Maintenance logistics in the Dutch Dredging Industry\textsuperscript{1}

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Abstract - This paper explores the benefits of supply chain collaboration in the dredging industry. More specifically, it looks at maintenance management in the dredging industry and the logistic consequences of different maintenance policies. The research uses a simulation model of a clearly identifiable component in a dredging vessel and the related spare parts supply chain. Various maintenance policies, such as predictive maintenance and condition based monitoring are analysed for their impact on the spare part supply chain in terms of stock keeping, order fulfilment and productivity of the dredging vessel. The model shows that both parties could indeed benefit from more collaboration as this would result in reduced costs and increased production output.

Index terms – dredging industry, maintenance management, spare parts logistics

I. INTRODUCTION

The dredging industry is a highly capital intensive industry where the productivity of the assets is the number one priority in daily operations. As a result, maintenance activities are often seen as a nuisance that prevents the ship from achieving full productivity. On the other hand, operating the ship in less than perfect state also subtracts from full productivity. Dredging operators have to find the optimum between continuous operation and pro-active maintenance.

There is little insight in the dredging industry at the moment where this optimum may be, and what is the best maintenance policy over the life time of the ship. Some dredgers have a policy of monitoring the deterioration of critical components, but the knowledge and time to perform and evaluate these measurements is slipping away due to increasing pressure on productivity and crew costs.

This paper describes one of the results from a long running project that aims to develop collaborative solutions for this and other related problems in the dredging industry. While the dredging companies seem to be the problem owner, their main suppliers are also subject to adverse effects of reactive maintenance policies and last minute spare part ordering. In fact, this is a classic case of the well known bull whip effect in supply chains; see for instance Lee et al. (1997). As a result, the problems have to be addressed in an integrated fashion, and solutions will result from collaborative efforts.

While this problem has presented itself years ago, no successful efforts in terms of supply chain cooperation have yet been developed in the dredging industry. One of the main reasons for this is the lack of relevant information and insights, and the unwillingness to share information with supply chain partners for fear of revealing their competitive position. Some type of wear and tear information could be translated back into different types of soil, and the latter information is considered extremely sensitive for competitiveness.

On the other hand, the suppliers, especially the main supplier of newbuildings and major spare parts has built up extensive know-how and experience through the fabrication of thousands of dredgers. This single company serves 50% of the world dredging market. Challenged with fierce competition in the production of capital goods in the dredging industry, the supplier is extending the delivery of products and spare parts with the delivery of services, such as planning and preparing dock maintenance projects, and has recently set up two local service centers in areas where most of the current dredging activities take place. This company has information that could also greatly benefit dredging companies in their day to day operations and their maintenance and repair activities.

This paper will first give a brief overview of the relevant maintenance literature. Then we introduce the modeling approach. Thirdly, we describe the specific case that was analyzed, and we present the main results. The paper closes with concluding remarks and suggestions for further research.

II. LITERATURE REVIEW

There is a substantial body of literature on maintenance management, supply chain collaboration and spare part logistics. This section gives a brief overview only.

A. Maintenance theories

Waeyenbergh and Pintelon (2002) discuss the history of maintenance concepts by illustrating a movement from maintenance as a "necessary evil" to maintenance as a potential profit contributor. Recent developments in several manufacturing industries (copiers and elevators are early examples) indicate that products are accompanied by services that do not only persist during the full lifecycle of a product, but in addition involve several business functions and parties in the supply chain. In cases when the customer is actively involved in the operation and maintenance of the product, supply chain partnerships enable knowledge sharing and further development of the assets at hand. By delivering functionality instead of a physical product, the customer may be triggered to outsource part of its functions to the supplier, such as asset maintenance, personnel training, and even operation, upstream the supply chain. In all cases, there is a shift in supplier revenues from product sales to services. Besides these developments, maintenance concepts have improved considerably.

Indeed, there is a shift from failure based maintenance to use based and increasingly towards condition-based
maintenance. This enables service contracting based on performance guarantees instead of reactive repair billing. According to Bin Jabar (2003), the most common maintenance strategies are these four: (1) Breakdown/Corrective Maintenance is totally failure based which means that it reacts only when a part/equipment needs to be repaired/replaced. (2) Preventive Maintenance is a time-based maintenance strategy where on a pre-determined periodic basis, equipment is taken off-line, opened up and inspected. (3) Predictive Maintenance is based on continuously measuring the condition of the equipment in order to assess whether equipment will fail during the coming period, and then taking action to avoid the consequences of those failures. (4) Pro-active Maintenance concentrates on the monitoring and correction of root causes to equipment failures. The proactive maintenance strategy is also designed to extend the life-cycle of the equipment.

B. Spare parts inventory theories

According to the review of Kennedy et al. (2002), spare parts inventories differ in several ways from other manufacturing inventories. Firstly, the functions are different. Work-in-progress (WIP) inventories are used to smooth out irregularities in the production flow. These irregularities can be caused by equipment breakdowns, different production rates between processes, material handling etc. Finished products inventories on the other hand, exist to protect deliveries against irregularities in lead time demand, differences in quality levels, scheduling problems, differences between capacity and demand etc. The function of spare parts inventories, however, is to assist a maintenance staff in keeping the equipment in operating condition. Secondly, the policies that govern spare parts are different from those of WIP and finished products. WIP and finished products inventories can for instance be changed to reduce order lead time, increase serviceability, quality etc. Spare parts inventory policies are determined by the use and maintenance of equipment. Cohen and Lee (1990) recognize the importance of an after-sales service strategy as a key ingredient of product quality and consequently competitive success. They describe the structure and performance goals of a service parts distribution network. In addition, they look into inventory control policies, systems technologies and cost-service trade-offs. Cohen et al. (1997) presented a benchmark analysis of service parts logistics for technologically complex high-value products, i.e. the computer industry and an earth moving company.

Huiskonen (2001) states that four elements are to be taken into account for the design of any logistics system. These elements are basically similar to the aspects researched by Cohen et al. (1997). These elements are: the strategy/policies/processes (1). This element describes for example what service levels are to be delivered and whether there are differences per customer segment. The network structure (2) defines the number of inventory echelons and locations used in the system. Cooperation between suppliers and customers play a role here. For instance, management practices such as vendor managed inventory or just-in-time, which are based on cooperative use of other party’s facilities and/or resources, can be considered. Element three is supply chain relationships (3) and focuses on aspects such as degree of cooperation, sharing of risks, as well as responsibility control. The final element is coordination control (4) which entails for instance decisions about inventory principles, performance measures and information systems used. Collaboration between the customer, supplier and other parties is needed while designing the system and the importance of open information sharing is crucial for managing the inter-company supply chain effectively (Huiskonen, 2001). This underlines the importance of collaboration with other supply chain parties such as suppliers.

C. Supply chain collaboration

Collaboration in supply chains has been widely discussed and a wealth of literature is available. Projects such as efficient consumer response (ECR), vendor managed inventory (VMI) and collaborative planning, forecasting and replenishment (CPFR) are examples of strategies which can be used to collaborate amongst supply chain actors. Holweg et al. (2005) have analyzed instances of supply chain collaboration within multiple industries such as the automotive, electronics and construction sectors, and retail. They propose a very intuitive water tank analogy representing inventory and ordering policies in the system. They use this analogy to discuss the four basic supply chain configurations that they encountered in practice, ranging from a traditional supply chain to a supply chain where both demand visibility and decision-making responsibility is shared with suppliers. The configurations are distinguished by the different inventory control and planning collaboration policies.

III. APPROACH

The problems in the dredging supply chain were analyzed by using the case study method which is widely discussed by for instance Yin (2003). The concepts found in the literature study are combined with the problems analyzed in the case study and are studied in a simulation model. This model reflects the operations of a single set of components of a dredging vessel namely gate valves and the resulting spare part supply chain. Valves are not a critical component, which made it possible to engage in the discussions about information sharing in a neutral manner. Since no data on wear and tear were available in maintenance systems, data for the simulation model has been gathered through expert
opinions. Different maintenance concepts were analyzed in terms of their logistic and operational impact.

The simulation is done with a discrete-event simulation package called Arena Simulation Software. The system is modeled as a terminating system, based on the 20 years lifetime of a dredging vessel.

A. The dredging company

The dredging industry is a global, very competitive, and capital intensive industry. The main activity of dredging is moving sand. There are basically two performance indicators, namely number of operational hours and number of dredged cubic meters within those operational hours. The production speed is enormous and increases when the vessels become larger. Every minute counts and down-time is a killer for productivity. A typical ship is operational 160 hours a week for 45 weeks a year, producing at almost 100%. The dredger sustains its leading market position by pursuing training of competent personnel, fleet innovations and fleet rationalization, improvements in business processes and processing technologies, and the development and optimization of modern ICT systems.

There are some issues that threaten the dredgers’ leading market position. First of all, the dredger is losing the onboard knowledge needed for proper maintenance of the vessels. Furthermore, due to several acquisitions, maintenance policies throughout the fleet have become scattered.

At the moment, the dredger is not able to monitor the condition of the valves continuously. The components of the valves which are subject to wear and tear are the knives, houses and rings. However, the condition of the valves is mostly determined by the thickness of the pipes. This is measured at every inspection and gives an indication of the condition of the valves. This process is dependent on the knowledge and experience of the crew on the ship. Besides this, there are also valves which are located under water. The actual condition of these valves can only be determined when the vessel is put into a dry dock.

A maintenance plan is scheduled and is based on inspection reports, current inventory level, and expected consumption of spare parts and future moments of maintenance. The maintenance plan assigns which maintenance is to be done during which moment of maintenance.

B. The supplier

The supplier is the builder of the four dredgers in this case and delivers after sales service for these dredgers. The business unit Parts & Services is responsible for the delivery of spare parts that are necessary for the maintenance of the dredger. Parts & Services can offer additional services, such as supervision during a docking, which is necessary as the regular shipyards do not have the required knowledge to maintain special equipment.

Parts & Services are not structurally involved in the maintenance management of the dredgers. They are also not aware of the maintenance done on the dredgers themselves. Parts & Services are therefore confronted with ad hoc demands for spare parts.

C. The supply chain

The supply chain structure for the dredging industry is laid out in Figure 1. The figure puts emphasis on the various possible inventory points in the chain. These are marked with numbers 1 to 5.

![Supply chain overview](image)

**Figure 1. Supply chain overview**

*Numbers indicate storage locations; C = components, EP = End Product*

The supply chain response in this case depends on several factors: demand predictability, order process times, production lead times, transportation times, stock keeping points and their inventory levels. Total response time can amount to 15 to 17 weeks, although quicker throughput times are possible in emergency situations. The production lead times and inventory levels are a consequence of certain product characteristics (Huiskonen, 2001). These characteristics are low/average demand, average inventory holding costs, specificity and average criticality. The transportation times are more or less constant and depend on service agreements with third party logistics service providers.
D. Inventory and Order Policies

The dredgers maintain a spare part inventory on board of the ships of around 30% of the valves. This level differs according to the type of soil which is dredged.

Most of the components for the gate valves are special components designed by the dredger, which precludes risk pooling among several customers. As a result, demand for these parts is fulfilled make-to-order and this increases the total lead time (from placing the order until delivery on the vessel).

IV. Model Setup

A dredging vessel contains many different valves, but the current study has focused on the 5 valves that are the most critical for a high performance operation. The valves are not so critical that the ship will suffer from serious productivity loss in case a valve stops working. The most sensitive part in the valve is the rubber ring that connects the valve blade to the valve casing. The deterioration process is modeled in three different deterioration scenarios: base, average, and extreme deterioration.

A. Maintenance

Three different maintenance strategies are considered: reactive, preventive, and predictive maintenance. Replacement of the valve rings is done when the 5 rings have reached the critical status of 70%. With preventive maintenance this critical level is 80%. With predictive maintenance, the condition of the rings is monitored and future wear can be predicted so that parts can be ordered in advance.

B. Inventory

There are two different supply chain structures. The first represents the delivery from The Netherlands to the dredging location in Singapore. The rings are stored on board of the vessel. The second represents the situation where there are two inventory points: one on the vessel and one at the service centre in Singapore. Thus, the component is made-to-stock instead of made-to-order. This scenario has a large impact on the order lead time: the lead time is reduced by ± 125 days. Furthermore, the inventory policies at the service centre are not taken into account. It is assumed there is always inventory present.

C. Collaboration

Apart from the different supply chain structures, the model also considers two different lead times within the same supply chain structure. The first represents the present situation with all the existing steps resulting in a lead time of 155 days. The second represents a shorter lead time due to a standardized order process where redundant steps are removed from the process.

This leads to 36 possible scenarios by combining the different possibilities. The most important outcomes are analyzed and discussed below.

V. Model Outcomes

The model outcomes are based on 10 replications per scenario of vessel's life time of 7335 days. The selection procedure of best scenario(s) is based on statistical theory developed by Nelson et al (2001). The model results can be found in Table 1 below.

The analysis of the scenarios shows a few things. First of all, there is a clear reduction of redundant wear costs (due to additional damage to valve casings) when more replacements are made. These replacements, however, lead to additional costs of spare parts that quickly mitigate possible savings in damage or increases in production.

Second, results in the scenarios with extreme deterioration are much clearer and more positive than the base case, where reactive maintenance shows a negative cost and productivity result to begin with. In this set of scenarios, the model shows that predictive maintenance with a short lead time scenario can in fact improve the current situation both in terms of costs and in terms of productivity.

Third, in both cases, the service centre greatly reduces lead times, and thus enhances productivity, but also results in considerable costs.

The central insight in all these observations from the results is that there is a sensitive balance between productivity and maintenance effort in this particular case. More maintenance is better for productivity, but because the component is not very critical, the productivity gain is not substantial, and quickly offset by the additional maintenance costs.

To evaluate the impact of the criticality of the component, the model was changed to reflect a more critical component. The original model contained the premise (resulting from expert opinion) that when the ring is completely worn a productivity of 90% is still achieved. Alternatively, we consider a hypothetical linear productivity decreases from 100% to 40% for the average status of the five rings. The assumptions in this case result in a much lower productivity in the base case of 96 mln m3 for the average deterioration and 73 mln m3 for the extreme deterioration case, with base case productivity figures of 67% and 52% respectively. As a result, the productivity gains are not much more substantial, and are sufficient to offset the cost increase due to more diligent maintenance.
Still, however, the costs per m³ in all scenarios remain more or less stable. This means that the productivity gains, which in this alternative analysis are substantial, do not result in a higher margin on the m³ of sand dredged.

VI. CONCLUSIONS

The model as developed here shows that having information on wear on tear helps on designing and planning the maintenance activity. Condition based monitoring helps predicting future wear and tear and thus failures can be prevented. Furthermore, the responsiveness of the supply chain can be an important factor in achieving satisfactory productivity levels of the dredging vessel. However, all these improvements come at a cost. In the current case, the efficiency gains in the supply chain and the resulting productivity gains are usually compensated by increasing maintenance costs due to more frequent replacement of defect parts. We believe that the main reason for this was the choice of the component, which was not very critical for the productivity of the vessel. Alternative analysis shows that for more critical components, more advanced maintenance concepts become more important for maintaining required productivity levels of dredging vessels.

Further research could extend the model for use with more critical components and sudden breakdowns. Furthermore, more research on order costs and redundant wear costs would improve the model's reliability and validity.

VII. REFERENCES


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