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ECONOMIC JUSTIFICATION OF VIRTUAL COMMISSIONING IN AUTOMATION INDUSTRY

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ABSTRACT

Virtual Commissioning (VC) is the latest trend in automation assembly. VC offers, among other benefits such as product quality improvement, promises a great reduction in the system ramp-up time, and a resulting shortening of the product's time to market. This paper presents an approach to economic justification of VC application by considering and evaluating its tangible and intangible costs and benefits through case studies and applying Fuzzy Analytic Hierarchy Process (FAHP). The results of this research are useful for justifying emulation efforts such as VC in almost any automation business which requires warehouses, manufacturing or production, assembly, distribution centers, or handling of mails, cargo, and baggage.

1 INTRODUCTION

Strong competition, short product life cycle, and increased complexity of products and processes are the characteristics of today's manufacturing environment. Therefore, the need to offer innovative and individual products of good quality, produced in shortest possible time, at the lowest price, has given an optimistic feeling about digital factory concept. The digital factory concept offers an integrated approach to enhance the product and production engineering processes and has been the strategic goal of many manufacturing enterprises for the last years (Ding et al. 2009). As product life cycles are reduced in the continuously changing marketplace, modern manufacturing systems should have sufficient responsiveness to adapt their behaviors efficiently to a wide range of circumstances (Mehrabi, Ulsoy, and Koren 2000). In this context, one of the main challenges that modern assembly systems are faced with, is the cost-driven demand for faster and more secure ramp-up processes. The pressure arising from the complexity of automation systems themselves and from the growing importance of a short ramp-up phase on the other hand, are addressed by VC (Reinhart and Wünsch 2007). VC targets industrial equipment and automated systems. It uses a virtual model that represents an accurate and realistic 3D simulation of mechanical, electrical, and control systems in order to validate the operation of a production system prior to actual physical implementation (Salamon and Heidari 2012). The examples can be application of VC onto a robotic cell that welds the parts of a passenger car floor or conveyors and material handling systems.

The conventional design procedure consists of three major design stages: 1) process design, 2) mechanical design; and 3) electrical design (Ko, Ahn, and Park 2013). Discrete event system simulation which provides an intuitive and flexible approach to representing complex systems was the only technology supporting the full design procedure of a production system across the three major design stages. For the analysis of an automated manufacturing system, simulation technology has been considered as an essential tool. Simulation is useful for calculating utilization statistics, finding bottlenecks, pointing out scheduling errors, and even for creating manufacturing schedules (Wang and Ng

2012). The traditional simulation languages have been widely accepted both in industry and in academia; however, they are not very helpful for the implementation of a real control program. For example, real production lines are usually controlled by Programmable Logic Controller (PLC) programs involving sensors and actuators, but conventional simulation languages roughly describe the control logic with independent entity flows (job flows) between processes (Anglani et al. 2002). Today 3D models are applied beyond the classic simulation for system design and decision support. They are applied in software testing / VC and these models are re-used in operator training prior to ramp-up and during the year-long operation phase for testing frequent software updates, patches, and system modifications. Applying emulation models is also for safe retrofitting of running systems, which extends the life time of automation systems and investments.

Overall, VC holds the potential to increase the value of the system by leveraging services throughout the system lifecycle. This research was initiated by Xcelgo who was interested in supporting the validation of the economic application of creating, designing and validating a new complex automation service, distinct from the physical product based on VC. The paper contributes to the field of automation systems by identification of a novel economical approach to effective design of a new service. The paper is subdivided into the following sections: literature review, methodology, discussion and conclusion.

2 LITERATURE REVIEW

VC has roots in soft commissioning. Soft commissioning tests industrial control software by connecting a controller to a commercial Discrete Event Simulator (DES), which provides system reactions and sensor signals similar to the behavior of real hardware (Schludermann, Kirchmair, and Vorderwinkler 2000). The method however did not consider the entire life cycle of a technical system including requirements engineering and “classical” simulation analysis which can be fulfilled by VC now which enables to produce the virtual world and anticipate the behavior of the real system, weeks before its physical build (Makris, Michalos, and Chryssolouris 2012a).

2.1 Focuses and Premises of VC

The aim of VC is to enable control software engineering to both take over the initiative in system design and to perform important activities earlier in the design process of production equipment. As indicated in Figure 1 total premises are as follow:

- Addresses one of manufacturing’s fundamental issues: getting product to market in a timely and competitive way.
- The general trend toward shorter product lifecycles is driving the importance of the production ramp up to a new model’s economic success in the market.
- Substantially reduces the product launch lifecycle.
- Allows manufacturers to create complete virtual production facilities in order to optimize and validate their real world manufacturing processes.
- VC eliminates many of the time and resource consuming tasks that otherwise must be physically performed by control engineers.

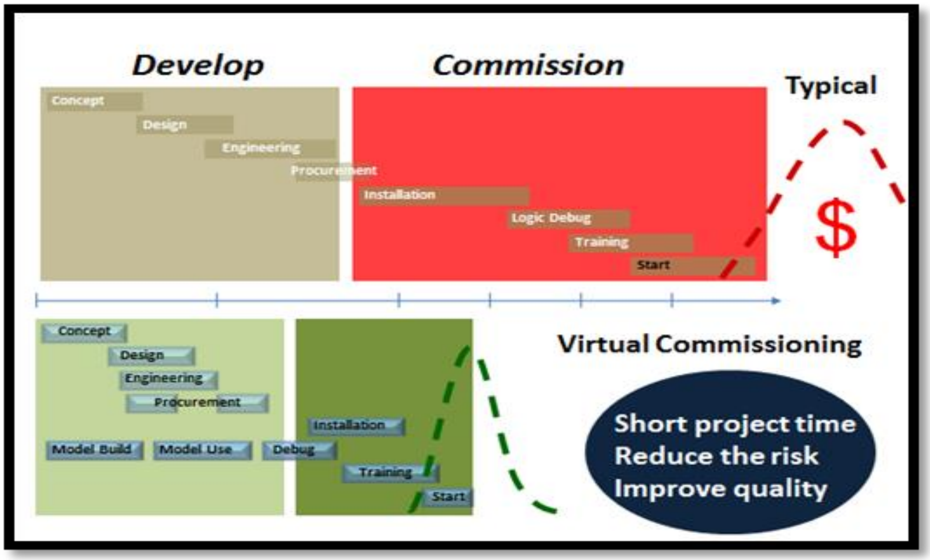

Figure 1: VC vs. traditional commissioning (TC) process.

This research deals with a particular Product Service System (PSS) as a case of effective modeling, design and deployment. The purpose of this document is to analyze the economic scalability of VC for mechatronic production systems. The general premise is that implementation of VC has the potential to increase the benefit of the system with regards to time, cost and quality. If the premise can be instantiated in the case studies and FAHP results, then we get the evidence that VC is an effective approach, in almost any automation industry.

2.2 Previous Studies

The area of VC has undergone an extensive investigation so far which mostly addresses technical application and benefits theoretically. However, it has not been researched widely from economic application perspective. Table 1 describes studies dealing with VC and the results of its application.

Table 1: Studies and corresponding results from VC application.

Author	Area of study	Result
(Seidel, Donath, and Haufe 2012)	Simulation-based verification tool for all stages of an Material Handling Systems (MHS) project	One common simulation model is used for all project stages.
(Ko, Ahn, and Park 2013)	VC between a real controller and a virtual plant in a production system	Saving of the delays in time to market.
(Makris, Michalos, and Chryssolouris 2012b)	VC of an assembly Cell with cooperating Robots	Ramp-up time reduction, affecting the total installation time by 15–25%. Reduction in investment costs by decreasing to the minimum. The cost is reduced even more through the reduction by up to 15% of the human resources, required for troubleshooting during the ramp-up process. Enhancement of the re-configurability of assembly

		equipment
(Drath, Weber, and Mauser 2008)	-	A seamless re-usability of VC models through the complete engineering life cycle.
(Seidel, Donath, and Haufe 2012)	Simulation and VC environment for controls of material handling systems	The additional work of modeling the material handling process in the simulator was compensated with a reduced commissioning stage on-site. Intense testing of PLC and Material Flow Controller (MFC) programs significantly boosted the software's maturity and reduced the required time on-site to 25% of the planned time.
(Reinhart and Wünsch 2007)	VC to mechatronic production systems	A significant amount of time and cost can is saved in the production ramp-up process. Delivering a system with a higher software quality for startup.
(Møller, Chaudhry, and Jørgensen 2008)	A virtual enterprise architecture for logistics service	Testing and bug finding under controlled testing environments. Validation of controls software for automation, early identification of errors and actions taken early in the development process. High visibility of quality state of the software during the development process-reveal problems and opens for action-taking in the early process. Continuous test in parallel with installation while the real system is occupied by other activities. Low cost of future developments and changes.
(Hloska and Kubín 2014)	VC of mechatronic systems with the use of simulation	Shortening of the process of Standard Operating Procedure (SOP). Possibility to carry out part of the SOP in more convenient environment (not necessarily on site) combined with the opportunity to use the emulation model for training of workers. Parallel development and optimization of mechanical parts, especially mechatronic mechanisms. Simultaneous programming and debugging of the control software (of MFC or individual PLCs).

In order to empirically support the existing literature regarding VC contribution especially from an economic point of view, case studies and FAHP method are considered in this paper which will be explained in the next chapter.

3 METHODOLOGY

This study is based on a study of the large scale deployment of automation in five automation companies in Denmark. The aim is to evaluate and justify value creation and economic justification of VC in terms of tangible and intangible parameters related to time, cost and quality. The values can be defined in terms of either being tangible or intangible. Tangible values are the ones that can be obtained in dollar value; the example can be saved capital investment for area lock up when applying VC. However, the intangible values cannot be described in dollar value, for instance the potential obtained by getting positively recognized by OEM. We have identified the following parameters related to automation commissioning:

1. On-site work (regarding man day): what we analyzed by on site work is the working-hours that e.g. control engineers need to spend onsite. The concept is to estimate the importance of this parameter and to evaluate the difference in the working-hours that is specially spent onsite when applying VC and traditional commissioning (TC).
2. Ramp up length (regarding area and capital investment lock up): what we assessed by ramp up length is the time and capital spent to lock up the area during ramp up.
3. Risk of delay and interruption during ramp up: we evaluated the probability of delays and interruptions during ramp up of the automation equipment for two mentioned practices.
4. Deadline control: what we assessed is the ability of VC to control lead-times
5. Frequency of changes submitted by customers: we evaluate the frequency of the changes that customers submit especially during the ramp up phase and assess the importance of this parameter and see the difference of two practices VC and TC according to this parameter.
6. Software quality in relation to future operation: what we investigated is that the intensive virtual testing upfront increases the "quality" of controls software during ramp-up, and daily operation (the gain in productivity). We assessed this parameter and compared the two practices according to this driver.
7. System debug control: we evaluated the ability of the VC to reduce number of the bugs and validate control software prior to system debugging onsite (in the plant environment).
8. Usage of reference model for future changes: if there is any update or changes in future, the reference model can be still used and we assessed the importance of this parameter.
9. Synergy: we evaluated the synergy in the project.
10. Recognition by OEM: faster ramp-up is one of the enabling factors to be first on the OEM market. We evaluated the importance of “Recognition by OEM” and assess the two practices according to this parameter.
11. Cost of modeling and simulation

Most of the parameters mentioned above are intangible which makes it difficult to describe their benefits in dollar value. To empirically support the premises regarding economic application of VC, case studies are considered in order to analyze the above parameters. Besides, one of the approaches to evaluate intangible values is FAHP which is also applied in this paper. The process in this study is to use questionnaire or interview VC stakeholders and experts to get data for FAHP calculations which will be done in Excel.

3.1 Data Collection

The research material for this study consists of interviews and questionnaires. Two employees responsible for modeling, design and operation of this technology were interviewed as the initial step to identify the tangible and intangible drivers so they can be later evaluated from supplier perspective. Twelve interviews were arranged with simulation and emulation experts, production and development project leaders to get the required data for FAHP questionnaires and their experiences with VC and TC. Therefore the study is both qualitative and quantitative. Finally, structured and semi structured interviews were arranged with half an hour durations.

3.2 Result from Cases

This part of the study was carried out in form of interviews in five Danish companies. Questions involved effect of applying of VC on each of the selected automation parameters in terms of value creation regarding operational excellence and optimized system. We have gathered our observations and findings in Table 2.

Table 2: Effect of VC on value creation of each automation parameter.

Automation parameter	Remarks
On-site work (regarding man day)	We are saving 50 % of the onsite man hours. In terms of absolute numbers we are saving roughly a man year at least. Less onsite works also means that employees will have an improvement in their working conditions. They will experience less stress as they get the time to test their software with their coworkers in the office which avoids the unexpected problems on site.
Ramp up length (regarding area lock up and capital investment)	No direct influence on the ramp up, but there are indirect influences. Because we have tested the system much more thoroughly we are experiencing less errors, but the ramp up itself is the same in terms of money and man hours, but it is much more fluent and it is a better system that we are starting to ramp up. The ramp up length in our case is shortened from four to three months by using emulation which also results in a decrease in cost for area lock up.
Risk of delay and interruption during ramp up	That's the big benefit we get from working with emulation. That we experience much less interruption which makes the whole ramp up more efficient so we do not have to stop and do it over again.
Deadline control	Projects need to have emulation and virtual commissioning to bring up the standards of the software to meet the deadlines at the right time. The software will be in a certain condition that makes it possible to meet the deadlines on time and we will be able to hand over the entire system to the customer as planned which is a huge advantage. However it is very challenging to introduce this tool to a company. The reason is that it is similar to maintenance related projects; it is difficult to convince them that the money they spend is to meet the deadline and save the time and money.
Frequency of changes submitted by customers	It is surely shortened.
Software quality in relation to future operation	We get a much more stable system and every time we apply a new software version, we do a virtual test and we have caught many errors, sometimes big errors and we are able to catch them before they get into the production system. And if you have a big production system, even one error can make us stop working for one day if we do not use emulation. So in this way we can save a lot, maybe a couple of man years. So if we can just catch a few errors before they get to the production system then it is a huge saving. So in sum, the intensive virtual testing upfront increases the "quality" of controls software during ramp-up, and daily operation. It is a great advantage that working with VC will provide customers with solutions that have been thoroughly tested before being put into operation.
System debugs control	System debugging control is very much improved. It is easier to do systematic debugging control which will definitely increase the quality of the software.
Usage of reference model for future changes	We do have a model in all our projects that can be used for future changes which mean savings in both time and money.
Synergy	We get an operational excellence when working with emulation.
Recognition by OEM	Reduction of implementation time and costs, results in a competitive

	advantage in the market.
Cost of modeling and simulation	No exact numbers but we are convinced it is a good investment. Shorter ramp up means less time spent on site and less time used on capital investment lock up, so we are having people testing at home instead of testing on site, which means that cost of the testing will be very low. Moreover, higher software quality with less bugs mean decreased man power and saving money.

In overall, reaping the benefits from VC may not be as easy as it seems. It can be hard for people who are not into IT to understand what the benefits of VC are. Thus it can be challenging to convince decision makers to spend money for building a model without being able to provide an exact or quick saving. However, lead time which is the time from customer order to receipt by customer is an increasingly important attribute of production, as the sooner we complete the projects, the sooner we realize the benefits, the more capacity we expose. Controlling project lead times is promised by VC and it always leads to providing companies with a competitive advantage. Sometimes this competitive advantage is obvious to see: getting products to market faster, quoting shorter lead times than competitors on projects, and realizing internal benefits sooner. Sometimes this competitive advantage is harder to see: delivering more projects with the same resources lowers the overall labor cost per project. The common reasons to control or shorten lead-time are as follows:

- Increase predictability: reducing variability in lead time will allow consistently knowing and committing when something can be delivered. Delivering consistently will help to increase the trust within the system. One of the very beneficial outcomes from increasing trust in the system is that it leads to a dramatic reduction in expediting. Once the system becomes predictable, the business may be able to make new offers to customers based on the high level of predictability.
- Faster feedback: reducing lead time duration results in faster feedback. Faster feedback can result in increased quality. There are a number of reasons for this. Less work is done based on work items that require rework. Shorter cycles result in better fit since the feedback can be gathered and applied frequently. Also, faster feedback means that the team can minimize the work required to meet the objectives.
- Flexibility and responsiveness: shorter lead times and trust based on predictability increases options for flexibility. You can delay some decisions until very late – deciding just before you pull into the system the details of solution. Expediting now means putting an item into the queue as the next item. Also, you can make new promises to customers based on this increased level of flexibility and responsiveness.

Interviews have defined some of the remarks related to applying VC. In the next section, we have applied the FAHP to assess and compare intangible contribution of VC and TC to value creation based on the defined parameters.

3.3 The Interpretation of the FAHP Method, Questionnaire and Data Analysis

Analytic Hierarchy Process (AHP) method is applied in this research to take the intangible parameters of VC, which cannot be converted easily into dollar value, into consideration. AHP is applied in solving complex problem solving decision by using qualitative data. It is mostly used to assess the value and weight of intangibles. The basic idea behind AHP is that the goal components have to be identified. It includes what the integral parts and criteria are (Zahedi 1986). However, conventional Saaty's AHP does not completely indicate the significance of qualitative criteria. The reason is that human uncertain thoughts cannot be reflected in the AHP scale (Özdağoğlu and Özdağoğlu 2007). In order to solve this problem, triangular fuzzy numbers (TFN), a quantity whose value is imprecise, rather than exact as is the case with single-valued numbers, and conventional AHP are joined together to form FAHP in order to remove the negative aspect of subjective assessments of decision makings (Kwong and Bai 2003). In this study, FAHP based on Chang's Triangular fuzzy conversation scale as indicated in Figure 2 is applied. Due to lack of space please refer to (Chang 1996) for further reading about FAHP.

Linguistic scale	Number put by respondents	Triangular fuzzy conversation scale	Triangular fuzzy reciprocal scale
Equal importance /preference	1	(2/3, 1, 3/2)	(2/3, 1, 3/2)
Moderate importance /preference	3	(1, 3/2, 2)	(1/2, 2/3, 1)
Strong importance /preference	5	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strong importance /preference	7	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Extreme importance /preference	9	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)
Intermediate values	2,4,6,8		

Figure 2: Triangular fuzzy conversation scale (Chang 1996).

This paper first contributes to the use of FAHP to first defining the overall weight of VC and TC in terms of their contribution to value creation by affecting the related parameters separately. Second, it calculates and compares the value of each parameter with regards to value creation. Overall, this technique identifies the importance/preference weights of alternatives (VC, TC) according to defined drivers as illustrated in Figure 3.

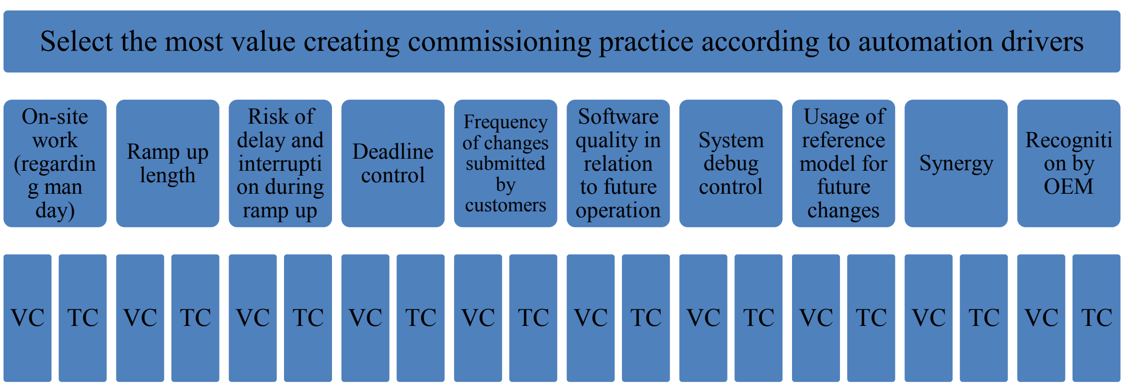

Figure 3: Structure of the proposed method.

For this purpose, the FAHP questionnaires were prepared to be filled out by simulation and emulation experts, production and development project leaders. We had received twelve responds. The questionnaire consists of two parts. First, the parameters are compared to each other in pairs. The comparison examines their importance to value creation regarding time, cost and quality. The scale of the comparison for relative importance/preference is given in Figure 3. Second, the preference of two practices of VC and TC is separately compared according to each of the parameters.

The first part is the relative comparison of parameters to each other from scale of one to nine. For example as indicated in Figure 4, a respondent would believe that "On-site work regarding man day" has a moderately more important influence on value creation than "Ramp up length (regarding area and capital lock up)", or one might believe that "Risk of delay and interruption during ramp up" has a strongly more important effect on value creation compared to "On-site work (regarding man day)".

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
On-site work (regarding man day)							X											Ramp up length (regarding area and capital lock up)
On-site work (regarding man day)													X					Risk of delay and interruption during ramp up

Figure 4: Example of first part of questionnaire.

The second part is the same. As shown in Figure 5, one respondent would consider that VC, regarding [Onsite work (regarding man day)] is strongly more preferred ((3/2, 2, 5/2) according to TFN scales as shown in Figure 3) than TC.

Onsite work (Regarding man day)																		
Alternative	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative
Virtual commissioning					X													Standard commissioning

Figure 5: Example of second part of the questionnaire.

Next chapter will include results of the analysis of the responses from FAHP questionnaires.

3.4 Results of FAHP Analyses

We analyzed overall weight of virtual and traditional commissioning in terms of their contribution to value creation by affecting the related parameters, separately. On the other hand we evaluated the value of each of the automation parameter with regards to value creation. Figure 6 indicates comparison of the two practices regarding value creation.

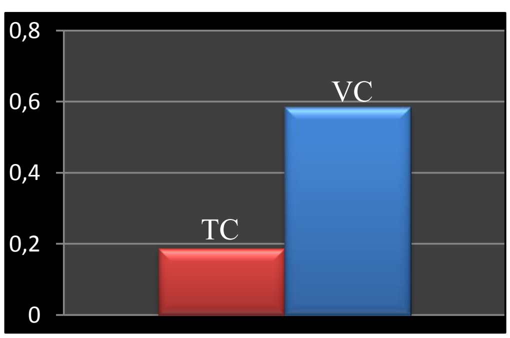

Figure 6: Overall weights of VC and TC in terms of their contribution to value creation.

Result of the FAHP for the overall weight of VC and TC in terms of value creating business cases show that VC has obtained around three times higher potential to result in operational excellence and optimized system. However, it is important to note, when implementing VC that a general change of mindset in the organization is needed. The benefits related to VC are beyond getting a software tool and it is a long term investment. As explained earlier within the cases, there are several intangible values created by VC that makes a good business case in the long run.

Moreover, as shown in Figure 7, comparison of the nine parameters related to automation commissioning with regards to their importance to creating value indicates that "Deadline control" has the highest importance and VC promises to meet the deadlines and hand over the entire system to the customer on time. Risk of delay & interruption during ramp up and software quality in relation to future operation are the second and third parameters which are important in value creation and VC assures less interrupted ramp up and a more stable system.

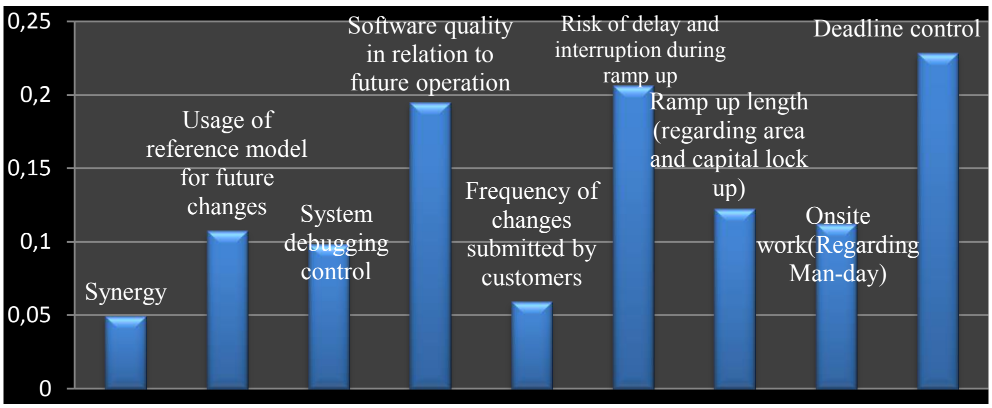

Figure 7: Value of each parameter with regards to value creation.

4 DISCUSSION AND CONCLUSION

Any successfully completed project has to achieve three simultaneous objectives for scope (or content), schedule, and cost. While this is well known, it is hard to achieve in reality. Often, companies find themselves forced to sacrifice one (or even two) of the objectives to achieve any one of them. Many of us have heard about situations where companies go over budget in order to deliver a project on time or even worse, ship a project to a customer (to achieve schedule) and finish it in the field. There are many, many stories and anecdotes that people share during conferences and training sessions about projects that have gone 'wrong'.

The root causes as to why projects are often late, over budget, and/or under scope project environments are characterized by high degrees of uncertainty. Uncertainty in content (for many projects the work has never been done before and the customer may not have fully determined what it is they want), vendor performance and internal skill sets. Because of this uncertainty, the common complaints related to successfully managing projects include:

- Original due dates are not met
- Too many changes to scope or timing
- Resources (internal and external) are not available when needed
- Necessary things are not available on time – material, information, specifications, approvals, etc.
- Disagreements about priorities among projects
- Budget overruns
- Too much rework

Meanwhile, a significant part of commissioning and ramp up phases in service industry consists of software implementation or even software redesign, which results in longer ramp up (Reinhart and Wünsch 2007). To analyze the importance of automation parameters and value creation of VC and TC we applied interviews and questionnaire with employees responsible for modeling, design and operation of this technology, simulation and emulation experts and production and development project leaders to get the required data for FAHP questionnaires and their experiences with virtual and traditional commissioning.

The FAHP method offers an evaluation between two practices of VC and TC especially from an intangible point of view and importance of automation parameters separately. "Deadline control", "Risk of delay and interruption during ramp up" and "Software quality in relation to future operation" are the three most significant drivers in automation industry that have a higher impact on value creation. Additionally, we get the justification for more effective complex service modeling, design & deployment and leveraging the business value of the service offered through VC which is around three times higher than TC. On the other hand, the interviews have justified that much less interruption is experienced through VC which results in a more efficient ramp up and makes it possible to hand over the entire system to the customer on time. Furthermore the intensive virtual testing upfront increases the "quality" of controls software during ramp-up, and daily operation.

In overall, as many automation solutions are applied in the logistics and material handling systems, this work contributes to the field of logistics, supply chain management and transportation by focusing on economic justification of VC in automation industries based on a new assessment model. FAHP (for the first time to our knowledge in simulation areas) in addition to case studies was considered to justify the cost savings in VC. Values of VC in terms of time, cost and quality are validated and supported to overcome the TC. Yet, working with VC requires a mindset that accepts spending money for building a model without being able to provide a quick saving and believes that benefits are to be harvested in the future. Finally, this study is not without weaknesses, uncertainty of the human thoughts in FAHP method and lack of any real number indicated in business cases as the benefits of VC are the gaps that can be a future research focus.

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