Dynamic Model for Estimating the Added Value of Maintenance Services

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Abstract: A dynamic model of production plant maintenance services is presented in this paper. The focus is on the service (i.e. value co-creation) perspective and the main purpose of the model is to facilitate the service provider's understanding of their customer's business and of the added value of services. Estimating the added value of services is important since it helps developing value propositions. Additionally, knowing the value is essential as the pricing of services is based on added value rather than costs. The modeled services described in this paper vary by their complexity and their effects on the system. The model was built to act a communication tool between customer and the service provider to enable shared understanding of the system and the effects of different collaborative services.

Keywords: system dynamics, maintenance service, service system, dynamic complexity

Introduction

The transition from hardware and software to services is changing the world everywhere. Still, the understanding of services is poor compared to conventional manufacturing. Accordingly, there is a great need for tools and methods to understand, control, and predict service systems. This need enabled the introduction of the concept of service science in the early 2000's. Service science, which is a specialization of systems science, strives to understand complex service systems. It is a broad-ranging discipline that seeks to integrate across several disciplines such as economics, law, management sciences, and management of information systems (Spohrer and Maglio 2010).

In order to study services we need proper definitions for the terms service and service system. Service has been defined in different ways in literature. As Sampson (2010) points out, some of those definitions are useful and some are more or less useless. Sampson (2010) proposes a unified service theory in which customer involvement has central role in giving input to the service process. Spohrer and Maglio (2010) define service simply as value co-creation between a customer and a service provider. Service dominant logic sees service as a fundamental basis of exchange and defines service as all appliances of knowledge and skills for the benefit of a customer (Vargo and Lusch 2004). IHIP-view draws a distinction between physical products and service by characterizing service as: intangible; heterogeneous in a sense that service can be standardized; inseparable in a sense that production and consumption are simultaneous; as well as perishable in a sense that service cannot be inventoried (Mott 2010). Evidently, the service science literature is somewhat disunited on the definition of service. Most of the definitions concentrate on value creation – with or without customer's input. Many definitions, however, emphasize customer's central role in creating the added value in cooperation with service provider making the service process a collaborative system.

Service systems consist of at least two parties called entities which are co-creating value. The size of the service systems vary from systems of two people to massive global economies in which entities are nations, cities, businesses etc. Furthermore, service systems can consist of complex networks of interacting entities. These interactions which are typically nonlinear and may be delayed, determine the system's behavior. That is to say, in addition to a huge amount of detail complexity service systems can be dynamically complex.

Transition from products to services

Traditional manufacturing companies are facing increasingly fierce competition on the global market as the production is moving to countries of cheaper labor costs. Accordingly, producing purely physical products has become less profitable. It has been pointed out by many authors that conventional manufacturing companies should integrate services to their product offerings and expand their business perspective to cover more the business of their customers (Kalliokoski 2003, Oliva and Kallenberg 2003). Besides satisfying customer's demand, services have potential to offer (Brax 2005):

- steady and high margin revenues
- they support the sales of physical products
- opportunities to grow in matured markets
- lengthening of customer relationships through committing the customer to one service provider
- reduction to the effects of economic cycles

Kalliokoski et al. (2003) describe several industrial service business models and roles for manufacturing companies starting from machine supplier and system supplier which are how the traditional manufacturing companies work. Maintenance partner is a role in which supplier's business perspective expands to cover maintenance of customer's system and spare part aftermarket. As a performance partner supplier is strongly engaged with the operation of customer's technical process. Finally, in value partner role supplier is closely concerned with entire business of the customer. Naturally, the more service provider has responsibility for the customer's process the more profound understanding of customer's business is needed. The transition process from machine supplier to the value partner can be challenging, as Brax (2005) argues. Oliva and Kallenberg (2003) present their way to overcome the obstacles in the transformation process from manufacturer to service organization.

According to value based pricing business strategy the pricing of the service should be based on customer's added value, not on the expenses service provider experiences. It would be useful to know the value in advance since it facilitates developing value propositions which in turn could motivate the customer. Unfortunately, determining the added value is challenging since the value is created in a complex system and arises from different sources, which may be difficult to measure. For example, it is relatively easy to calculate the monetary value of increasing the utilization rate by 1% whereas measuring the value of lower operational risk is more elusive. As Brax (2009) points out, removing technological and operational risk from the customer is an essential value generating mechanism.

The aim of this paper is to examine value co-creation process of the specific maintenance services. The scope of the paper covers mostly the added value of customers. We used system dynamics modeling and simulation as an approach to study the service process (especially customer's processes and business) and to estimate the value.

Maintenance

Maintenance is an inseparable function of any production plant. It is an essential part in a large system which consists of multiple organizations, such as spare part suppliers, logistics, customers to name but a few. Sub-systems such as production control and maintenance are closely connected and interdependent. Interactions between these subsystems, which are typically nonlinear and inflicted by time delays, give rise to the dynamic complexity. Moreover, there is a great deal of detail complexity distracting us from understanding the essential patterns of dynamic behavior. In this paper the focus is on the dynamic complexity.

There are several papers presented in the literature which examine the dynamic complexity of maintenance management systems. Sterman (2000) presented the case in which Dupont's maintenance management had encountered problems resulting from flawed mental models. Jambekar (2000) presented a qualitative model for maintenance and quality programs and studied the system and behavioral aspects from systems thinking perspective. Honkanen (2004) examined maintenance models with a particular focus on automatic condition monitoring enabled by electronics and software in industrial machines. Thun (2004, 2006) studied the dynamic complexity related with total productive maintenance. Bivona et al. (2005, 2010) examined the interactions between bus fleet maintenance and other parts of the organization. Sterman, Jambekar, and Thun stressed the system's tendency to follow "worse-before-better-behavior". This tendency is a fundamental problem of maintenance, since the inability to predict system's long term behavior (resulting from the system's complexity) is tempting into short sighted policies, which in turn, leads to even greater problems – or to be more precise better-before-worse-behavior.

To fully understand the complexity, maintenance must be examined as an interacting part of a larger entity - not as an isolated and unconnected system. Correspondingly, reducing the problem by dividing the system into smaller separate subsystems tends to lead suboptimal solutions. Interactions between maintenance and other parts of the system have an important role in shaping the system's long term behavior. In fact, the longer the time span over which the system and policies are evaluated the more significant are the interactions between subsystems. The key element is to understand the feedback structure between maintenance and other operative, tactical and strategic processes of the system. As soon as the role of the maintenance in this large system is clear it is easier to set the objectives so that they serve the company's needs in the best possible way. Bivona et al. (2005, 2010) examined some of the most essential interdependencies between bus fleet maintenance and other subsectors in the organization, especially production, asset management, and finance. They describe how hard it is to understand the relationship between maintenance and finance. It is apparent in the short term as the maintenance generates costs. The beneficial effects of maintenance, however, are not so obvious and easy to reach. Maintenance managers can improve financial results by increasing the maintenance efficiency or effectiveness which leads to lower maintenance costs or higher equipment availability respectively, which in turn leads to higher revenues (Bivona 2005). Furthermore, there is a great deal of uncertainties and time delays involved before the beneficial effects of preventive maintenance efforts can be seen as improved financial performance.

Maintenance policies

The maintenance policies are divided into two main categories by the timing of maintenance actions: corrective and preventive maintenance Corrective maintenance, which is also called breakdown maintenance, is a reactive way of carrying out upkeep considering that it takes place after the component's failure. Preventive maintenance is a proactive upkeep since it is carried out before the failure.

The easiest policy to put into practice is corrective maintenance because the decision to repair the broken component is based only on the fact that component does not work. This policy, nonetheless, has serious shortcomings. First of all, failures are somewhat unpredictable. Unpredictability of a failure makes it difficult to plan maintenance actions, the need for spare parts, and the need for maintenance workforce (Bivona 2005). In addition, failures cause often prolonged downtime and significant production losses. Furthermore, failure of a component may cause consequential damage to other components (Albin et al. 1992, Bivona 2005).

Due to the shortcomings of corrective maintenance it is often more affordable on the long run to prevent failures in advance and according to a plan than to repair or replace the failed component after an unpredictable failure. To tackle the problems of corrective maintenance the idea of preventive maintenance was presented 1950's (Nakajima

1989). Since it is done in advance it is possible prearrange the maintenance and carry it out in a way that suits best the needs of production. Moreover, preventive maintenance makes it possible to plan the need of maintenance personnel and spare parts as well.

Preventive maintenance can be divided into different categories typically according to the events that trigger the maintenance action. The most important preventive maintenance policies are predetermined maintenance (which is also known as scheduled maintenance) and condition based maintenance. Predetermined maintenance is carried out according to a schedule which is set up to predefined calendar time or certain age or operation time of the component. Condition based maintenance strives to predict the need for maintenance by monitoring the condition of equipment (PSK Standards Association 2003).

Scheduled maintenance has potential for solving the most critical weaknesses of corrective maintenance but its efficient implementation can be challenging. Maintenance is carried out at fixed intervals or by an opportunity despite the actual condition of components. As a result it often leads to waste of resources as components which are still working fine are unnecessarily maintained or replaced. Furthermore, scheduled maintenance needs a lot spare parts and maintenance personnel and it is still unable to prevent all the failures (Bivona 2005).

Condition based maintenance tasks are performed only when potential incipient failures have been detected. In addition to its tendency to decrease the probability of total failure, it strives to minimize the waste of resources too. Nevertheless, predicting the failure of a component is difficult. In fact, it is applicable only to some types of failures. Furthermore, certain failures, such as software bugs, cannot be predicted at all.

The Modeling Process

Problem articulation

The main interest was to understand the business of the service provider's customer and especially the processes directly connected with maintenance. The secondary goal was to understand three maintenance related services and their value to the customer and to the service provider. Giving pure predictions of the value was not the goal but to give guidance to robust policies and locating critical factors considering the service system. In this paper we concentrate on the customer's added value. We focus on the following problem areas:

- What is the added value of services?
    - What is the estimated monetary value?
    - Can we estimate the value of reducing certain risks?
- What are the most critical factors in creating the value for both customer and the service provider?
- What kind of behavior can be expected in short and long run when the services are introduced?

- When the desirable effects of services can be seen?
- Are the chosen policies sensitive to assumptions made in modeling process or to assumptions made in policy formulation?
- Are the formulated policies sensitive to changing external factors?

Background

The model presented in this paper is based on the publicly funded generic maintenance model (documented in detail in Jokinen 2007 and Jokinen and Ylén 2007). The model was built in cooperation with several companies and does not represent any specific process plant. Quite the opposite, it was tuned with data from several plants in order to make the generic model suitable for wide range of applications. The main purpose of the model was to facilitate formulating robust maintenance strategies. The model describes the dependencies between equipment condition, maintenance, spare parts, workforce, production, reputation as a reliable supplier, and finances in a production plant. The idea was to build a model that can be easily modified and tuned to more specific purposes.

The generic model was used as a starting point for building more specific detailed models such as the model presented in this paper. Afterwards, the model has been modified and re-tuned to represent the maintenance of a pulp and paper mill. The purpose of the new model is to facilitate understanding and evaluate service system consisting of a customer, a service provider and a set of specific services. The idea is that the model could enable better communication between customers and service provider. Furthermore, the model assists understanding the added value of maintenance services.

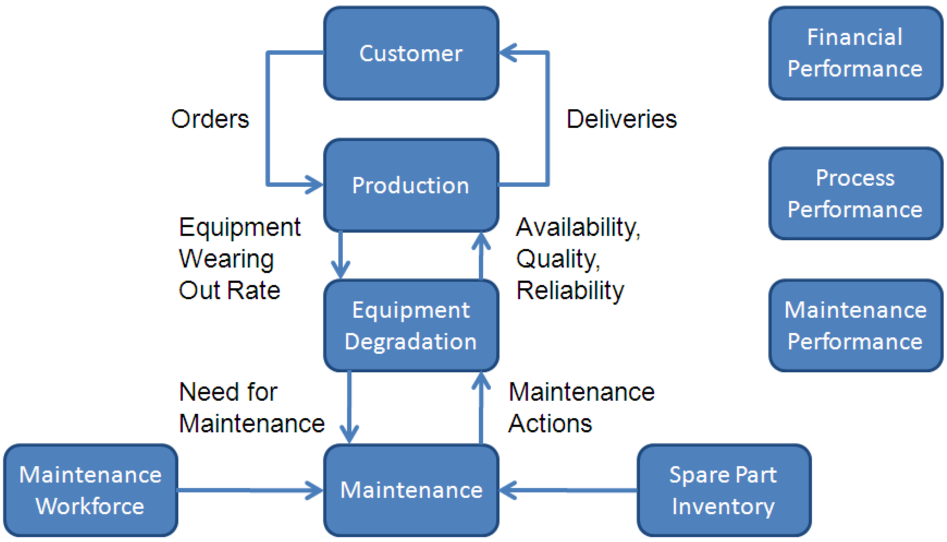


Figure 1: The original model consists of several modules

Originally, the model included four general maintenance policies: run-to-failure, scheduled maintenance, condition based maintenance by periodic inspections, and condition based maintenance by automatic condition monitoring. Afterwards, three specific maintenance services were added to the model, namely, spare part inventory service, field device monitoring service, and control loop monitoring service.

The Inventory management service is tailored for each customer, so the content of the service varies based on the customer's needs. Typically, the Inventory Management Services for pulp and paper customers include full scale inventory management, in which the service provider takes care and manages the spare part inventory. The service makes it possible to keep the inventories at significantly lower level due to the ability of the service provider to assemble the modular components for specific purposes from a set of modules. Lowering the spare part inventory levels reduces directly the inventory costs.

Field device monitoring service is in essence same as automatic condition monitoring of valves. It enables sophisticated early failure detection for valves, which in turn strengthens predictive maintenance. As the accuracy of predictive maintenance improves, total failure rate of valves decreases which leads to higher equipment availability and less corrective maintenance as well. Additionally, improved predictive maintenance decreases the need for scheduled maintenance, which in turn lowers the total maintenance costs since the components are overhauled or replaced only when needed. Of course, the condition based maintenance generates costs as well, but when it is applied to the most critical valves the benefits tend to be higher than the costs. Figure 2 explains the effects of field device monitoring service.

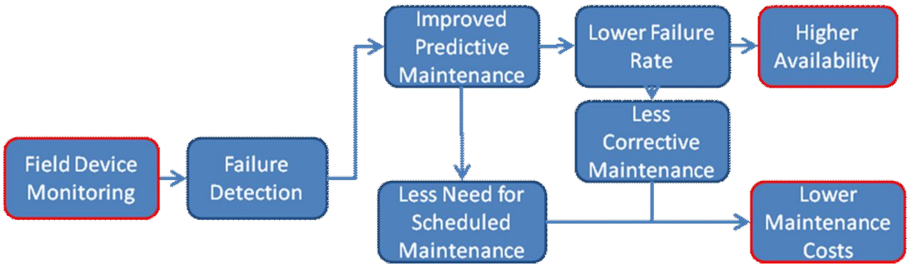


Figure 2: The effects of field device monitoring service

The aim of a control loop monitoring service is to find out problematic loops from the process and report them in order to achieve high control performance. As with field device monitoring service this service also enables early failure detection which in turn leads to improved predictive maintenance and higher availability. Loop monitoring service includes guidelines for better operation policies which can extend the lifetime of the production equipment substantially. Furthermore, it facilitates improved process control which in turn improves quality rate and extends lifetime of the production equipment as well. Figure 3 explains the effects of loop monitoring service.

With a high control performance the customer will achieve the following benefits in the long term:

- more accurate product quality
- improved production availability
- lower production and maintenance costs

- lower environmental emissions
- improved safety

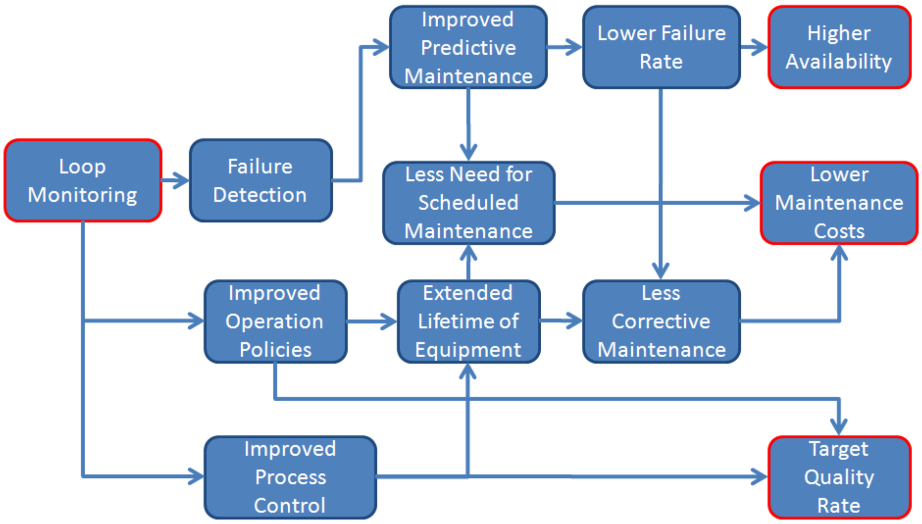


Figure 3: The effects of loop monitoring service

As it can be seen in Figures 2 and 3, the services as such are quite complex. But in order to fully understand the added value of the services they have to be studied as part of a complex dynamic process. Highly simplified and reduced causal diagram of this process is presented in Figure 4.

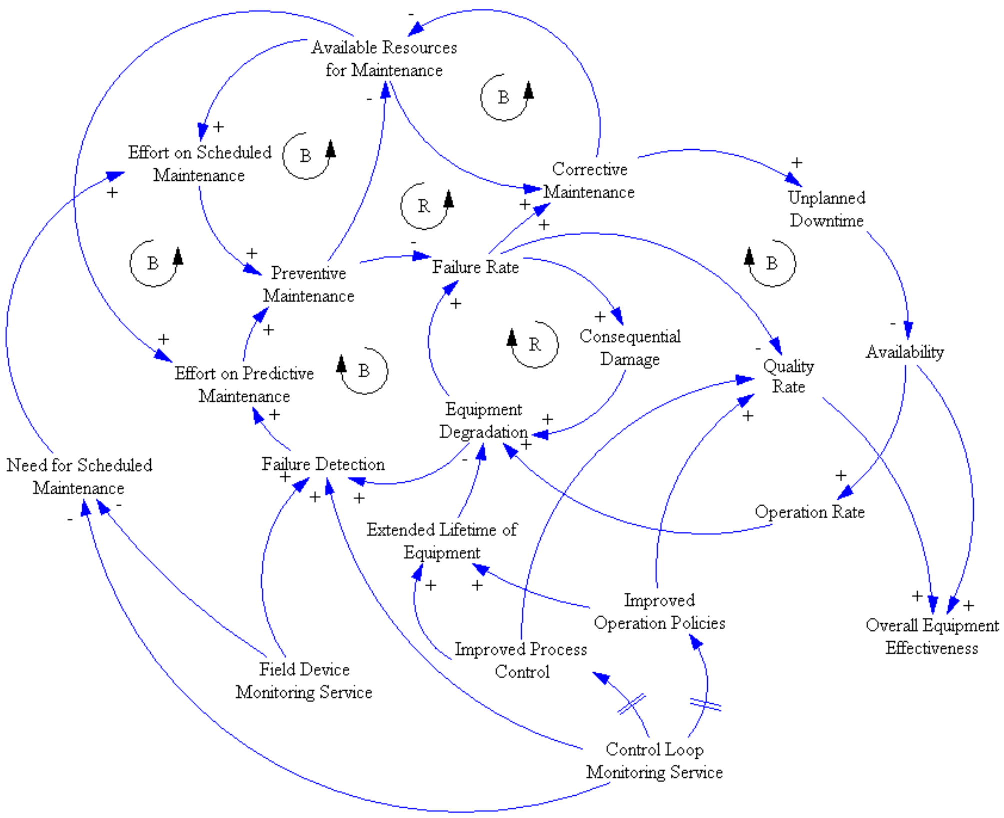


Figure 4: Highly simplified causal diagram of service system. The service provider has been removed from the diagram.

Model Description

The process plant has been modeled from the maintenance management point of view and therefore the maintenance activity is modeled in great detail. The rest of the organization has been described in lower resolution in a way that the essential feedbacks and the indirect costs of maintenance have been taken into consideration.

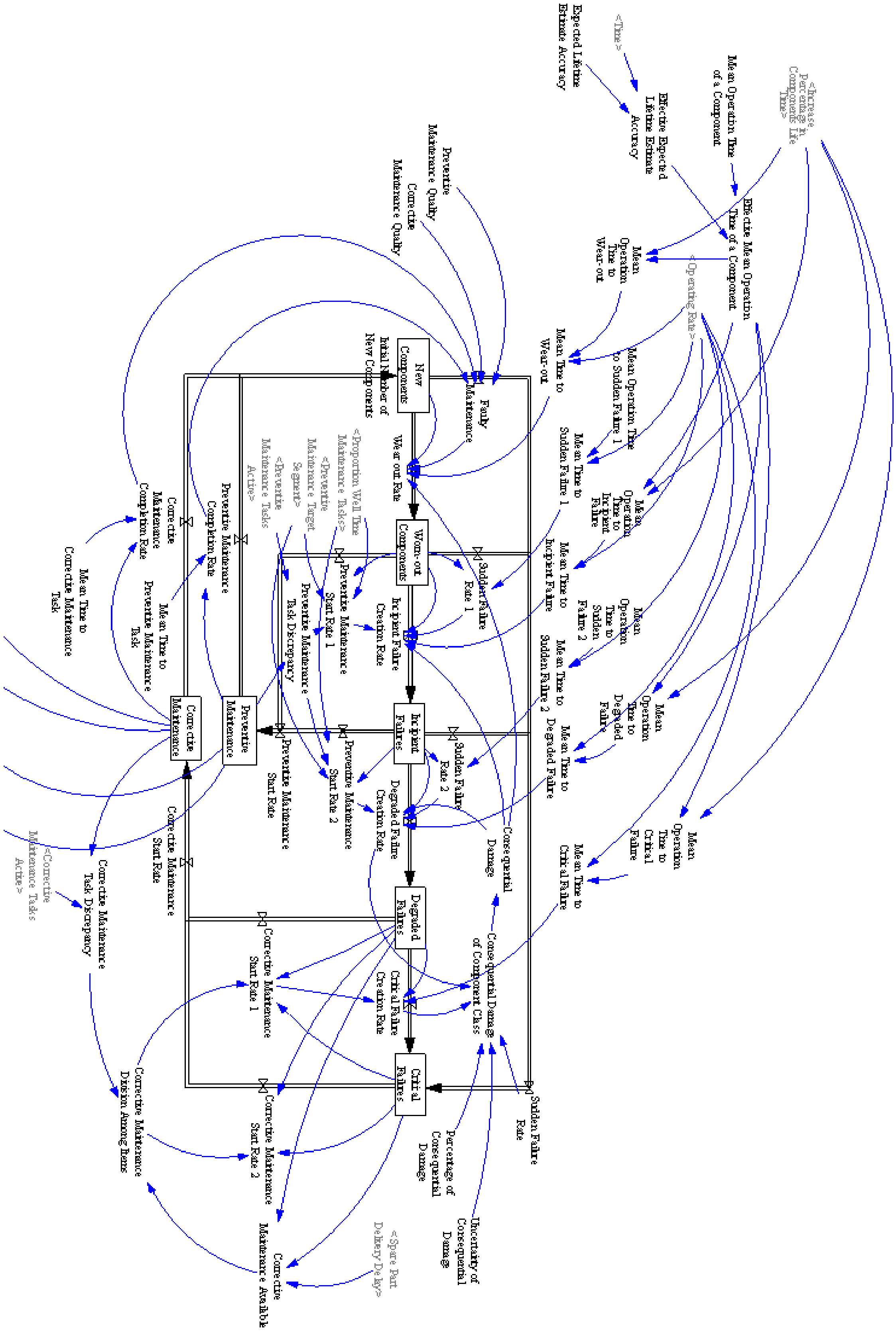


Figure 5: Component degradation and maintenance module

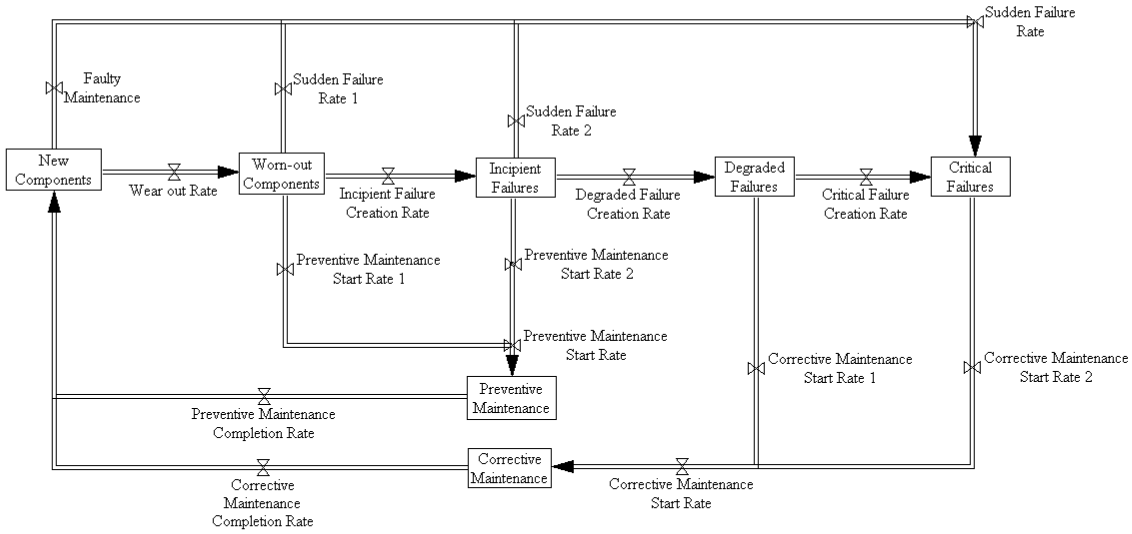
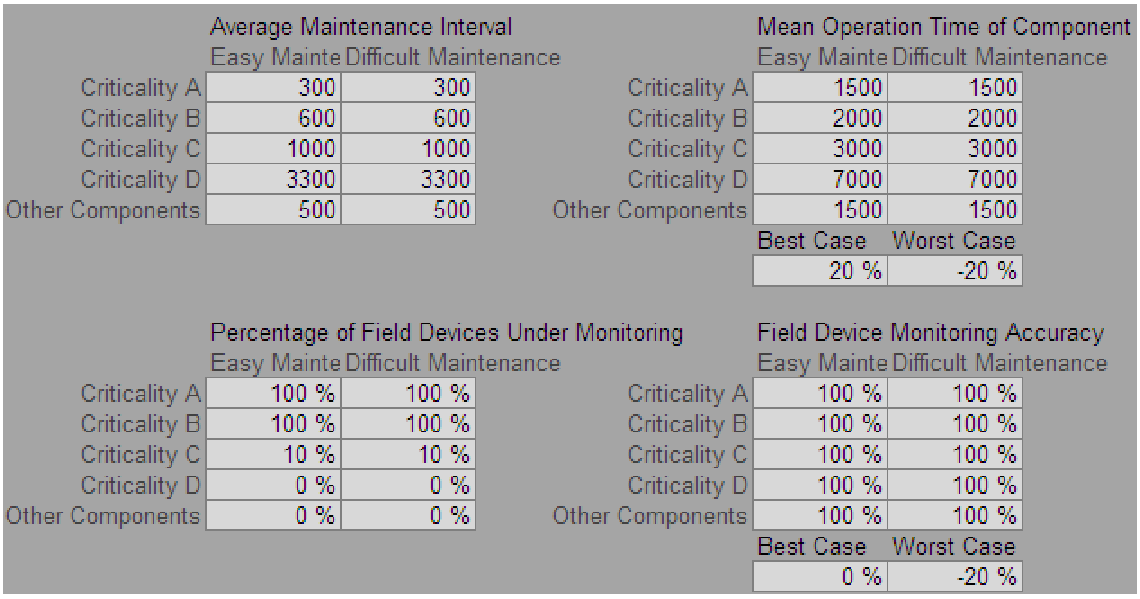


Figure 6: Stock and flow diagram of component degradation and maintenance

The model consists of several modules: production equipment degradation, maintenance policies, spare part inventory, workforce, production process, reputation as a reliable supplier, and finances. The production equipment degradation module (see Figures 5 and 6) describes how equipment wears out and eventually fails. Furthermore, it describes also how the equipment can be fixed by corrective maintenance or preventive maintenance. Workforce module describes the maintenance tasks (i.e. idle, corrective maintenance, preventive maintenance, inspections, and training) to which the workforce can be allocated. Spare part inventory module describes customer's spare part inventory and service provider's spare part inventory service. Maintenance policy module describes different maintenance policies (i.e., corrective maintenance, scheduled maintenance, and condition based maintenance) along with service provider's maintenance services (Field device monitoring service and Loop monitoring service). Production process module is a modified model of Sterman's production model of manufacturing supply chain (Sterman, 2000). Reputation module describes customer's reputation as a reliable supplier and its influence on the product's price. Finances include costs and proceeds as well as some financial performance measures. For more detailed description of the model see Jokinen, Ylén (2007) and Jokinen (2007).

Besides the simulation model, a spreadsheet user interface was built for the end user. With the user interface it is possible to simulate scenarios with different kinds of parameter settings, policies, and uncertainties. It is possible to set parameters for factories of different sizes and ages. Figure 7 shows a set of example parameters. The idea is that the model could easily be re-tuned for different kinds of customers. Figure 8 shows parameters for introduction times of the services and different uncertainties that can be varied. The uncertainties concern different parameter values (see Figure 7 Field Device Monitoring Accuracy or Figure 8 Expected Lifetime Estimate Accuracy for example).



	Average Maintenance Interval	
	Easy Mainte	Difficult Maintenance
Criticality A	300	300
Criticality B	600	600
Criticality C	1000	1000
Criticality D	3300	3300
Other Components	500	500

	Mean Operation Time of Component	
	Easy Mainte	Difficult Maintenance
Criticality A	1500	1500
Criticality B	2000	2000
Criticality C	3000	3000
Criticality D	7000	7000
Other Components	1500	1500
	Best Case	Worst Case
	20 %	-20 %

	Percentage of Field Devices Under Monitoring	
	Easy Mainte	Difficult Maintenance
Criticality A	100 %	100 %
Criticality B	100 %	100 %
Criticality C	10 %	10 %
Criticality D	0 %	0 %
Other Components	0 %	0 %

	Field Device Monitoring Accuracy	
	Easy Mainte	Difficult Maintenance
Criticality A	100 %	100 %
Criticality B	100 %	100 %
Criticality C	100 %	100 %
Criticality D	100 %	100 %
Other Components	100 %	100 %
	Best Case	Worst Case
	0 %	-20 %

Figure 7: Example set of parameters for components in different criticality classes and maintainability classes

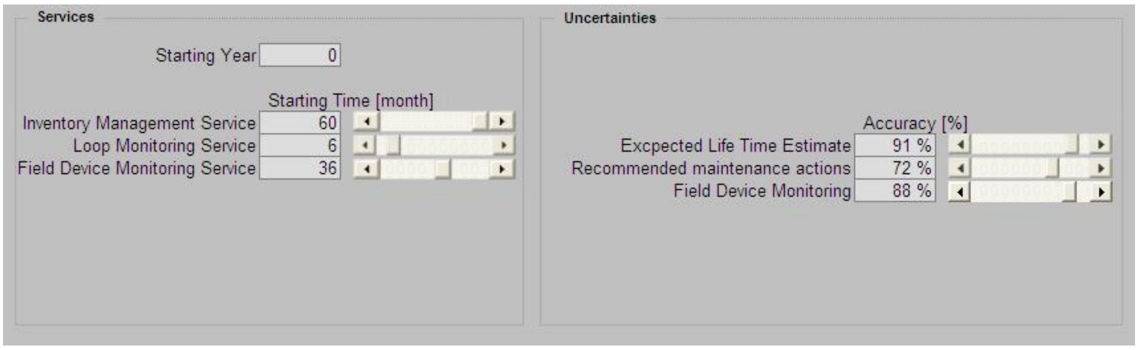


Figure 8: Parameter settings for introduction times for different services and different uncertainties

Simulations

The model is used to simulate customer's maintenance policies (i.e. run-to-failure, scheduled maintenance, automatic condition monitoring) and service provider's services (i.e., Spare part inventory service, Field device monitoring service, Loop monitoring service) and their effects on the system's behavior. The simulation time is 5 years. Example simulation (in which Loop monitoring service has been introduced at 6 months and Field device monitoring service at 36 months see Figure 8) in Figure 9 shows the maintenance cost reductions and in Figure 10 shows improving production process performance. Upper left graph of Figure 9 shows the situation in terms of maintenance costs per produced ton in which it is possible to see the "worse-before-better-behavior" whenever service is adopted.

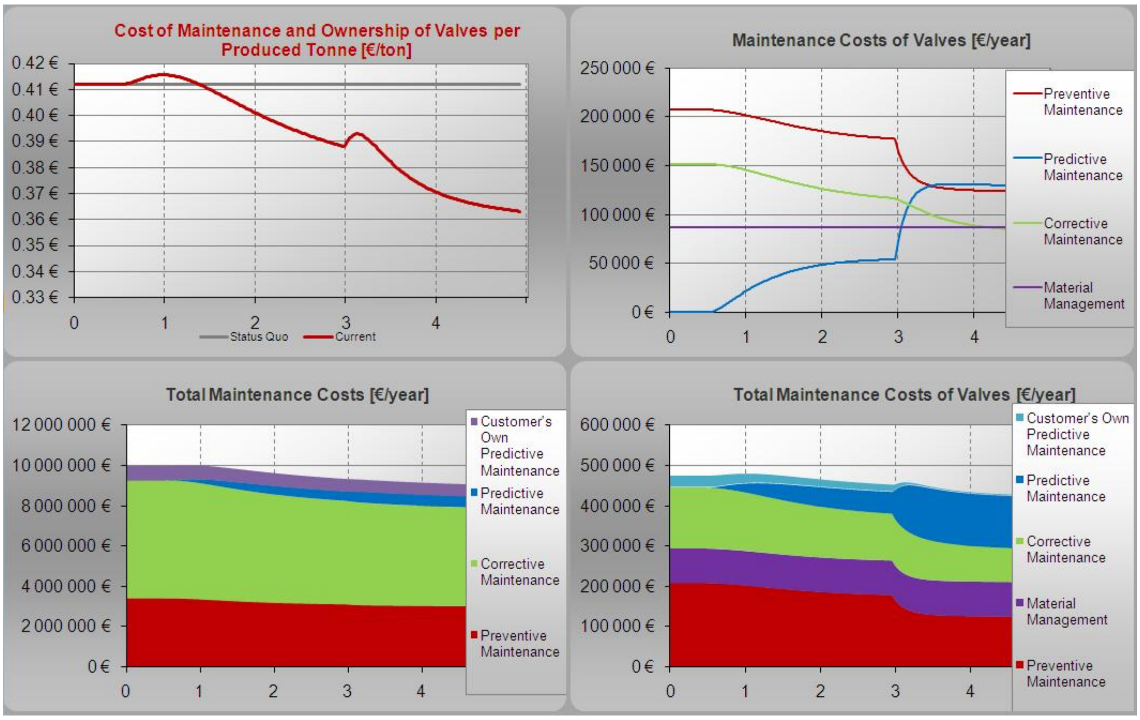


Figure 9: Maintenance costs of example simulation

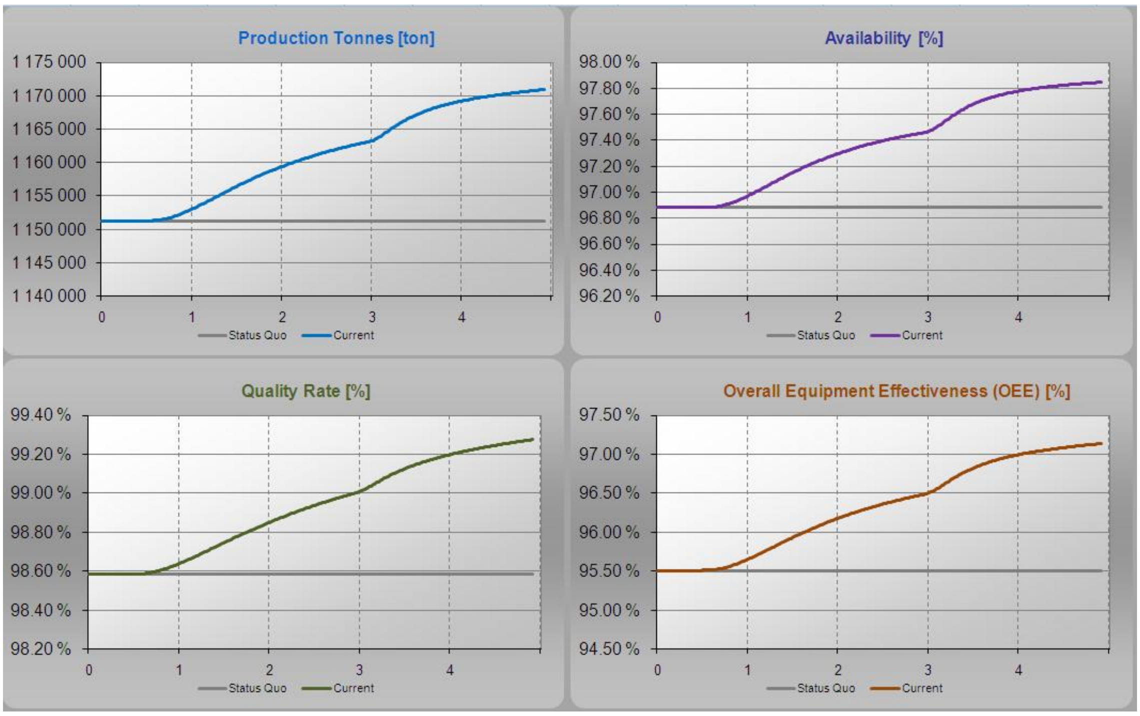


Figure 10: Production performance measures of example simulation

Moreover, we simulated the combined effects Field device monitoring service and Loop monitoring service where both services have been introduced simultaneously at time 0. The results can be seen in Figures 11 and 12. As can be seen in the lower left graph in

Figure 11 the total maintenance cost reduction is significant in the long run. The Figure 12 shows the improvement of production process performance measures.

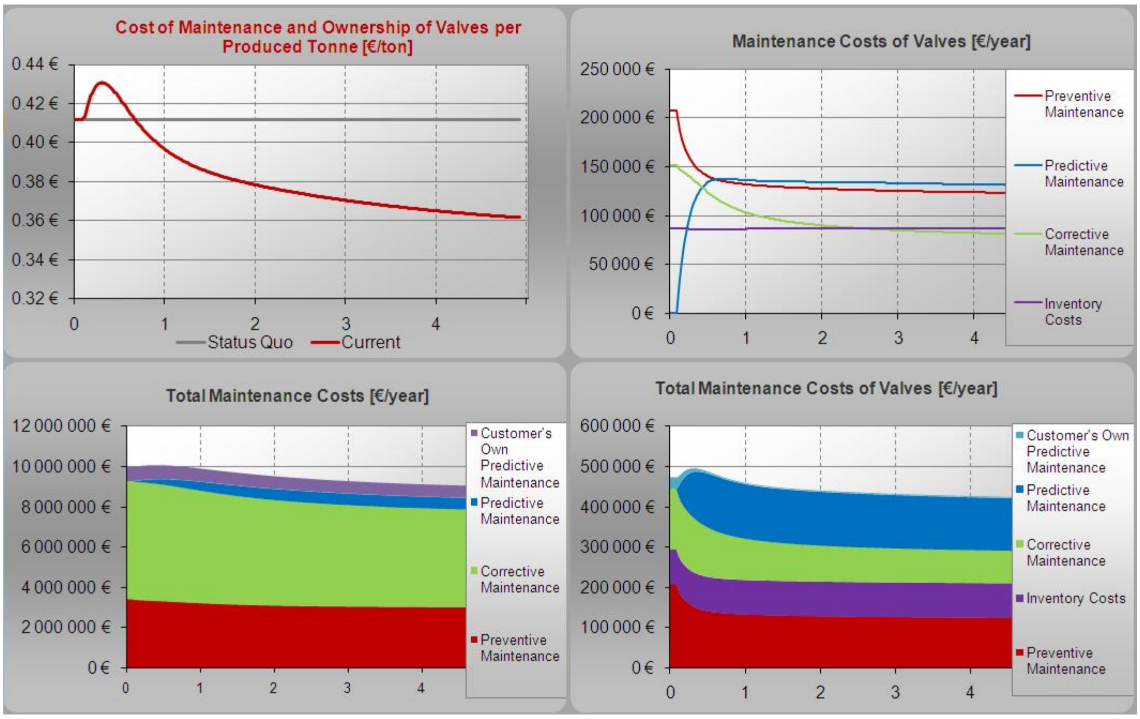


Figure 11: The combined effects of Control loop monitoring service and Field device monitoring service on maintenance costs

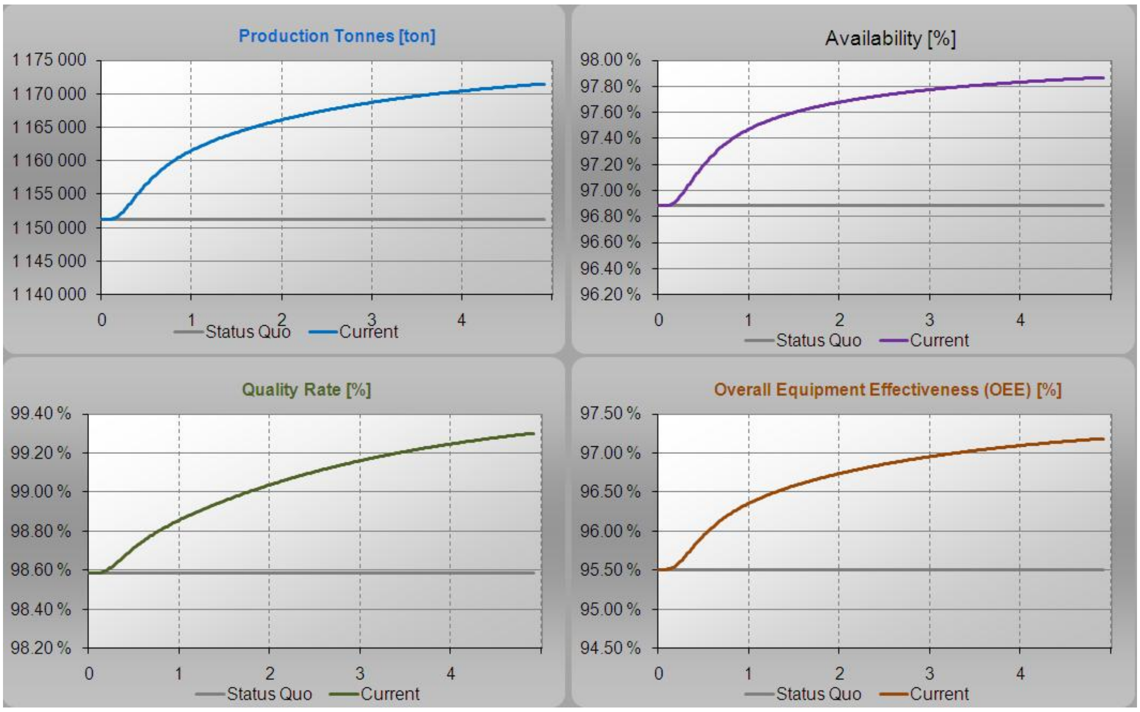


Figure 12: The combined effects of Control loop monitoring service and Field device monitoring service on production process performance measures

We simulated the introduction of Inventory management service as well. The effects of inventory management service on inventory costs can be seen in Figure 13. In the beginning of the simulation customer takes care of its own spare part stock. Then, after six months, the Inventory management service of valves is introduced. After that the customer does not have to pay for facilities or the costs of stock keeping. Furthermore, the capital expenditure shrinks as the desired inventory level is reached.

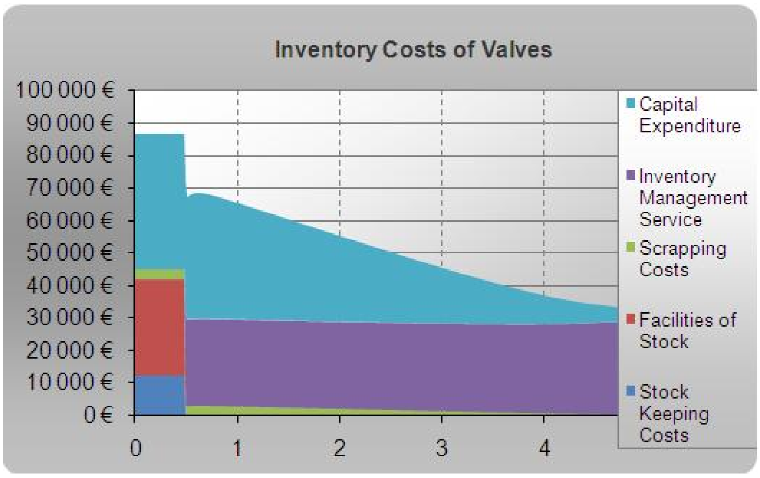


Figure 13: Spare part inventory management costs of valves after the introduction of Inventory management service

Finally, we ran sensitivity simulations by varying several uncertain and critical parameters. The example sensitivity simulation results can be seen in Figures 14 and 15. In this case the varying variables were the accuracy of estimated lifetime of components and the effect of consequential damage due to a component failure. In the left graphs of both Figures no services have been introduced and in the right graphs of Figures Field Device Monitoring service and Loop Monitoring service have been introduced. In Figures 14 and 15 it is possible to see slight reduction in the variance of availability and cumulative sales margin when services are at work. The results suggest that the services may improve the robustness of maintenance policies.

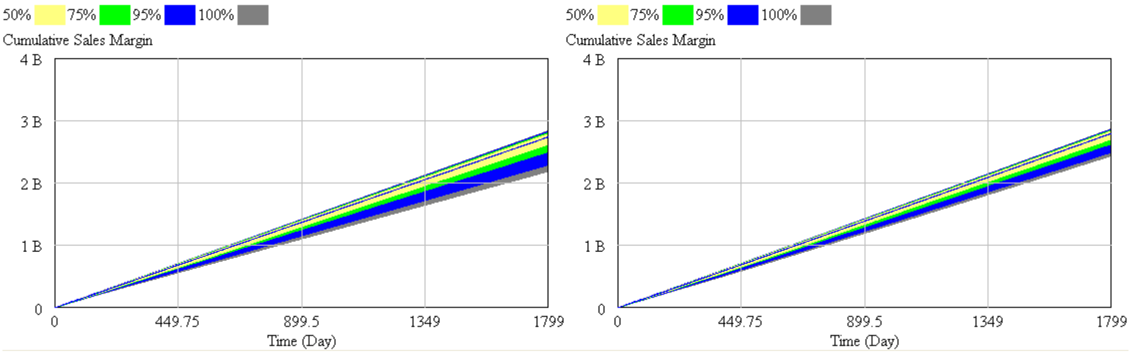


Figure 14: Sensitivity simulations for cumulative sales margin (in the left graph no services have been introduced and in the right graph Field Device Monitoring service and Loop monitoring service have been introduced)

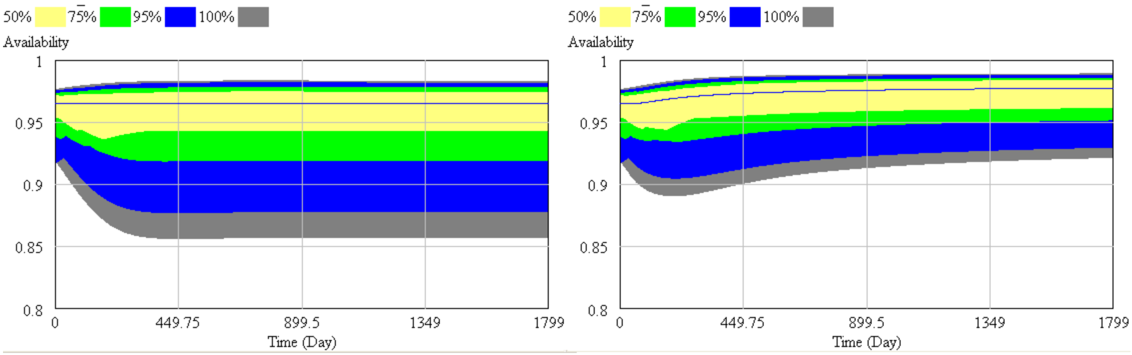


Figure 15: Sensitivity simulations for availability (in the left graph no services have been introduced and in the right graph Field Device Monitoring service and Loop Monitoring service have been introduced)

Conclusions

Maintenance is an inseparable part of large and complex system. The complexity arises from the interactions between maintenance and operative, tactical and strategic processes of the system; time delays between causes and effects; along with nonlinearities. Therefore, evaluating maintenance services is a challenging task.

System dynamic modeling was used to facilitate understanding the service system consisting of a customer, a service provider, and three industrial services. The model assists in communication and enables shared view of the system. The initial purpose of the model was to understand more customer's business and especially processes directly connected to maintenance. The secondary purpose of the model is to serve as a service sales tool of the service provider. Moreover, it can be useful in value based pricing since it helps assessing the added value of services. Giving pure predictions of the added value, however, can be dangerous as they are unreliable due to myriad uncertainties and inaccuracies. Instead of giving mere predictions the model can be used to identify robust policies and locating critical areas of the system. Locating the most sensitive parameters and variables can be very educational.

Currently, there is an ongoing research project in which these tools are developed further. The models are simulated with a system dynamic tool built on Simantics platform using OpenModelica as a simulation engine to study service systems with modularized models.

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