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USING DISCRETE EVENT SIMULATION TO INVESTIGATE ENGINEERING PRODUCT SERVICE STRATEGIES

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ABSTRACT

As companies develop business models based on service provision through engineering products the role of information becomes increasingly important to achieving high levels of service performance. One approach to achieving higher levels of service performance is to deploy sensing technology in the product to provide the service operation with diagnostic and prognostic information. Simulation modelling techniques are able to capture operational performance of complex systems involving product and information flows and are therefore appropriate to modelling such service provision. This paper documents work carried out in this area and demonstrates the application of simulation when providing a service through engineered products. It would seem logical that receiving increasing product performance information would enable higher levels of service performance to be achieved. The work here shows how performance can be captured and the circumstances in which diagnostic and prognostic information is beneficial as well as when it has little effect.

1 INTRODUCTION

Service provision, including maintenance, in engineering operations behave as complex systems. Research in this field is very narrow in scope, can focus on manufacturing system maintenance or pure service systems. Work is emerging in the area of complex service system operations in which service spares, availability and capability contracts exist the work but there is a gap in the area of evaluation.

It is suggested that most manufacturers have to offer services into their core product offering for economical and competence reasons (Oliva & Kallenberg, 2003). A service, as an element of a product-service system, is defined by Baines et al. (2007) as “activities (work) done for others with an economic value and often done on commercial basis”. Maintenance or services companies, regardless of whether the maintenance is part of a manufacturing company or a pure maintenance company, have different types of customer contracts, but often use the same resources for all of their customers. Some contracts involve only preventive maintenance; others involve repairs only, while some highly valued contracts are concerned about the availability of the equipment.

Discrete Event Simulation (DES) involves the modelling of a system, as it evolves over time, by representing the changes as separate events. In discrete event simulation, the operation of a system is represented as a chronological sequence of events. Each event occurs at an instant in time and marks a change of state in the system. There are numerous applications that make use of DES particularly in manufacturing systems (Pidd, 2004) but with potential beyond.

This paper explores the use of DES for modelling complex engineering product service provision, firstly examining the potential of DES and then presenting the results of simple test scenarios of reactive, proactive and prognostic based service provision. These scenarios are used to explore the behaviours that simulation can illustrate rather than making specific predictions on performance. The novelty of this research lies in creating and developing DES model to test different service contracts types to in turn help decision makers to understand their operations and how best to satisfy the service requirements.

2 AIM AND METHOD

The aim of this work is to better understand how discrete event simulation (DES) can be applied to modelling complex service contracts types, and to evaluate the current service contract types. In particular, the work seeks to uncover the applicability of DES software functionality to this area and to understand role of information in enabling higher levels of service provision and/or offering the same level of service provision with less resources.

The approach used examined available literature on modelling work for evaluating service provision performance. From this base a prototype simulation model was created to investigate the functionality needed to capture the key features of a simple service system. Then, simple experiments are performed using the model to understand the performance changes. The work is exploratory and seeks to understand the challenges through development and experimentation rather than predict performance.

3 MODELLING SERVICE SYSTEMS USING DISCRETE EVENT SIMULATION

The use of discrete event simulation (DES) has been quite extensive and its application varies from supply chain (Rytila and Spens, 2006), health care (Wang et al. 2009), production systems (Kiba et al., 2009) and construction (Hassan and Gruber, 2008).

DES has also been used as a decision instrument in the maintenance and services sector. An evaluation on automotive manufacturing performance was performed by Ali et al. (2008) especially in recognising the bottlenecks and choosing the appropriate policies by means of simulation and optimisation. They argued that the majority of production systems at present have unsatisfactory overall availability caused mainly by too much downtime due to machine/component failures and quality issues. In the meantime, Roux et al. (2008) advocated a new approach that combined optimisation algorithms and simulation methods in the effort to evaluate the strategy of maintenance performances for manufacturing systems.

Oyarbide-Zubillaga et al. (2008) have opted to focus on the optimisation of preventive maintenance in the manufacturing field. Finding the optimal frequencies for the preventive maintenance for the multi-equipment systems was their main objective which was done under the criteria of cost and profit. Meanwhile, Ng et al. (2008) designed a Machine Service Support System (MSSS) to enable a service and maintenance expert to analyse and diagnose disturbances that crop up even at remote locations.

A few papers examine maintenance operations beyond the factory boundary. Greasley (2000) designed DES model for a company which was going to bid for the operation of a train maintenance depot. A DES model was also created by the Finnish Air Forces in their bid to study the impact of maintenance resources, policies and operating conditions on the availability of aircrafts (Mattila et al., 2008). Nevertheless, these models have not addressed the impact of studying the maintenance operations specifically when more than one maintenance contract types for different customers are involved.

Extensive literature has been written mainly on maintenance; however, the focus tends to be on manufacturing systems. Maintenance is paramount as a breakdown time or downtime on a particular machine could have a chain reaction on other machine which will slow down efficiency by starvation or blockages

(Langer et al., 2010). Wang (2010) addresses this issue, by developing a service contract design, negotiation and optimisation model. In the manufacturing environment maintenance, the use of prognosis and diagnosis systems has been advocated by a number of researchers. In fact, Vardar et al. (2007) argued that in an effort to reduce maintenance, capital costs and improvement productivity, there have been serious development efforts in the semiconductor industry for implementing remote diagnostics (RD) in wafer fabrication. The field of discrete event simulation and the commercial tools available (such as WITNESS, Arena and Simul8) have so far focused on modelling traditional manufacturing and service systems.

From this base of literature, this research is a novel application of discrete event simulation to the domain of engineering-based service environments.

4 DEVELOPMENT OF A PROTOTYPE SIMULATION MODEL

The work developed here is taken from the perspective of a service provider. The service provision is for the availability of complex products (or assets) in a single fleet to satisfy the demand by user(s) to carry out activities. No distinction is necessary as to whether the fleet assets are owned by the service operation or by another company. The focus of the work is on performance of assets which can fail and in turn reduce the availability to users. The maintenance operation and inventory for failing parts of the assets is included. The conceptual model of the system being investigated is shown in Figure 1.

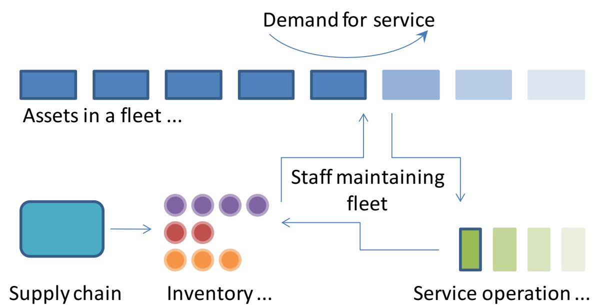

Figure 1. Conceptual model of the service system

The work investigated the maintenance of multiple fleets under different user demands and different levels of service provision, however, to avoid the complexity of interactions between fleets the work described here focuses on a single fleet. Superficially the system described can be modelled using standard simulation software, however, particular challenges arise here. The modelling features itemised below require additional work using typical simulation software despite being typical of production and service:

- Asset failure is due to particular sub-system or part failure which requires replacement
- Asset can only be repaired when specific parts (and maintenance staff) are available
- If an asset is predicted to fail and has a particular part replaced impending failure will not occur
- If staff cannot fix an asset on first visit, it remains down. Staff return later complete the repair.

The scenarios that are modelled in this work use the system shown in figure 1. The three scenarios are:

1. Reactive. A basic system in which the asset fails and maintenance is informed. Maintenance staff, when available, attend to the failed asset, diagnose the fault and attempt repair. If appropriate inventory is not available they leave the asset down return once their spare order arrives.
2. Diagnostic. This represents a basic level of sub-system sensing in the asset. When an asset fails the fault diagnostic is automated and service staff attend when both they and the required part are available. Only one visit is made by the staff to complete the repair.
3. Prognostic. Here sensors are deployed in the asset to predict likely failure and trigger service. Depending on the response time of staff, part availability and accuracy of prediction the asset can be taken out of service, maintained and returned to service without actual failure in service.

The three scenarios contain multiple assets in the fleet, multiple failure types, corresponding multiple part types, variable maintenance staffing, scheduled and on demand inventory ordering, lead times for parts and variable levels of demand. Within any given run, maintenance staff and fleet size are fixed and other parameters from cycle time through to breakdown patterns are controlled by probability distributions.

5 EXPERIMENTATION USING THE PROTOTYPE MODEL

Experimental runs are repeated for different values of the functionality that can significantly influence performance such as fleet size and maintenance staff levels. Run-in is for one year and results are collected from the following four years of operation. The focal scenario is washing machines owing to associated work with real washing machines in a lab modified to provide information of machine component health. The model created in WITNESS is shown in Figure 2.

Over time washing loads arrive randomly and are randomly allocated to an available washing machine. Each machine processes the load according to a variable cycle time and then exits the model adding to the number of loads 'completed'. There is a small amount of buffering for incoming washing should no machines be available to process the washing. If the buffering is exceeded the washing loads are 'lost' (equivalent to a customer walking away from a launderette).

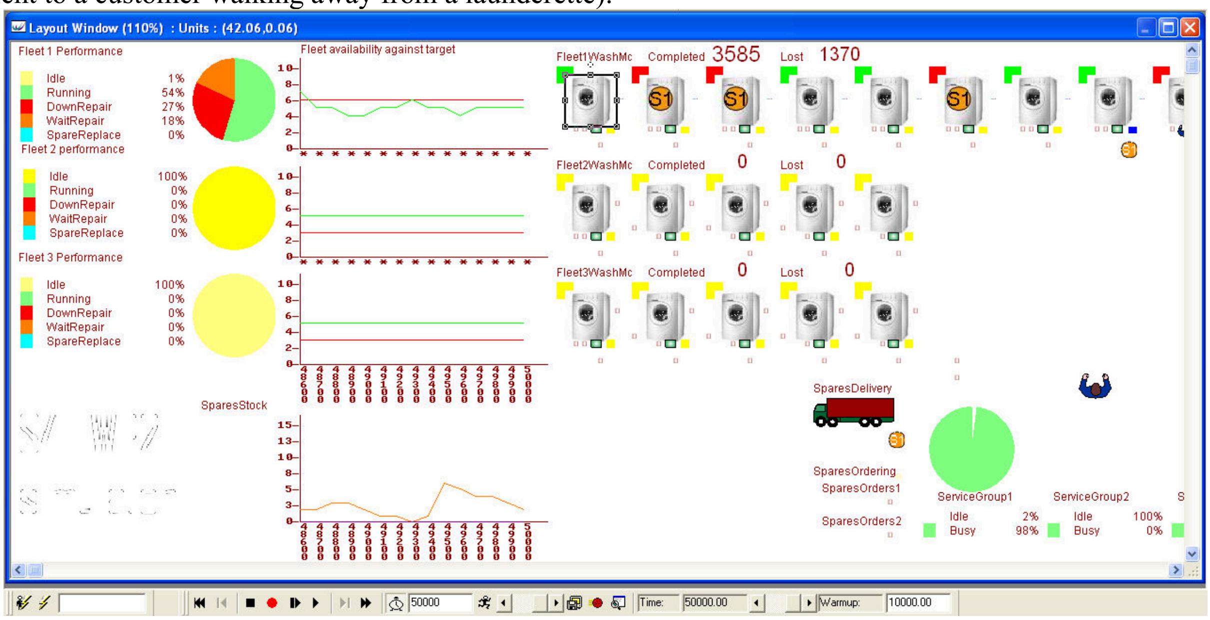

Figure 2. Screen shot of the model after being run for the reactive scenario for fleet 1 only.

6 RESULTS OF MODELLING

The experiments carried out were to investigate the potential of simulation to model of this problem domain and its limitations rather than to examine performance of a particular service configuration. The results from these three simulation scenarios were examined to assess the impact of number of assets, fleet availability, demand satisfied and staffing. The results are therefore presented in Figure 3 and Figure 4 in a comparative way to show the potential for simulation rather than observe any other effects.

The results shown in Figure 3 from the scenarios in Section 4 can be in part considered obvious, in that greater information availability about an asset performance can lead to actions that result in higher fleet availability. In the reactive scenario the maintenance staff 'waste' time making multiple visits to assets and in the prognostic scenario maintenance staff can use the available information to arrive at an asset and maintain it prior to failure without any delays associated with repairing a failed asset on demand.

The three scenarios are modelled with the system 'under stress' with the fleet unable to meet the demands placed on it (assets = 10) and inadequate maintenance staff available (staff = 1). As the assets in the fleet are increased the availability rises as they are able to meet demand fully and will each fail less frequently as they are being used less heavily. In turn maintenance staff repairing assets is less urgent and therefore less impact on availability. The availability falls for more machines in the reactive scenario as the larger fleet attempts to meet more of the demand and the maintenance staff fail to cope. The results show interesting effects, e.g. provision of more maintenance staff for reactive service is equivalent to low maintenance staff and basic sensing for diagnostic service.

The results shown in Figure 4 compare the ability to meet the service demand according to the fleet size, sensing technology and staffing. As would be expected if fleet size is increased then demand can be better satisfied up to the maximum level and as more staff are available more assets are available to meet the demand. What is interesting here is when a system is under stress due to constraints such as inventory availability, staffing or fleet size then sensing technology to detect or predict failure is beneficial. However, where there is sufficient overall system capacity then technology has minimal impact.

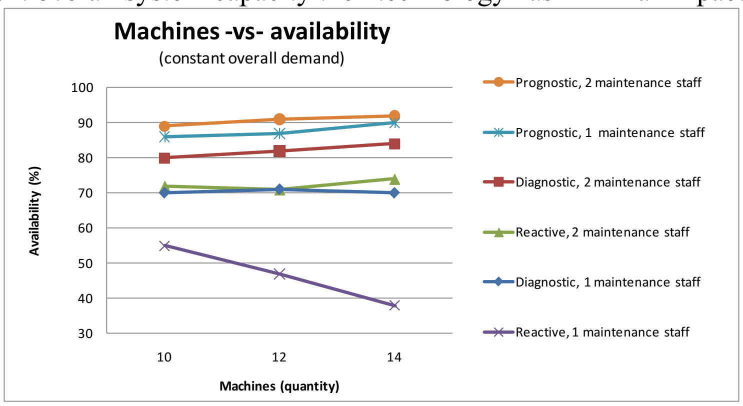

Figure 3. Number of assets in the fleet against aggregate average fleet availability

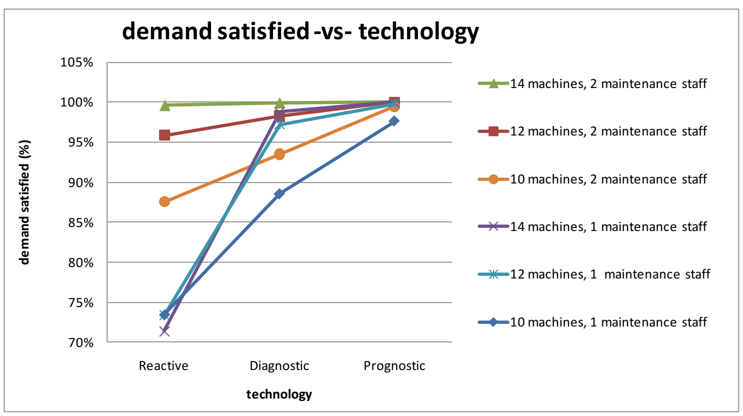

Figure 4. User demand satisfied against the level of technology deployed

7 DISCUSSION

The work here shows the potential for simulation modelling to understand how effective a service delivery is depending on resource levels and the sensing technology deployed in fleet assets. The modelling has shown that when a system has multiple constraints (inventory, service, assets) the effectiveness of sensing technology can be judged operationally. Taking a financial perspective, therefore, the trade-offs between the number of assets, inventory levels, maintenance operation size and technology deployment can be measured in order to most effectively meet expected demands and service contract conditions.

Further work is necessary to understand the behaviours exhibited when multiple fleets are deployed sharing inventory and service operations as appropriate. Additionally the inventory was assumed here to be single use and the repair and re-lifing loop for valuable parts needs to be added. Schedule maintenance was not included here and needs to be added. Additionally the complexities of moving assets and 'robbing' parts from one failed asset to repair another failed asset have not been captured. Importantly cost modelling needs to be incorporated within the simulation model or driven by the simulation outputs.

8 CONCLUSION

This paper has examined the work carried out to date in the area of simulation modelling and in particular maintenance and service modelling. The paper has presented the development of a prototype service model using standard discrete event simulation software and the results of experiments carried out to examine the potential value of sensing technology on complex products used in service provision. The work has illustrated areas in which simulation can discern the performance of systems that could in turned be used to examine different means of meeting service contracting levels through different technology.

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