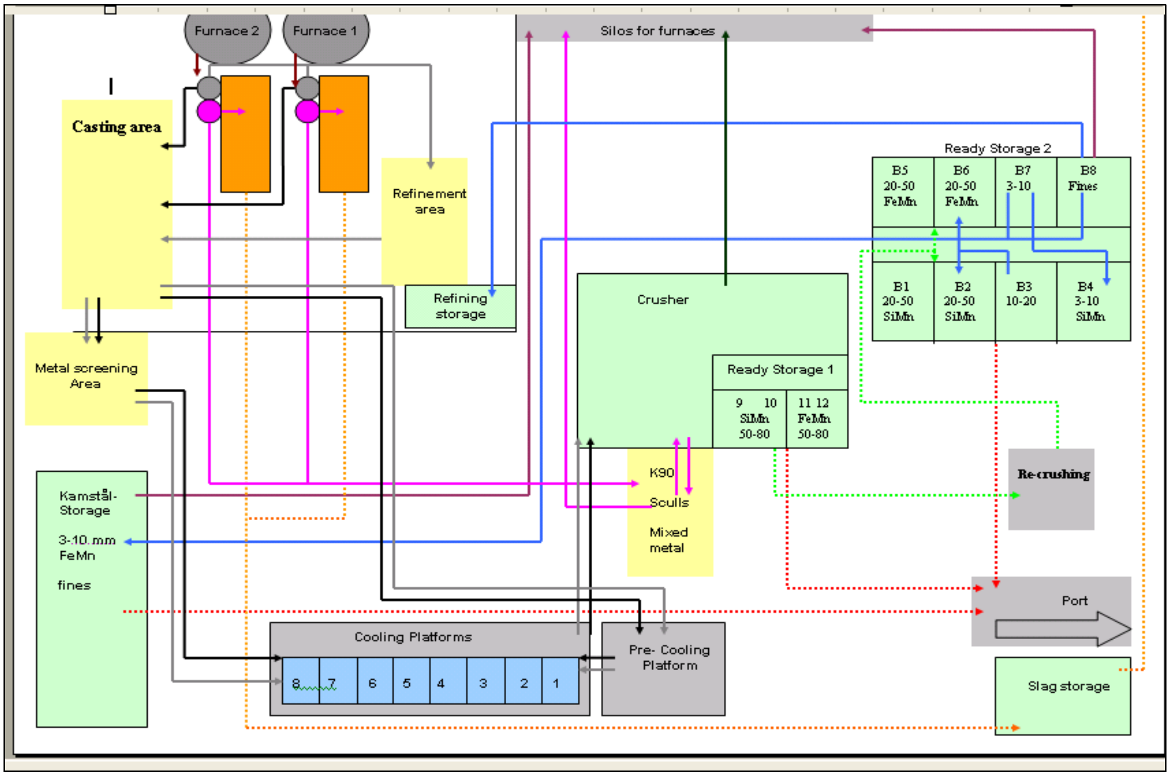

Figure 5: Geographical model of the FSFP system

During the process of applying the Systems Engineering tools and the two hour presentation a number of suggestions for possible areas for improvement were discovered (table 1). These improvements were discovered by the systems engineer and the other RDMN employees. The last suggestion in the table can be considered a more general find then the other suggestions. But the need for more invested effort in early project phases and a need to understand systems better is considered so significant that it has been included in the table. The authors discovered this need while working with the IDEF0 diagrams in particular. This was also a suggestion that was mentioned on a more general basis by the participants of the two hour presentation.

The results indicate that the Systems Engineering tools provided different aspects to the systems engineer and to the non-Systems Engineering employees. This was also an expected finding seeing as background knowledge can be expected to have significant impact on the understanding of the tools. The degree of value of the Systems Engineering tools has been ranked in terms of the added knowledge they added for the systems engineer, the amount of activity they triggered during presentation and the number of improvements they provided. Figure 7 shows how the amount of added knowledge, audience activity and number of improvements has been ranked. The different tools provided different degree of value both to the systems engineer and to the audience. The tool that most stood out in that effect was the geographical model which triggered a lot of discussion, but did not provide a significant amount of added knowledge to the systems engineer. This finding indicates that simpler models may be needed to effectively communicate results from the application of Systems Engineering tools to non-SE trained personnel. IDEF0 diagrams were rated as providing the most added knowledge about the system for the systems engineer. However the diagrams triggered little discussion during the two hour presentation. Besides the geographical model the context diagram and the physical architecture triggered a significant amount of audience activity. Use Case Scenarios was rated medium in terms of amount of activity while IDEF0 and tracing gave the least amount of audience activity. Tracing actually triggered no activity from the audience. However the limited available time for explanation added with the complexity of the tools is expected to have an impact on these results. The physical architecture and the geographical model were rated as providing the least amount of added knowledge to the systems engineer. Use Case Scenarios, context diagram and tracing all added a significant amount of knowledge to the systems engineer. The geographical model triggered the most suggestions for improvements, while IDEF0 triggered 2 suggestions. Use Case Scenarios and Context Diagram each contributed 1 suggestion for improvements. The tracing and the Physical Architecture did not directly trigger any suggestions for improvements.

Table 1: Suggestions for improvements

Suggestions for improvement	**SE tool**	**Suggestions for improvement**	**SE tool**
Screen 3-10 mm SiMn directly to box 4 in Finished goods storage	Geographical model	Provide more functionality for feedback in the system.	Use Case Scenarios
Expand Finished goods storage 2. Avoid transport of 3-10 mm and fines	Geographical model	Eliminate screening of 10-20 mm, and screen directly to 10-50 mm	Geographical model
Do recrushing of 50-80 mm internally instead of sending it to outside system	IDEF0 diagrams	Introduce PBL contracts for major outsourcing partners such as MIT and Miras	Context diagram
Invest more effort in early project phases. Cost and time saving. Invest more effort in understanding our systems and their demands.	IDEF0 Diagrams (general finding)		

At the end of the two hour session the audience was encouraged to share any thought or comments on the subject of Systems Engineering in general. The authors experienced the feedback as generally positive. The message that came across was that the company lacked knowledge in the application of such tools and that this was very much welcomed in the future. The CEO emphasised the need for such tool in the planning of a new tapping and casting area and commented that this was one of their main motivations for hiring a systems engineer. Other commented on the value these tools provided as means of communication both between RDMN colleagues and with external parties. The process of applying these tools has added significantly to the authors' knowledge of the flow and storage of finished products in RDMN. The Systems Engineering process has provided a better basis for making modifications to the FSFP system and for communicating the need for modifications to the company. As mentioned earlier some of the Systems Engineering tools have also been used by other RDMN personnel, which we interpret as an acceptance of the tools inside the company. Figure 6 provides a good overview of the direct value that the different tools have provided both for the systems engineer, personnel with non-Systems Engineering education and RDMN as a company. The results give a good indication that the Systems Engineering tools provide a high degree of value for the systems engineer in manufacturing industries. The Systems Engineering tools have also provided value for the non-Systems Engineering educated personnel. If the suggestions for improvements are implemented this would possibly give a good indication of the value of the tools for the company RDMN.

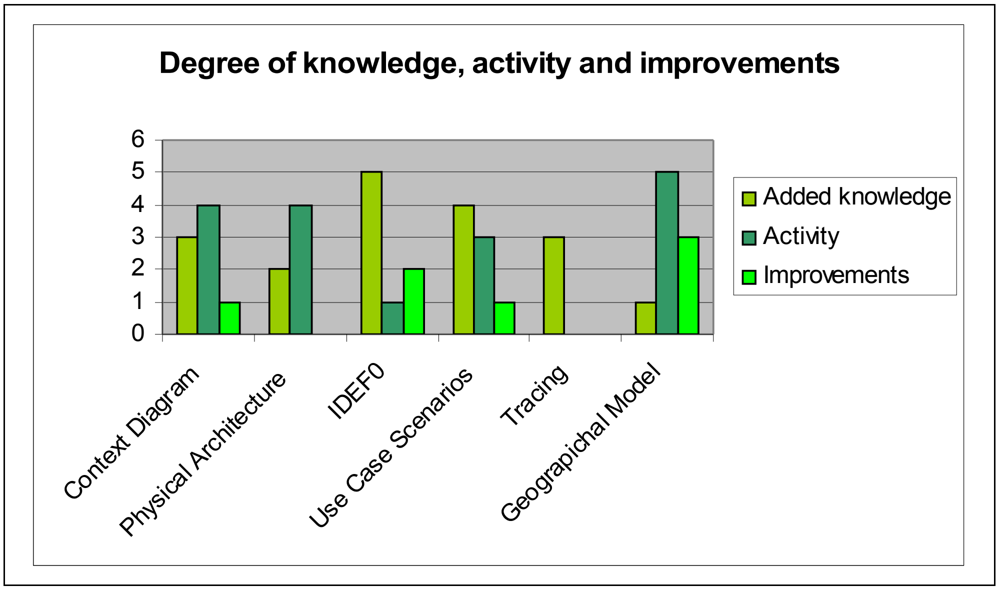

Figure 6: Graphical representation of amount of knowledge, activity and improvements

Conclusion

This paper has investigated the value of Systems Engineering in manufacturing industry. Six Systems Engineering tools have been applied to the Flow and Storage of Finished Products system at RDMN and the results have been presented for RDMN employees. The main research questions of this paper were what value the selected tools provided for a systems engineer working in the manufacturing industry and what value the selected tools provided for employees of a manganese alloys plant, without SE background. The results of the process of applying the tools and the two hour presentation has been analyzed according to three main parameters; the amount of added knowledge, amount of activity and the number of suggestions for improvements. These parameters have been ranked according to the authors' experience of the process. The analysis indicates that several of the tools provide significant amount of added knowledge for the systems engineer working in manufacturing industries. Especially IDEF0 diagrams and Use Case Scenarios provided a lot of information to the systems engineer. For the employees without Systems Engineering background the tools that provided the most value were the geographical model, the Context Diagram and the Physical Architecture. It is important to keep in mind that these results may vary if more time had been available for presentation and explanation. The geographical model and the IDEF0 diagrams provided most suggestions for improvements. In general it is concluded that the RDMN employees are positive to the value that Systems Engineering may provide for their company. The value of the tools as a mean for understanding and communicating the systems of the company was emphasized. The results also conclude that the applied tools may provide direct value for RDMN as a company if the suggested improvements are implemented. RDMN wishes to use Systems Engineering tools when they start developing a new layout for the tapping and casting area. Some of the employees have in cooperation with the authors started using the Systems Engineering tools for other areas inside RDMN. The Systems Engineering community has requested more studies regarding the value of Systems Engineering. The authors sees a need for more research related to the value of Systems Engineering in the manufacturing industry. This paper has only covered a small amount of the available Systems Engineering tools and the need for research on the value of other Systems Engineering tools is apparent. Another area of interest that was discovered during the project process was the possibility of Performance Based Logistics in manufacturing industries.

References

Barker, B. 2003. *Determining Systems Engineering Effectiveness*. Conference on Systems Integration. Stevens Institute of Technology. New Jersey

Buede, D.M. 2000. The *Engineering Design of Systems. Models and Methods.* USA: John Wiley & Sons Inc

Cheng-Leong, A, K.L. Pheng, and G.R.K. Leng. *IDEF*: a comprehensive modelling methodology for the development of manufacturing enterprise systems.* International Journal of Production Research. Volume 37 Issue 17 November 1999. Pages 3839-3858

Forsberg K. and H. Mooz. *The relationship of systems engineering to the project cycle.* Engineering Management Journal 4(1992): 36-43

Franz, W.F. 1995. *The Impact of Systems Engineering on Quality and Schedule – Empirical Evidence.* INCOSE International Symposium. St.Louis.

Gruhl, W. *Lessons Learned, Cost/Schedule Assesment Guide*. Internal presentation at NASA Comptroller's office. 1992.

Hole, E, V. Dinesh, J. Rashmi, V.Vitale and P. Popick. 2004. *Development of the ibm.com Interactive Solution Marketplace (ISM): A Systems Engineering Case Study.* www.interscience.wiley.com

Honour, E. C. *Technical Report. Value of Systems Engineering.* LAI Consortium. September. 2004.

Honour, E. C. *Understanding the Value of Systems Engineering*. 2004 www.incose.org

INCOSE Systems Engineering Handbook Version 3(2007) http://www.incose.org/ProductsPubs/products/sehandbook.aspx (04.01.09)

Karangelen, N.E. and N.T. Hoang. *Partitioning complex systems engineering into five views. In systems engineering: A competitive Edge in a changing world*. J.T Whalen, D.Mc.Kinney and S.Shreve (eds.) 4th annual Int. Symp. Of INCOSE pp.675-681. 1994

Kludze, A.K. *The Impact of Systems Engineering on Complex Systems.* Conference on Systems Engineering Research, University of Southern California, Los Angeles. 2004

Long, J. E. *Relationship between common graphical representations used in systems engineering.* Handout from the course: Fundamentals of systems engineering 11-15 September 2006, Buskerud University College.

Mar, B. L. & E. C. Honour. *Value of Systems Engineering – SECOE Research Project Progress Report.* INCOSE International Symposium, Las Vegas, Nevada, 2002.

Miller, R, S. Floricel, D.R. Lessard D.R. 2000 *The Strategic Management of Large Engineering Projects.* MIT press

Muller, G. *SARCH Systems Architecting*. Course presented at Buskerud University College, Kongsberg, Norway, April 14-18, 2008. (www.gaudisite.nl)
Muller, G. *MA611 Systems Modelling and Analysis*. Course presented at Buskerud University College, Kongsberg, Norway, October 1-5, 2007. (www.gaudisite.nl)
Muller, G. 2004. *CAFCR: A multi-view Method for Embedded Systems Architecting*
Pennotti, M. C. *SDOE625 Fundamentals of Systems Engineering*. Course presented at Buskerud University College, Kongsberg, Norway, September 11-15, 2006.
Ring, J. 2006 *Requirements Management Obscures Systems Engineering*
Rhodes, D. H. *Workshop Report Airforce/LAI Workshop on Systems Engineering for Robustness.* LAI consortium, July 2004.
Stokes, C. 2001. *The Value of Use Case Methodology*. www.archwing.com
Willoch, B-E. 1994. Business Process Reenigeering – en praktisk innføring og veiledning. Fagbokforlaget Vigmostad & Bjørke AS, Norway.

Biography

Marianne I. Drotninghaug has an MSc in Systems Engineering from Stevens Institute of Technology. She has worked for Volvo Aero Norway where she was responsible for creating simulation models of the production. She is currently employed at Vale Norway as a process manager, where she is responsible for the logistics of the plant.

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, Mike 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.