



MASTER THESIS

THE EFFECT OF SYSTEMS ENGINEERING ON PROJECT MANAGEMENT SUCCESS

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The effect of Systems Engineering on the Project Management Success in the Dutch civil engineering industry

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ABSTRACT: In the Dutch civil engineering industry, clients increasingly prescribe Systems Engineering as a tool to manage projects. Studies have identified a positive relationship between Systems Engineering and Project Management Success. Whether these relationships are present in the Dutch civil industry is unknown. This research explores if a relationship is present in the Dutch civil industry between Systems Engineering and Project Management Success. Based on a literature study, a measurement tool was created. The tool measures; (1) the extent to which Systems Engineering is applied, (2) the perceived quality of Systems Engineering, based on employees' views, and (3) Project Management Success, expressed as three KPI's. With the help of the measurement tool, eight cases were analysed. The data shows that the extent to which Systems Engineering is applied has no relationship with Time Performance and Price Increase. Systems Engineering has a relationship with Profit Performance in three projects. But, other cases prove the contrary. Other factors have been identified which have more impact on Project Management Success than the extent to which Systems Engineering is applied. In the end, recommendations are stated that help to exploit Systems Engineering to its full extent.

Keywords: Systems Engineering, Project Management Success, Dutch Civil Industry.

1 INTRODUCTION

Integrated contracts, whereby the contractor is accountable for the design and construction of the system, are becoming more standard in the Dutch civil industry. The consequence is that the business model of a contractor is changing. From constructing systems based on a design delivered by the client, to not only constructing a physical system that satisfies the needs of stakeholders and the client, but also includes designing of the system. Wherein the needs are based on ill-defined system specifications drawn up by the client. What the finished system will be is insecure during the procurement phase. Still, clients are asking contractors to create a competitive offer based on those ill-defined systems specifications. This may result in misinterpretations and could cause that the contractor to offer a different system than the system that the client desires. Thus, the uncertainties for the contractor are higher, which results in an increase in the risks that the contractor faces.

Applying Systems Engineering helps to manage these uncertainties. Therefore, the interest in Systems Engineering is growing across the civil construction industry (Elliott, O'Neil, Roberts, Schmid, & Shannon, 2012; Locatelli, Mancini, & Romano, 2014). Particularly in the Netherlands, since the two main clients, ProRail and Rijkswaterstaat, have mandated Systems Engineering in their projects (ProRail, 2015). Rijkswaterstaat and ProRail have even developed their own guidelines to standardise and improve Systems Engineering within the industry (ProRail, 2015; Werkgroep Leidraad Systems Engineering, 2013).

According to INCOSE, the definition of Systems Engineering is: "An interdisciplinary approach and means to enable the realisation of successful systems. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that

meets the user needs" (INCOSE, 2015). Systems Engineering helps with maintaining control over the project, the demands and wishes of clients and stakeholders, and the technical quality. The budget and planning are taken into account as well. Systems Engineering manages and migrates the uncertainties and risks for the contractor. The result is a better Project Management Success in terms of budget, planning, and quality.

Previous research confirms a relation between Systems Engineering and project success (Honour, 2013; P. Elm, 2011). Elm discovered that project teams with a higher Systems Engineering capability delivered higher project performance in terms of costs, schedule and scope. The results of Honour are in line with Elm. Honour stated that all Systems Engineering elements have a correlation with cost compliance, and nearly all Systems Engineering elements have a correlation with the schedule compliance. Most Systems Engineering elements correlate with stakeholder satisfaction as well. Though not definitive, indications of causality are found in the qualitative and theoretical factors. However, data is missing to identify this relationship in the Dutch civil engineering industry. Therefore, it is unknown if Systems Engineering has similar positive effects on Project Management Success in the Dutch civil engineering industry, as found in literature.

This research explores if Systems Engineering has a positive effect on Project Management Success. The research is conducted at a contractor in the Dutch civil engineering industry. The main research question is: 'How does Systems Engineering affect Project Management Success in the Dutch civil construction industry?'. The structure of this research paper is as follows: section 2 describes the theoretical background of the effect of Systems Engineering on Project Management Success, Systems Engineering in the Dutch civil construction industry, and measuring Project

Management Success. Section 3 presents the research design and the methodologies used in this research. Subsequently, the results from the research are stated in section 4, followed by the discussion of the results in section 5. In section 6 the conclusions are stated. The recommendations are stated in section 7. Section 8 contains the limitations of this research.

2 SYSTEMS ENGINEERING AND PROJECT MANAGEMENT SUCCESS

Systems Engineering and Project Management Success are discussed in this paragraph. This is to establish a clear view of the research topic. First, the focus will be on Systems Engineering and its relationships with Project Management Success. Second, Systems Engineering practice in the Dutch civil construction industry is explained. Third, methods for determining Project Management Success are described.

2.1 The effect of Systems Engineering on Project Management Success

Systems Engineering helps to deliver a system that complies with the needs and wishes of stakeholders while taking the budget and planning into account. Systems Engineering is about system thinking from the beginning. A system consists of several sub-systems, which have interfaces with the internal and external environment. Identifying the sub-systems with the corresponding interfaces is the basis for Systems Engineering. This enables the possibility to identify and migrate risks in an early phase of the project and should cause fewer defects. The work needed for resolving defects increases considerably as the project progresses. The extra work upfront, due to Systems Engineering, should be lower than the work otherwise required for solving the defects in a later project phase. This creates the possibility to develop the system with lower costs and in less time.

The scientific community has verified these statements. The effects of Systems Engineering are identified within the American defence industry. According to project managers, Systems Engineering can create an overall project success (Compton, Dorneich, & L. Hansen, 2015; Dvir, Raz, & Shenhar, 2003). The results of more detailed quantitative research, within the defence and aerospace industry, shows a relation between Systems Engineering and Project Management Success expressed in time and budget (Bruff, 2006; Honour, 2013; P. Elm, 2011). These relationships between Systems Engineering and Project Success are also found in a commercial company working on new products as well (Vanek, Jackson, Grzybowski, & Whiting, 2017)

Honour has found a quantifiable relationship between Systems Engineering efforts and program success, expressed in cost compliance, schedule compliance, and overall success (the perceived quality of the entire program by stakeholders). Systems Engineering has a positive Return of Investment because of this relationship. It was also found that the correlation between Systems Engineering effort and technical quality is missing. This missing relation can be explained, as Systems Engineering monitors and guides the technical quality of programs to technical benchmarks stated in contracts. The focus is to reach those benchmarks and not exceeding them. Literature suggests that the

optimal investment percentage in Systems Engineering is 14.4% of the total program costs. This percentage can vary between 8% and 19% depending on the project characteristics. Still, most projects have invested less in Systems Engineering than the optimum (Honour, 2013).

Elm showed that projects with more Systems Engineering capabilities resulted more often into better project performance (P. Elm, Goldenson, El Emam, & Donatelli, 2008). Of the projects with a high Systems Engineering capability, 56% had the highest project performance, while 13% have a moderate performance and 31% have a low performance. From the projects with a moderate Systems Engineering capability, only 12% of the project have the best project performance, than 59% have a moderate project performance and 29% have a low project performance. The projects with a low Systems Engineering capability, 15% of the projects have best performance, while 46% of those project have a moderate performance and 39% have the lowest performance (P. Elm et al., 2008). In other words, projects in where Systems Engineering is applied to a higher extent, and with more quality, will have a better Project Performance. Another finding is that projects with are more complex, exhibit on average, a poorer Project Performance compared to projects with a smaller project challenge. Also, Systems Engineering activities with the strongest relationship with Project Management Success, share two common aspects, (1) they start early in the project and (2) they influence the approach to and/or the organisation of the project (P. Elm, 2011).

Similar findings are found in a research performed at a commercial company, which working on new product development. The Systems Engineering input of 19 cases is compared to the budget and schedule adherence. These two factors combined represent Project Performance. The Systems Engineering input varied between 41% and 92% across the projects. The projects were divided into three groups based on the Systems Engineering input, namely higher, medium or lower Systems Engineering input. The project performance is divided into three divisions, superior, satisfactory, and shortfall. Two projects were found to have "low" Systems Engineering input, three others "high" input, and the remaining 14 "medium" input. In the group, with high Systems Engineering Input, two cases scored superior on the Project Performances. While the other project in that category, scored only satisfactorily on the Project Performance. In the medium Systems Engineering input category, one case has superior performance, while 11 projects performed satisfactorily and one project had a shortfall. The two projects with a lower Systems Engineering input have both a satisfactory Project Performance (Vanek et al., 2017). Thus this research shows that the relationships between Systems Engineering and Project Management Success, is present in other sectors than the aerospace and/or defence industry.

2.2 Systems Engineering in Dutch Civil Industry

This paragraph describes the Systems Engineering process in the Dutch Civil industry. The process is based on previous research on Systems Engineering in the Dutch Civil industry (de Graaf, Voordijk, & van den Heuvel, 2016; de Graaf,

Vromen, & Boes, 2017), guidelines from larger Dutch civil infrastructure clients (Guideline for Systems Engineering Working Group, 2013; ProRail, 2015), and a book about Systems Engineering in the Dutch construction sector (de Graaf, 2014). A visualisation of the process workflow is depicted in Figure 1.

The Systems Engineering process is composed out of thirteen elements which contain Systems Engineering activities. These elements can be divided into four groups; core elements, feedback loop elements, in/output elements, and verification & validation elements. The process diagram embodies the Vee-model, with the design phase on the left and on the right, the realisation phase. During the design phase, the process is performed at multiple levels of detail until the system is designed detailed enough for construction. The number of design iterations differs from case to case. If the procured design is more detailed, fewer design iterations are needed. Below, the elements, including their purpose, are clarified.

Core elements

The first core element is the Requirement Analysis. Deriving new requirements, based on the previous specifications, is the purpose of the Requirement Analysis. Requirements are a measurable description of the demands expressed as performance parameters. The result is a requirements overview. Performing the Requirements Analysis is essential to guarantee that the system design is based on relevant and correct requirements. The requirement overview forms the basis for verification and validation (V&V) plans. Which state how, when, and by whom the requirements are verified and validated in later stages.

Functional Analysis & Allocation is the second core element. The project team determines the functions of the system, and of which objects the system should exist. The functions and objects are defined in a solution neutral manner, which increases the understanding of the system and can result in creative solutions. Breakdown structures are used to structure the functions and objects, the Functional Breakdown Structure (FBS) for functions, and the System

Breakdown Structure (SBS) for objects. Requirements, functions and objects are allocated to each other, creating the specification needed for designing the system.

The last core element is Design Synthesis, in where designers translate the specifications into design solutions. Several potential design solutions are developed from which one is selected based on considered choices. Every step in the decision-making process should be recorded and traceable, as Systems Engineering requires. Based on the chosen design, the V&V plan can be extended with the V&V procedures for the design and realisation phase.

Feedback loops elements

Keeping the requirements, the FBS, the SBS, and design solutions consistent with each other is the goal of the feedback loop elements. The first feedback loop is the Requirements Loop, which runs between the Functional Analysis & Allocation, and the Requirements Analysis. The Requirement loop is needed because the Functional Analysis & Allocation may lead to new functions or objects, not covered by the requirements. The second feedback loop is the Design Loop, which runs between the Design Synthesis and the Functional Analysis & Allocation. During the Design Synthesis new functions or objects, uncovered by the FBS and/or SBS, can be specified. A check is needed to review if the FBS and/or SBS cover the complete design. If not, updating the FBS and/or SBS is necessary. Subsequently, it is necessary to perform the Requirements Loop again. The feedback loop elements can be performed as often as desired.

In/output elements

The Project Start is the input for Systems Engineering. It has the purpose to determine the project scope and to formulate project missions. A stakeholder analysis is performed during this stage to identify relevant stakeholders and their needs. Requirements from the client's and other stakeholders are documented in the Customer Requirements Specifications (CRS), which is the basis for Systems Engineering.

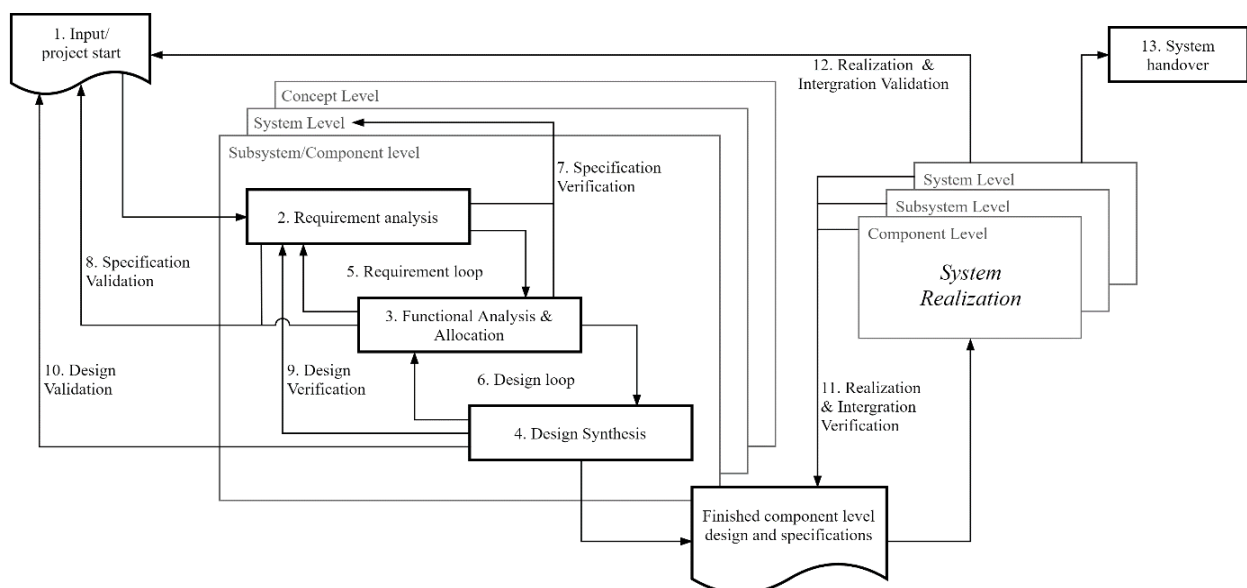


Figure 1: The Systems Engineering process in the Dutch civil industry (based on De Graaf et al.)

The output element is the System Handover. When the complete system is realised, then the system is handed over to the client including the corresponding documentation. The corresponding documentation exists out of evidence that the system works safely and is built as intended. Drawings of the realised situation should be included too if the Systems is not realised as planned. This is called configuration management, the process adjusting the documentation from the designed system to the realised system (as built).

Verification & Validation elements

Three verification and three validation elements are present in the Systems Engineering process. Those are verification and validation of the specifications, the design, and the realisation & integration. Verifications are internal checks to make sure if the newly produced work complies with previously created products. Validation is performed together with the client and/or stakeholders, to see if new and/or realised products meet their views. The goal of the Specification Verification is comparing if the new derived specifications comply with the specification at the upper level of detail. Validation of the specifications comprises reviewing the new derived specification together with the client. The following four elements, verification and validation, of the design and the realisation & integration are performed similarly as described.

2.3 Project management success

Systems Engineering results in better Project Management Success. But, the challenge is measuring this effect. In scientific literature, discussions are focused on the exact definition of project success, but it stays rather elusive (Baccarini, 1999; Bannerman, 2008). The three classical parameters of project success are schedule (time), budget (cost), and scope/quality (Barnes, 1988). The three parameters are often called the triple constraint, or iron triangle of project management. In more recent research is discussed that this constraint does not measure project success, but Project Management Success (Baccarini, 1999). Project success includes more than the three parameters of the iron-triangle, it also includes process success, product success, business success, and strategic success (Bannerman, 2008).

Project management success can be measured in different ways. The most common method is based on the three indicators of the iron triangle, by measuring: time, budget and within scope (Barnes, 1988; McLeod, Doolin, & MacDonell, 2012). The project success in the construction industry benefits from reducing the design rework when integrated contracts are applied (Li & Taylor, 2014). The goal of Systems Engineering is to create a system matching with the wishes and needs of the client and stakeholders. By measuring the perceived quality of the process, is it possible to measure if the system complies with the scope/specification (Componation et al., 2015).

Other scientific research is calculating the project performance based on Key Performance Indicators (KPIs). These KPIs are benchmarks that are identified to compare projects with each other (A. Chan, 2001; Takim & Akintoye, 2002). Two types of KPI's are present. The first type of KPI's

are the objective measures. Those are calculated with the help of a mathematical formula. Subjective measures are the second type, which can be measured based on the perceived satisfaction of key participants (A. Chan, 2001).

Examples of objective measures are construction time, speed of construction, time variation, unit cost, percentage net variation over final cost, accident rate, and Environment Impact Assessment (EIA) Scores. Quality, functionality, end-user satisfaction, client satisfaction, design team's satisfaction, and the construction team's satisfaction are examples of subjective measures (A. Chan, 2001). The tree parameters of the iron triangle are included in the KPI's. Some KPI's are better suitable than others depending on the characteristics of the cases.

3 METHODOLOGY

As stated in literature, Systems Engineering affects Project Management Success. It will be explored if these relations are also present at a contractor in the Dutch civil industry. The extent to which Systems Engineering is applied within a project is measured with the help of a measurement tool. This makes it possible to compare cases to each other and the normative theoretical ideal. The measurement tool is developed by De Graaf et al. (2016) and De Graaf et al. (2017). The measurement tool also measures the perceived quality of the *process* and *products* in the thirteen Systems Engineering elements. This is achieved by measuring the extent to which employees agree with statements (Componation et al., 2015). Project Management Success is determined based on three KPI's. The first KPI is aimed to measure the Time Performance, by comparing the actual project duration with the planned duration (Barnes, 1988; McLeod et al., 2012). The second KPI calculates the extra work within the project and is called the Price Increase. The third KPI determines the Profit Performance. These KPI's are aimed to determine financial success.

A case study research methodology is used to explore the relation between Systems Engineering and Project Management Success at a contractor (Yin, 2014). The case study methodology is relevant since it allows to create in-depth insight into the cases. This helped to establish the context of the case. Moreover, the researcher has control over the data collection. This is necessary since specific interpretations are included in this research, and thus it reduces the chance of misinterpretations during the data collection.

3.1 Getting Started

The research questions were defined in the beginning. These were aimed to create a measurement instrument that could measure the effect of Systems Engineering on project success, analysing the results of the measurement tool within a case, and to draw conclusions and understandings with the help of a cross-case analysis.

The measurement tool is validated by the means of an expert meeting. Three experts from the university and three experts from the field take part in the expert meeting. The verification is done in two steps 'Delphi-like' method. First, the experts were interviewed individually, and could express their opinion of the measurement tool. Secondly,

the received feedback is processed in the measurement tool and presented to the experts together during an expert meeting. Discussions emerged about the suggested improvements between the expert. The results from the discussions was a consensus, that is implemented in the measurement tool.

3.2 Data Collection

The projects were selected from the project portfolio of the contractor. Only two selection criteria were used. Systems Engineering is applied during the project, and the project is finished. The Project Management Success and the extent to which Systems Engineering is applied was unknown during the case selection. The selected projects are stated in Table 1.

Table 1: Case overview

CASE	CLIENT	ASSIGNMENT
1	Municipality	Improving a major inner-city road.
2	Province	Improving a trunk road in the Netherlands.
3	Municipality	Building a bus rapid transit line between two communities.
4	Rijkswaterstaat	Replacing a highway bridge across a canal.
5	Municipality	Renewing an inner-city drawbridge bridge.
6	Rijkswaterstaat	Renovating an old ship lock.
7	Municipality	Rearranging the road layout of an inner-city road.
8	Municipality	Developing a drawbridge for cyclist and pedestrians in a harbour.

The eight cases were analysed with the aid of the measurement tool. Data regarding the extent to which Systems Engineering is applied was gathered with the help of a questionnaire. The questions in the questionnaire measure if certain steps, of the thirteen Systems Engineering elements, have been performed. The answer possibilities are: 'yes' if the step is completely done, 'yes/no' if it is performed partly, and 'no' when it is not done. The answer 'yes' receives 5 points, 'yes/no' as answer receives 2.5 points, and 'no' as answer receives 0 points. The outcome was a percentage that indicates how much Systems Engineering was applied, compared to the 100% theoretical ideal (de Graaf et al., 2016; de Graaf et al., 2017). A document review was used to gather the data needed to answer the questions. The gathered data has been verified and reviewed on completeness together with the responsible Systems Engineer of the project. A percentage, that indicates how much Systems Engineering is applied within an element and for the overall project, was the result. The perceived quality of Systems Engineering was determined based on the employees' opinion of the Systems Engineering processes and products (Componation et al., 2015). Project members were asked to express their opinion of the process quality and the quality of the produced products, per Systems Engineering element. The scores were awarded based on a six points scale. The lowest score is 'not done', which means that the product or process

is not carried out and no points could be awarded. After that, a one-to-five point scale follows, from 'very bad' to 'very good'. Dividing the allocated points between the maximum number of points resulted in a percentage that indicates the perceived quality for the process and the products within a Systems Engineering element. A higher percentage stands for better quality and a lower percentage indicates a worse quality or that certain steps have not been carried out.

The average of the thirteen elements indicated the perceived quality of the Systems Engineering process and products. The average of these two factors is the overall perceived quality of Systems Engineering. Three different employees, with different functions, were interviewed per case. The first employee was the Systems Engineer, the second employee had a management function while the third employee has a technical role within the project. This ensured a broad perspective on the perceived quality of Systems Engineering.

Project Management Success was calculated by the means of KPI's. The wide variety of project scope made some KPI's more suitable than others. Comparing the unit costs or the construction speed, of a road widening with a lock renovation was not doable. So, KPI's were used which compare planned results with actual results.

The first KPI determined the schedule compliance by calculating the time overrun of the project. This was done by dividing the actual project duration through the planned project duration. The outcome of that calculation was then subtracted from one. The result was Time Performance of the case expressed as a percentage.

The other two KPI's were used to determine the success in terms of costs. The second KPI measured the Price Increase during the project and the third one determined the Profit Performance. To calculate these KPI's, extra steps were needed. The following numbers were gathered as data: (1) the bid price, (2) the invoiced amount, (3) the actual cost, (4) cost for extra work and (5) financial result (profit/loss). The Profit Performance (dividing the financial result through the invoiced amount) and the Price Increase (subtracting the division of the actual cost and the bid price from one) were calculated from these numbers. These three indicators together were integrated into the measurement tool. The result was a percentage with indicates the performance, whereby 0% indicates that the project went exactly 'as budgeted', lower than 0% indicates 'better than budgeted', and higher than 0%, indicates 'worse than budgeted'.

3.3 Data Analysis

Analysing the data was done in two ways. The first way was the 'cross-case analysis' and the second way was the in-depth 'within-case analysis' (Yin, 2014). The goal of the cross-case analysis was to compare the results of the different cases with each other and try to find patterns between the cases. Finding possible explanations for the patterns within the cases was the goal of the in-depth analysis.

4 RESULTS AND EXPLANATIONS

The results and explanations are presented in this section and an overview is stated in

Table 2. First, the main research question is answered with the means of a cross-case analysis. The cross-case analysis compares the extent to which Systems Engineering is applied with three KPI's used to express Project Management Success. Followed by an in-depth analysis per case where explanations for the results are founded.

When looking at the extent to which Systems Engineering is applied in

Table 2, it appears to be possible to divide the cases into three groups. The first group consists out of case 1 and case 4. These cases have applied Systems Engineering extensively. Case 2, case 5, case 6, and case 8 are part of the second group. The extent to which Systems Engineering is applied in these cases is 'average'. The third group, case 3 and case 7, exists out of cases with the least Systems Engineering applied. When including the perceived quality of Systems Engineering as well, than case 6 is remarkable. It is the only case where a significant gap between the percentages that express the extent to which Systems Engineering is applied and the perceived quality of Systems Engineering.

4.1 The effect of Systems Engineering on the Project Management Success.

The main goal of this research was to explore if the extent to which Systems Engineering is applied influences Project

Management Success. Identifying the relationship is possible by analysing the extent to which Systems Engineering is applied and related that to the three outcomes of the three KPI's. First, the analysis explores the relationship between Systems Engineering and Time. As a second step, the focus is on the relationship between Systems Engineering and Price Increase. The last analysis is the relationship of Systems Engineering with Profit Performance.

Systems Engineering extent vs Time Performance

The results of the analysis between the extent to which Systems Engineering is applied and the Time Performance are stated in Table 3. The table is ordered based on the 'Time Performance' from high to low. Remarkably, only two cases did not meet their planning targets. A minor time overrun of 4% was present in case 8 while case 6 experienced an excessive time overrun of 161%. This while both cases have applied Systems Engineering on 'average'. The other cases were finished according to the schedule.

In conclusion, finishing projects on time is independent of the extent that Systems Engineering is applied. The two cases with time overruns applied Systems Engineering on 'average', while cases without time overruns applied less, more, or the same amount of Systems Engineering applied.

So, the relationship between the extent to which Systems Engineering is applied and the Time Performance not visible in this research.

Table 2: the results of the research

Case	Extent that SE is applied	Quality of process & product	Average of Extent and Quality	Time Performance	Price Increase	Profit Performance
1	78%	70%	74%	0%	12%	-7%
2	63%	62%	63%	0%	22%	2%
3	52%	63%	58%	0%	1%	-13%
4	83%	76%	80%	0%	9%	-3%
5	67%	65%	66%	0%	9%	0%
6	62%	34%	48%	-161%	53%	-15%
7	51%	53%	52%	0%	15%	-15%
8	59%	60%	60%	-4%	10%	-1%

Table 3: the results arranged based Time Performance from good to worse

Case	Extent that SE is applied	Quality of process & product	Average of Extent and Quality	Time Performance	Price Increase	Profit Performance
1	78%	70%	74%	0%	12%	-7%
2	63%	62%	63%	0%	22%	2%
3	52%	63%	58%	0%	1%	-13%
4	83%	76%	80%	0%	9%	-3%
5	67%	65%	66%	0%	9%	0%
7	51%	53%	52%	0%	15%	-15%
8	59%	60%	60%	-4%	10%	-1%
6	62%	34%	48%	-161%	53%	-15%

Systems Engineering extent vs Price increase

Table 4 states the analysis between the extent to which Systems Engineering is applied and Price Increase and sorted from low to high based on 'Price Increase'. Case 3 has, with 1%, by far the lowest Price Increase while case 6 has, with 53%, by far the highest. The other cases have an average Price Increase from 9% to 22%. Case 3 and case 6 are the two outliers in the results.

Case 3, which has the smallest price increase, had Systems Engineering applied to a limited extent. But, the other case with limited Systems Engineering applied has the third-highest Price Increase. Case 6, the other outlier, has an average extent to which Systems Engineering is applied. The two cases with the most Systems Engineering applied have an average price increase. The remaining cases have an average extent to which Systems Engineering is applied and have an average Price Increase.

Summarising, cases with little Systems Engineering applied, have a low Price Increase or an average Price Increase. Cases with an average extent to which Systems Engineering is applied, have very high Price Increase or an average Price Increase. Cases that have applied Systems Engineering extensively have an average Price Increase. Therefore, this analysis concludes that the relation between the extent to which Systems Engineering is applied and the price increase not visible.

Systems Engineering extent vs Profit Performance

The analysis between the extent to which Systems Engineering is applied and Profit Performance is stated in

this section. The outcome of this analysis is stated in Table 5, ordered based on the Profit Performance. Case 2 has made the most profit, with a Profit Performance of 2%. Case 6 and case 7 are the worst scoring cases with a loss of 15%. It is possible to divide the cases into three groups based on the results. The first group 'as budgeted' exists out of case 2, case 5, and case 8, which performed approximately as budgeted. Cases in the second group experienced a 'small loss'. Case 1, and case 4 are part of it. The last and the third group are the three cases which suffered serious losses (case 3, case 6 and case 7), the 'serious loss' group.

Indications of trends emerged while conducting this analysis. First, every case from the 'as planned' group has an average extent to which Systems Engineering is applied. The cases from the small losses group are the two cases with the highest extent to which Systems Engineering is applied. The group with cases that have serious losses, includes the two cases with the least Systems Engineering applied and case 6. Case 6 has applied Systems Engineering on average, but with a remarkable poor perceived quality.

Cases that had serious losses comply with the expected results. But the 'small loss' group and 'as planned' group do not meet the expectations. Than the cases in the 'small loss' group should have realised profit and cases from the 'as planned' group should have suffered a minor loss. Or the extent to which Systems Engineering is applied should be inverted between the cases in the first and second groups. In conclusion, the results do not confirm nor deny that Systems Engineering results in a better Profit Performance

Table 4: the results ranked based on the price increase from small to larger.

Case	Extent that SE is applied	Quality of process & product	Average of Extent and Quality	Time Performance	Price Increase	Profit Performance
3	52%	63%	58%	0%	1%	-13%
5	67%	65%	66%	0%	9%	0%
4	83%	76%	80%	0%	9%	-3%
8	59%	60%	60%	-4%	10%	-1%
1	78%	70%	74%	0%	12%	-7%
7	51%	53%	52%	0%	15%	-15%
2	63%	62%	63%	0%	22%	2%
6	62%	34%	48%	-161%	53%	-15%

Table 5: the results ordered based on the Profit Performance from the highest profit to the biggest loss.

Case	Extent that SE is applied	Quality of process & product	Average of Extent and Quality	Time Performance	Price Increase	Profit Performance
2	63%	62%	63%	0%	22%	2%
5	67%	65%	66%	0%	9%	0%
8	59%	60%	60%	-4%	10%	-1%
4	83%	76%	80%	0%	9%	-3%
1	78%	70%	74%	0%	12%	-7%
3	52%	63%	58%	0%	1%	-13%
6	62%	34%	48%	-161%	53%	-15%
7	51%	53%	52%	0%	15%	-15%

4.2 In-depth analysis

The goal of the in-depth analysis is to identify factors which could explain why the results of the cross-case analysis do not comply with the expectations. Within the cases, common explanations have been founded why the extent to which Systems Engineering is applied, has no relation with Time Performance and Price Increase. After that, the focus shifts to the individual cases and the relation between Systems Engineering and the Profit Performance. Identifying factors that explain the results, will be performed here.

Interviewees stated that the relationship between Systems Engineering and Time Performance is missing because of penalty clauses in the contract. These clauses state when the systems should open for public, and if not, fines are issued. The fines can be so high that it can be cheaper to invest in extra measures to complete the project on time (Miller, Lessard, Michaud, & Floricel, 2001). The opening dates will also be communicated to the public and delaying the opening results in unwanted negative publicity.

The specifications provided in the procurement phase are the main reason for the missing relations between Systems Engineering and the Price Increase. The problem is the lack of completeness, SMARTness, or correctness of those specifications. Within the cases, major differences exist in the quality of these factors. If the quality is less, then the contract will not result in a system that satisfies the client needs. The result will be extra work since it needs to be fixed.

Case 1

Employees who worked on this project stated that the fixed budget in the procurement phase was too low. It was impossible to finish the project within budget. Case 1 has the longest construction time and the largest budget. The project was among the more complex cases in this research. This due to the inner-city project location and the multiple levels of details that the contractor needed to design. The complexity and the too low budget, could be explanations why the high extend that Systems Engineering is applied did not result into profit.

Case 2

The client was inconsistent in his willingness to participate with Systems Engineering in this case. Sometimes, he demanded overkill of the process, while another time his willingness to participate was missing. Furthermore, a standard Systems Engineering process was missing. Which hindered the communication with the client. The contractor could not express to the client what he expected from him and when he expected it. Still, profit was made, and the system was finished on time. Therefore, was the impact of these factors not that high.

Case 3

The contract used in case 3 was a combination between a traditional bid & build contract and a design & build contract. Only this municipality used this contract, so the project team had no experience with it. Due to the combination of the contract types, were most specifications detailed enough for construction to start at the tender

phase. Experience with Systems Engineering was also missing at the side of the client. The project team of the contractor used a non-standard Systems Engineering process. All these aspects caused struggles within the project. Interviewees stated that the determined budget was tight and making a profit would be impossible. The combination of the struggles and the tight bid prices, can explain why the financial result was a serious loss.

Case 4

The client was experienced with Systems Engineering, which has smoothed the process. This was the only case whereby the contractor was accountable for the complete design, which increases the complexity of the case. Also, it was stated that they underestimated the costs of completing the design during the tender phase. This is a possible explanation for the small loss, given the high extent in which Systems Engineering is applied.

Case 5

The client was inexperienced with Systems Engineering was the only factor that surfaced in this case. That caused some minor difficulties during this project. However, since that is the only factor founded, the project went just as planned.

Case 6

Case 6 is the case with the worst Project Management Success measured. The scope was to renovate a lock from the 19th century. Since the high age of the system, the current state was unknown. The interfaces with the surroundings were not well defined during the procurement phase. As a result, the project scope of the systems was altered a couple of times. Thus the functions, and specification of the system as well. All these aspects combined, made it a complex project.

The contractor applied a traditional work process without Systems Engineering at the start of the project. This caused problems during the system handover. The client was unwilling to accept the systems since the documentation was incomplete. Without delivering the system to the client satisfactorily, the client is not mandatory to pay the contractor. Thus, the contractor needed to verify the design solutions after the design realisation. The implication is that the measurement tool measured that the project team took these steps. However, the perceived quality of the interviewees was much lower since these steps were done way too late. Conclusive, this project is an example of how Systems Engineering should not be applied and the results of it, can also be founded in the KPI's.

Case 7

This was the first Design & Build project for the project manager of case 7. Therefore, he was inexperienced with Design & Build contracts and Systems Engineering. The project team faced an inexperienced client again, but the client was realistic. Sometimes, the client demanded things that were impossible, but when the client was turned down for valid reasons, they accepted it. However, still a major loss occurred, thus the impact of the stated factors was quite big.

Case 8

The project team detected a problem with an element during the construction. Construction could continue after they repaired the element. As a result, extra costs were made, and the project team needed extra construction time. Which explains the minor time delay and the minor cost overruns. Also, the experience of the client with Systems Engineering was limited. The construction problem is a possible explanation for the cost and time overrun of the project.

5 DISCUSSION

The results show that the extent to which Systems Engineering is applied has no effect on Time Performance and Price Increase. The effect of Systems Engineering on the Price Performance is inconclusive. Despite that other research stated that Systems Engineering effects those KPI's (P. Elm, 2011). During the in-depth analysis, factors emerged which could explain why those relationships are missing in most instances. The factors found to explain why Systems Engineering has a missing link with the Time Performance and Price Increase, are clear. They leave little room for discussion since they were found in most case.

The expected relationship between the extent to which Systems Engineering is applied and Profit Performance was present in three cases, while in the other five cases it was missing. Several common factors are identified that could explain the missing relationship. The project's complexity weakened the relationships. Having a standard Systems Engineering process strengthens the relationship. Establishing a too low budget during the tender phase results in an impossible to achieve Profit Performance. The experience of the client with Systems Engineering influences the relationship as well.

Case 1, case 4 and case 6, should have scored a better Project Management Success when looking to the extent to which System Engineering is applied. However, the in-depth analysis showed that these cases were more complex projects. Elm and Honour both already have found that more challenging projects are likely less successful compared to less challenging projects (Honour, 2013; P. Elm, 2011). Systems Engineering is about keeping into control, and thus, trying to prevent cost and time overruns from occurring (INCOSE, 2015). Applying Systems Engineering will not result in a sudden profit. Systems Engineering has not the ability to diminish the loss that was made upfront. If the bid price is lower than the realistic actual costs, then it will result in a poor Profit Performance. This factor was identified in case 4, with an incomplete bid price or in case 1 and case 3, with a lower bid price because of strategic management reasons (case 1 and case 3).

The lack of a standard Systems Engineering process throughout the cases is another factor why Systems Engineering is not applied to its full potential. This caused that employees were not familiar with it, which hinders the efficiency of Systems Engineering. Ambiguity about the precise description of some System Engineering elements is present. This resulted in discussions between project members. Clients that have little experience with Systems Engineering, are stated as a reason in multiple cases as well.

The clients did not know what was expected from them in the Systems Engineering process. All the different factors stated above can play a greater or lesser role in the cases. They influence the measured Profit Performance and thus the outcomes of this research.

When applying these factors to the results, then could it be that cases 1, case 4 and case 6, have scored lower than expected for the complexity of the projects. Or that cases 1, 3, and 4, have a lower Profit Performance because of the incomplete bid price. While in other cases, are the results are tempered because they needed to deal with an inexperienced client. However, how significant the impact of these factors is, is unclear. Known is that they hindered, or diminished, the effectiveness of Systems Engineering.

6 CONCLUSION

To conclude, the relationship between Systems Engineering and Time Performance or Price Increase is absent in this research. The relationship between Systems Engineering and Profit Performance is unconvincing. Three cases indicate that a relationship could exist, while five other cases imply that no relationship is present. During the research, factors are identified that explain why those relationships are not found or unconvincing.

These factors are preventing the appliance of Systems Engineering with full effectiveness in the Dutch civil construction industry. Systems Engineering has no relationship with the Time Performance because of penalty clauses in the contracts. Incomplete, faulty, or not detailed enough specifications are the reason for the missing relationship between Systems Engineering and Price Increase. Other factors, than Systems Engineering, have more influence on Profit Performance. These factors are incomplete/faulty bid price, the complexity of the projects, using a standard systems engineering process, and the experience of the client with Systems Engineering. As a final remark, Systems Engineering itself cannot result in more profit, it only helps to keep in control of the project.

7 RECOMMENDATIONS

Other factors have more influence on the Project Management Success than Systems Engineering. Some of these factors fall outside the research scope, such as lowering the bid price for strategic reasons by the management. The factors independent of Systems Engineering are not covered by the recommendations.

Applying Systems Engineering with its full potential is the goal of the given recommendations. It is crucial to have standard Systems Engineering process. Employees need to comprehend every Systems Engineering element. Standard basic knowledge is knowing where the elements consist of, when to perform the elements, who to involve, when the element needs to be ready, and what to expect from partners. This reduces the interpretation differences across the project team and embraces the efficiency of the process since employees will get familiar with it. Also, it needs to cover the whole project, from the beginning to the end, with a complete and integrated team. The client and partners are also part of the integrated team. Therefore, they will also benefit from having a standardised process. This allows to

communicate upfront what you expect from the client and/or partners. If they are inexperienced with Systems Engineering, it raises possibilities to guide them upfront. This way, they will be more prepared and more willing to cooperate in Systems Engineering compared to asking them ad hoc to comply with the Systems Engineering process.

A proactive attitude will enhance the application of Systems Engineering. Detect and amend mistakes, illogical, incoherent and/or unpractical aspects early on; the lesser work needed to solve them. Continuing with these aspects will cause irritation. Solving it later creates extra work and thus frustration among the project members.

The last recommendation for improving Systems Engineering is that the reasons why Systems Engineering steps are applied should be clear. Do not perform random verifications and checks. Include the reasons for these verifications and the chosen verification method. Verifying the same thing a hundred times, without a valid reason, decreases the support for Systems Engineering. By making the V&V plan, SMART and efficient can save the project team unnecessary work. Knowing beforehand when verification or validation should take place is crucial. Nothing is more frustrating than being assigned to verify a requirement when the construction has continued and verifying is impossible.

8 LIMITATIONS AND FURTHER RESEARCH

Many disciplines need to work together in the construction sector, making the process sensitive to disruptions. All these disruptions influence Project Management Success. Therefore is measuring the impact of a single factor, like the application of Systems Engineering on Project Management Success, is difficult. A lot of different factors are always present in practice. Filtering the impact of every single factor out of the Project Management Success is an impossible challenge. Still, the measurement tool measures the impact of them. However, identifying and filtering out easy factors, such as a strategic discount on the bid price or mistakes in the bid price, will provide a better result. Enlarging the number of cases results in a more comprehensive overview of the situation in practice (A. P. Chan, Scott, & Chan, 2004; Nitithamyong & Skibniewski, 2006).

The situation of Systems Engineering in practice causes limitations. Within the construction industry, discussions are present about what Systems Engineering entails and what they need to do. Interviewees can, therefore, misinterpret the questions of the measurement tool. They can answer a question based on a misinterpreted term, which results in faulty measurements. Also, the measurement tool only the perspective of the contractor. Including the perspective of the client will strengthen the results of the research.

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