INFORMATION FUSION IN MAINTENANCE PLANNING

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Abstract: Industrial production service organisations, companies maintaining production machines and whole processes as well as factories, are in great demand of productivity and profitability improvement. Usually performance in these organisations arises from high utilization of personnel, superior engineering knowledge and purchasing expertise/power. However, small and medium sized maintenance service providers mostly differate themselves with two first mentioned items. In this paper we will propose information fusion cockpit to be used in the SME maintenance organisation to enhance problem solving, demand visibility and resource need estimates – hopefully this will enhance the performance of a case organisation. As a key input variable to manage large amount of different customers we identify incoming calls to trigger information collection from vast number of different databases – the integration of this incoming “demand” is the first step to be taken in the use of more advanced systems. We also speculate in this paper, how agent based artificial intelligence could be used in order to take full benefit from more advanced system.

Keywords: Maintenance management, services, information fusion and agent-based modelling

1. INTRODUCTION TO PROBLEM

Production supporting and maintenance focused companies are subject to a rapidly changing business environment strongly influenced by the Forrester Effect of non-stock production (service business context Akkermans & Vos 2003), and as research has shown information is vital in avoiding up- and downswings in resource needs. Additionally, these types of companies are essentially service-based (operations management challenges, please see Johnston 1994, key improvement areas are shown in Lai et al. 2001), their operations need to be wellbalanced in terms of utilization rate of resources (hours billed divided by hours worked) versus service rate towards customers. The maintenance is either preventive, conditional, or corrective (emergency) maintenance (Waeyenbergh and Pintelon, 2002; Garg and Deshmukh, 2006), and one important aspect is to keep a balance between maintenance cost and the up-time of the production systems. If the demand is highly volatile this can have strong implications on the maintenance; since it can force a very high output level close (or past) the limits of the production system. The combination of information gathered more traditionally at a machine (or component) level with information on a coming increase (or decrease) in output can have a major impact on the maintenance planning. However, as Komonen (2002) has shown with regression analysis that e.g. the higher the integration of different machines in production process, the lower are the maintenance costs; oppositely shift work-rate was identified in his research as increasing factor in maintenance cost.

This article focuses on maintenance providers whose business focus is to provide a mixture of maintenance services to a variety of customers. The main
resources are skilled personnel, e.g. technicians, engineers etc. The problem of maintenance management in a service organisation is even more complex since it can be even more difficult to gather reliable information from non-associated plants and production systems. These customers can have long-term contracts for pre-emptive maintenance, but perhaps more often require very rapid emergency maintenance assistance.

The objective of our research work in general is to identify how information fusion can advance decision making and improve the performance of the operation of service-related maintenance. Specifically the use of Agent-Based Modelling (ABM) is studied in a service-related maintenance organisation, both for modelling and simulation, as well as for data mining applications. This means to model a real-life organisation, its flow of information, material, and activities, for evaluation purposes, and suggest and evaluate alternative approaches using the ABM approach. Our research problem could be described with following two questions: (1) What are or which is the key sensor(s) in the maintenance organisation, which trigger service process, and (2) How and what kind of information sources should be included in the information fusion model to serve decision making and future resource need estimates.

In this paper we identify incoming customer calls (demand) as a key input variable (sensor). Customer calls definitely triggers service process and could also trigger collection of information from number of different databases. The integration of this incoming “demand” is the first step to be taken in the use of information fusion in service-related maintenance planning.

The remainder of this paper is structured as follows: First an introduction to information fusion with relevance to maintenance is made in Section 2, secondly the Agent-Based modeling (ABM) concept is presented in Section 3. In Section 4 preliminary empirical findings from a maintenance service provider industrial case are being presented. Finally in Section 5 we conclude our research work and propose areas for further research.

2. INFORMATION FUSION

Information fusion has a background in the defence sector, but has become more generic and has been introduced to many other areas. Information fusion theory is to some parts based on sensor fusion approaches, where the reliability and large data quantities needs to be fused, and to some parts on data mining, where the problem is to identify and fuse huge amounts of existing data, possibly from several sources. Information fusion encompasses the theory, techniques, and tools conceived and employed for exploiting the synergy in the information acquired from multiple sources – sensors, databases, information gathered by human etc. – such that the resulting decision or action is in some sense better – qualitatively or quantitatively in terms of accuracy, robustness, comprehensibility – than would be possible, if these sources were used individually without such synergy exploitation (Dasarathy, 2001). Some approaches to information fusion also include simulation, which provides of framework of past (databases), present (sensors), and future (simulation) information that can be fused (De vin et al., 2006).

In this paper we consider Information Fusion as the fusion of information from past operations of manufacturing systems (e.g., stored in databases), from the present (e.g., sensor signals, machine status, information gather by humans), and from the future (in particular, predictions obtained through simulations). The fusion of data with purpose of better information for maintenance planning is described by Moore and Starr (2006). Further more DeVin et. al. (2006) describes a generic model for Information Fusion and situations for decision making in a manufacturing environment.

One well known model for IF is the Joint Directors of Laboratories (JDL) model (Llinas et al., 2004), see Figure 1. This model describes a stepwise refinement of information but does not say how this refinement takes place and the model is specific for military applications. The model has five levels, which form a hierarchy of processing. On Level 0, “sub-object pre-processing” is performed, which is an iterative process of fusing data to determine the identity and other attributes of sub-entities (signals, features). On Level 1, “object refinement” is performed, which is an iterative process of fusing data to determine the identity and other attributes of entities (objects). This level also build tracks to represent their behavior. This results in a the situation picture. In Level 2, “situation refinement” is performed, which is an iterative process of fusing spatial and temporal relationships between entities. This results in a situation assessment. On Level 3, “threat refinement” is performed, which is an iterative process of fusing the combined activity and capability of enemy forces to infer their intentions and assess the threat that they pose. The result from this level is called the threat assessment. Level 4 performs “process refinement”, which is an ongoing monitoring and assessment of the fusion process to refine the process itself, including optimization of data acquisition.
An adjacent concept used in the information fusion community is ABM, that can be used specifically for modelling, simulating and evaluating future scenarios.

3. AGENT-BASED MODELING

ABM represents a new paradigm in modelling and simulation of complex and dynamic systems distributed in time and space (Jennings et al., 1998; Lim and Zhang, 2003). Since maintenance operations are characterised by distributed activities as well as decision-making, in both time and in space, and can be regarded as complex, the ABM approach is highly appropriate for these types of systems (Lim and Zhang, 2003).

There is a growing interest in using ABM in several business-related areas, such as manufacturing (Chun et al., 2003; Kotak et al., 2003; Lim and Zhang, 2003) and logistics and supply chain management (Gerber et al., 2003; Kaibara, 2003; Knirsch and Timm, 1999; Santos et al., 2003; Schieritz and Grossler, 2003). ABM is considered important for developing industrial systems (Davidsson and Wernstedt, 2002; Fox et al., 2000; Karageorgos et al., 2003) and it provides a pragmatic approach for the evaluation of management alternatives (Swaminathan et al., 1998).

In ABM the focus is on agents and their relationships with other agents or entities (Axelrod, 1997; Cicirello and Smith, 2004; d’Inverno and Luck, 2001; Jennings et al., 1998). An agent can be defined as a software object which can perform a specific given task and it must typically exhibit three general characteristics: (1) autonomy, (2) adaptation, and (3) cooperation (Chen et al., 1999; Yung and Yang, 1999). Adaptation implies that agents are capable of adapting to the environment, which includes other agents and human users, and can learn from the experience in order to improve themselves in a changing environment. Multi-Agent Systems (MAS) are formed when several agents interact and communicate with each other to achieved some shared goal(s). The agent’s ability to collaborate, coordinate and interact is the most important feature of MAS. By sharing information, knowledge, and tasks among the agents in MAS a collective intelligence may emerge that cannot be derived from the internal mechanism of an individual agent. The authors believe that this is a suitable approach for the complex domain of maintenance and service operations and by ABM for modelling, simulation and analysis, many improvements can be achieved.

4. EMPIRICAL FINDINGS

EuroMaint Industry is an independent service provider within production streamlining and maintenance. Their main focus is to provide products and services for improved productivity and improved reliability. Swedish automotive manufacturing industry is the main market, however, customer also exist outside Sweden as well as in other industries.

EuroMaint Industry’s product and services assortment is divided into four following segments: (1) maintenance, (2) component service, (3) production technology, and (4) production equipment. These segments stretch from small selective solutions to long-term overall solutions and their starting point is the customers existing production systems. Within the maintenance segment they offer consultative and operative maintenance services. Example of operative maintenance services is planned, preventive and emergency maintenance; while efficiency measurements and strategic development is example of consultative maintenance services. Within the component service segment they offer fault-tracing, function test, repairation, quality test, calibration and remanufacturing of components. Within the production technology segment they offer investigations and improvement of customers’ current production systems and correspondingly the production equipment segment they offer development and manufacturing of customer-specific equipment.

EuroMaint Industry has historically been a maintenance department of Volvo. At this time every production shift had a person responsible for receiving and managing all maintenance requests. The difference today is that EuroMaint Industry has a large variety of customers, both internally and externally, which requires a quite different structure.

4.1 The service organisation

Customer calls definitely trigger service process. Therefore it should be regarded as a key input
variable (sensor) for information fusion. In order to really exploit different sensors we have to know how they work, i.e. mapping them and their surroundings.

EuroMaint Industry tries to steer all customer order and inquiries through a Service Central (SC). The SC primary works with orders and inquiries concerning operative maintenance; amount of new customers and ‘one-stop shopping’ has been increasing during previous years. These types of orders stand for a big share of the total amount of orders. However, the SC also answer questions concerning product and service assortment and guide customer in the organisation. Only maintenance coordinators are connected to the SC and customer asking for other services is further guided in the organisation. Earlier were sales people connected to the SC.

Customer order and inquiries concerning other services than operative maintenance go through sales department, who handle customer contact and communicate with different coordinators in the organisation.

EuroMaint Industry also has an outsourced switchboard, which irrespective of what the customer asks for connects to the SC. Fig. 2 summarizes current customer entrance possibilities.

![Fig. 2. Current customer entrances](image)

However, as time goes customer tend to create relations with personnel in the organisation. In other words, customer contact people whom they have a relation with irrespective of their position. This implies that primary and secondary customer entrances exists (Fig. 3).

![Fig. 3. Primary and secondary customer entrances](image)

This leads to that almost every employee has contact with customers and that order entrance occurs at several places in the organisation. It is not clear who should receive customer orders or how the orders should be tied to the product and service assortment. Furthermore, the formal order control is undermined by an informal order control conducted arbitrariness from one person to another. This implies that EuroMaint Industry has little knowledge of their order fulfilment process. For example, how many orders do we receive (on daily, weekly and yearly basis), how many orders have we in pipeline and what is the status of these, how much is respective order worth, when should the orders be delivered or are the order completely delivered? In this situation maintenance planning is very hard, because the lack of this needed information.

4.2 Service process challenges

EuroMaint Industry has identified the order fulfilment process and its management to be one of the most important improvement areas and is currently working on mapping it. They have recognized that there is a need to change the service organisation. They want to steer all orders and inquiries irrespective of type through a Sales and Service Central (SSC) in order to make their organisation more efficient – optimize resource utilization – and more effective – enhance turnover and profits. Essentially it’s about enhancing the planning of maintenance services, which in a recently completed customer questionnaire has been ranked as one of EuroMaint Industry’s most important improvement areas.

EuroMaint Industry is, however, not clear on how the SSC should be structured and managed. One discussed solution is to enlarge the current SC responsibilities in order to create a centralized order entrance handling the entirely product and service assortment. Another discussed solution is to have today’s decentralised structure supported with a software application supporting the coordinators...
when they handle order entrance and customer service (virtual service organisation). An advantage with the decentralized structure is that experts interview the customers and a disadvantage is that it makes resource planning and follow-up more difficult. The decentralized structure is also beneficial, if tactical knowledge can not be transformed into explicit knowledge.

4.3 Possible solutions

Four possible scenarios have been identified as possible solutions for current two-fold situation: (1) People of central location handling all order entrance and customer service; (2) People of central location guide customer in the organisation; (3) An automated switchboard distribute customer calls in the organisation; and (4) A software application that support coordinators when they handle order entrance and customer service. Questions that need to be answered in order to evaluate the alternatives are: (1) what are the risks and benefits of the alternatives; (2) what kind of information and knowledge is necessary in respective alternative?; and (3) has EuroMaint Industry access – or could get access – to the needed information and knowledge?

Irrespective of alternative the SSC should store, collect, and fuse information to provide appropriate information for advanced decision making (Fig. 4).

Fig. 5. Information fusion in maintenance management

EuroMaint Industry does not store (in databases) information received during customer calls. However, this information is usually written on a specific form, which is used in the process to fulfil customer request. Today they throw away this form, after the maintenance services is provided. With the help going to be available through simple system, this information easily can be stored and used later on. Further more other useful customer information pieces can be received by log of customer calls.

Fig. 4. The process of maintenance management in a service organisation

Information can be gathered and fused from customers (customer information, service needs, location of target/problem, information about target/problem), simulations (simulate “what-if” scenarios), databases (customer information concerning system, equipment and what that have been done earlier) and staff (staff, skills, utilization, working radius) in order to support decision concerning needed maintenance services. This implies that the process of maintenance management could be seen as information fusion: where current information from customer and staff is fused with future information from simulations and historical information from databases (Fig. 5).

The authors believe that ABM is a suitable approach to realize information fusion in the complex domain of maintenance and service operations and by ABM for modelling, simulation and analysis, many improvements can be achieved. In other words by building models, simulations and software based on agent theory (instead of for example object oriented theory) many improvements can be achieved. However, it is unclear do only endogenous information pieces make the real value for maintenance organisation system, or are some
exogenous pieces also useful. It could be assumed that sudden weather changes (like thunderstorms) and general level of capacity utilization in industry (larger production lot sizes) are triggers for maintenance need among existing customers, but also ‘one-stop’ shopping as well as new ones.

5. CONCLUSIONS

Information fusion and agent based systems are currently at the implementation stage of numerous different private sector organisations. However, real success cases are still nearly non-existent, and description of real-life cases is scarce. This research has tried to fill this gap by describing industrial maintenance service provider operations, and potential applications areas of information fusion theory as well as agent based solutions. As generally could be noted, maintenance management is mostly about exchanging time with information (like in manufacturing supply chains information is substitute for inventory holdings), however, this transaction process could easily improve performance of an maintenance provider, and benefit customers with more flexible and predictive maintenance operations. Thus, still at the moment it is a bit unclear how highest levels of information fusion model should be used in a real-life. Most probably we need powerful simulation tools and artificial intelligence to produce different end-scenario estimates as operations proceed further (and these should be made available for managers and knowledge workers of an organisation instantly).

As a further research in this area, we will most certainly continue with the case company; in one side of the token we will continue with endogenous information storage and fusion efforts (and trying to solve customer entrance of primary and secondary customers), but will most certainly direct efforts into develop predictive features in the management cockpit from integration of external data. Currently we have identified type of weather and industrial capacity utilization as potential exogenous factors, and we are trying to analyze whether hours worked in service organisation in customer operations are somehow connected to these. We are also currently at the process of seeking other potential “sensors” from the outside world to help fusion and artificial intelligence built-up.

REFERENCES


