IMPROVING THE REMOTE SCHEDULING OF MANUFACTURING AND INSTALLATION OF LARGE CUSTOM-MADE PRODUCTS

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ABSTRACT

This paper illustrates the use of statistical inference techniques to improve the scheduling performance of a distributed simulation and scheduling tool based on the XLA-RTI architecture. Specifically, the timing of federation synchronisation events can be customised according to the local failure characteristics of the physical system so as to reduce the necessary delays in information and communications exchange among federates. Ultimately, these improvements can only be beneficial if they have measurable effects on the production performance of the physical system. The paper refers to an industrial application case to measure the production benefits that may be accrued by implementing the proposed methodology. The application context is the manufacturing and installation of railways switch point assemblies, which, to a large extent, are custom-made products in that they come in a multiplicity of assembly types and ultimately need to be customised to fit the specific application requirements.

INTRODUCTION

The research presented in this paper builds from the outcomes/developments of a project aimed at improving the manufacturing and installation processes of railways switch point assemblies. The original project focused on the activities of an Italian company that produces railways switch point assemblies for the national railway network as well as for industrial users. Part of the assemblies are produced for installation by third parties while others are installed directly by the company's own installation crew. Earlier studies on the performance of the company's operations led to the development of an improved HLA federation of simulation and scheduling modules, which reduces the impact of communication delays on scheduling performance, while retaining the benefits of de-coupled scheduling procedures and process control. The initial project involved the development of a simulator to analyse the current performance of the company and search for possible process improvements. An initial set of simulation-based experiments targeted the assessment of a number of performance measures including the percentage of on-time deliveries, resources utilisation, and production lead-times (Gunasekaran, 2001). During the course of the analysis, the drilling and the planning machines were identified as critical because their production rates appeared consistently lower than the others', thus creating the conditions for potential bottleneck effects. While this observation suggested that an investment might be advisable for the company in order to increase the capacity of these machines, the lack of a structured approach to the scheduling of incoming orders emerged as a critical performance issue. The company, which is relatively young (they have been in the business for approximately two years), had never really invested time and effort in the development of appropriate scheduling policies, and production performance clearly suffered, as reflected by the large percentage of late product deliveries (over 35%). A scheduling tool was then developed and linked to the existing simulation models of the manufacturing and installation processes to test the impact of alternative scheduling policies in relation to the current status of the machines on the shop floor and to the status of the installation process on the designated site (Chang and Maskatsoris, 2001). When the system is used in the loop with the production and installation processes, the first step is to rank the existing orders by due date and estimated production time. Then, based on the progress status of the current production and installation activities, the system decides whether to produce an assembly for third party or for own-crew installation.

The additional research presented in the paper refers to the integration of the simulation and scheduling modules into an HLA-RTI federation architecture, which enables the maintenance and update of the modules in separate locations: the scheduling module near the decisional centre and the simulation modules near the production centre. The integration of the modules into a single federation raises important performance issues related to the frequency of communication exchanges among federates (Juhasz et al., 2003; Hwang, 1993). To address these issues the

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paper proposes an approach based on statistical inference techniques to tailor the timing of synchronisation to the process characteristics of the simulated system with the double objective of reducing wasted simulation time and thereby improve the performance of remote scheduling (Bandinelli et al., 2004). The paper shows how this is achieved by applying the methodology to the scheduling of manufacturing jobs in the production and installation of railways switch point assemblies as described in the first part of this introduction.

Prior to illustrating the methodology a brief description of the actual production and installation processes will be provided to highlight the key characteristics of the processes and provide the context for the statistical analysis. As far as results the paper will provide a comparison between the scheduling performance corresponding to the standard synchronisation approach and the one measured using process statistics to time synchronisation.

MANUFACTURING AND INSTALLATION OF RAILWAY SWITCH POINT ASSEMBLIES

Railway switch point assemblies are pre-fabricated units including all the rail elements and connecting devices that are required to lead a train from its current track onto a different one, an example is shown in figure 1.

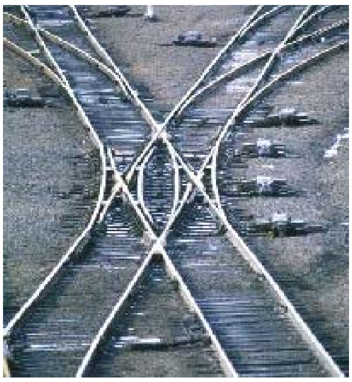

Figure 1: Example of Railway Switch Point Assembly

Each assembly consists of seven or more individual rail elements, depending on the particular design (single, double, or intersection) and on the required deviation angle. According to the industry practice, some rail elements may be recycled from old, decommissioned rail systems, others are processed from scratch starting from standard twelve-metre long rail segments. The different rail components pertaining to a given order follow similar manufacturing steps prior to their assembly into the final unit. These steps include cutting to the required length, drilling, bending, upper surface planning, and lower surface planning. The last two activities, depending on the type of component and on the design specifications, may be followed by a quality check on the deviation angle and re-bending, if needed. Most of the machining jobs take one to two hours to complete with the exception of upper and lower surface work that may take four to seven hours, depending on the particular size and design of the assembly. The production sequence includes cutting, drilling, bending, planning and milling, final bending, and partial assembly. The layout of the shop floor is shown in figure 2.

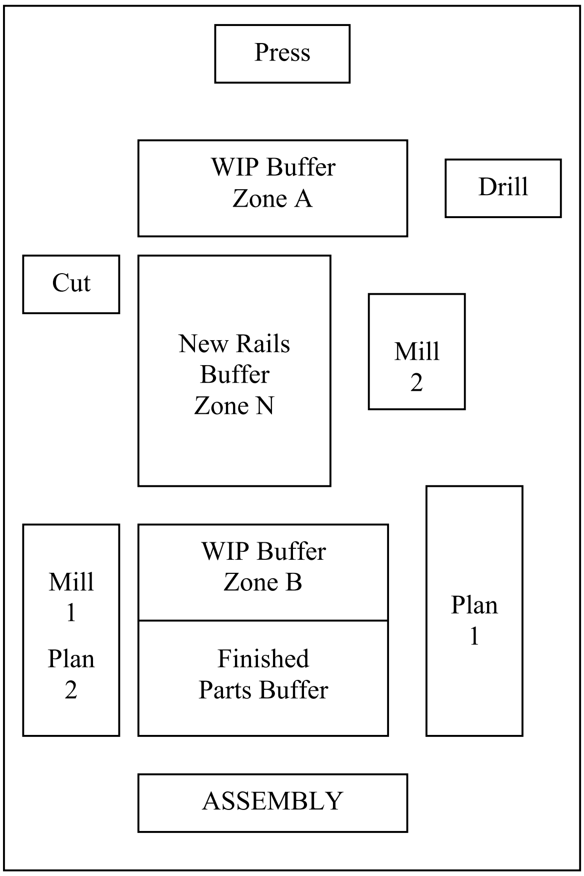

Figure 2: Layout of Manufacturing & Assembly Floor

The installation steps include excavation, placement of transverse units, placement of the switch point assembly, filling with gravel, levelling and alignment, and connection.

PROCESS SIMULATION & PRODUCTION SCHEDULING

Simulation is a widely accepted means of supporting real-time production scheduling because it provides estimates for the state of every machine at the time when a new order needs to be sent to production (Bandinelli et al., 2003; Williams et al., 1999). The scheduling tool provides correct results when fed with the current production parameters, machine status, and order status for the entire production system (Proud, 1999). The simulation models for the representation of the manufacturing and installation processes described in the previous section were developed using a commercial simulation package, ARENA 7.0. When simulation is used in the loop for on-line scheduling, time-performance becomes critical towards the choice of the right scheduling policies: the simulation estimates need to be available prior to the completion of the current job on each machine (Bandinelli et al., 2003; Bandinelli et al., 2004).

In the distributed simulation of stochastic processes, a major driver of time-performance is wasted simulation time related to the timing of synchronisation events among federate simulators. This is especially true when the simulated processes are stochastic: for instance the current production capacity of a plant depends on the number of machines that are currently down due to failures, while the ability to manufacture a particular item depends on the availability of the required raw materials in stock. The state of a machine (up or down) and the stock levels for different raw materials are random variables that need to be described through their probability distribution in the process simulation models.

For the representation of the mean times between failures of the individual machines, triangular probability distributions were built based on both historical data and on-site observations. Historical data for the entire period of operation of the company (nearly 2 years' worth of data) were also used to build probability distributions for the monthly order inter-arrivals. The strong variability in the data collected for this project, partly explained by the fact that the company is relatively young, causes the required length of the simulation run to be fairly long (57 months) as shown by the MSPE curve.

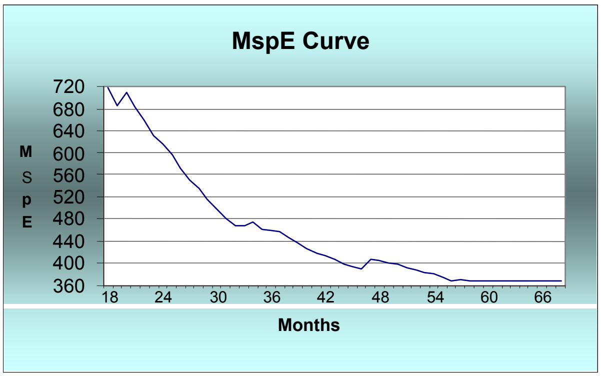

Figure 3: MspE Curve for Production Lead-Times

On the other hand, the scheduling tool was devised outside the ARENA modelling environment and physically located in the vicinity of the decisional centre. This approach provides the advantage of separating the development and the maintenance of the physical model from those of the scheduler. On the implementation side, this approach requires an infrastructure to handle the exchange of information between the physical model and the scheduler. Due to the high level of control that needs to be achieved over the production plan, and due to the choice of HLA-RTI as a framework for Inter Process Communication (IPC), an additional software had to be developed for the implementation of the framework. The additional software handles the interactions between the ARENA simulator and the RTI environment, and between the RTI environment and the control system. Specifically, the role of this software is to collect the information exchanged by the RTI environment in an asynchronous way, and to communicate this information to the physical model and to the controller, which work in a synchronous way.

The realisation of this software component may follow two different approaches (Tucci et al, 2001). The first one can be summarised in the definition of a Delegated Simulator module, which co-ordinates the logic of information exchanges among federates. The second solution proposes the introduction of a software tool "living" between the simulator and the RTI. This software, namely a proxy, is in charge of the two-way communications between the RTI environment and the simulator (Orsoni et al., 2003). The additional flexibility provided by the use of a proxy led to choose this second approach, which makes the Proxy entirely responsible for the information exchange between the federates and the RTI. While the simulator performs communication tasks ina synchronous way, by TCP-IP, the RTI performs these task in an asynchronous way: the proxy is then required to store the information coming from the RTI and transfer it to the relevant federates at the nearest synchronisation event and vice-versa.

For the purposes of time-management, a "next event" approach was chosen because the times when information exchanges would be needed could not be known a priori. In order to optimise the times when the federation stops simulating to allow for information exchanges between the physical model and the controller, a methodology based on statistics from the MTBF distributions of the critical components has been used. Details on the methodology and its application to the industrial case are provided in the following section. An important advantage of the devised infrastructure is the possibility to develop the scheduler as a separate unit using either a simulation package, such as ARENA, or an independent programming language.

A typical iteration of the communication process could be described as follows. Upon completion of a production/installation activity an event occurs which stops the simulation clock. The new state of the physical model is communicated to the proxy and thereby passed on to the RTI environment, which in turn delivers this information to the scheduler. The jobs sequence determined by the scheduler is then communicated to the physical model by the RTI, where the relevant job attributes (i.e. type of activity, activity identification code, work centre identification code, start time, and activity duration) are stored as an XML string. Additional details on this infrastructure can be found in [Bandinelli et al., 2003].

In order to validate the model and obtain suitable test results, some simplifications were introduced. In the first instance, the scheduling procedure was based on simple rules and the communication between the scheduler and the simulator was emulated to validate the proposed scheme and test the performance benefits of the methodology (Sargent, 1999). Because in the authors' opinion, HLA is still the most complete and mature IPC Standard, a simplified emulator of such infrastructure was built to reproduce the Next Event time management procedures for the communications between the scheduler and the physical model. In this respect it is important to remember that the aim of this work was to provide a new methodology to reduce delays in communication and information exchange, and not a new IPC standard.

PROCESS STATISTICS FOR THE TIMING OF SYNCHRONISATION

Changes in state and in the values of the dynamic process attributes are first recorded at the federate level and can only be communicated to the other federates (i.e. other simulation models, control system, scheduling module) when a synchronisation event occurs at the federation level. Because of the random nature of state and variable changes it is impossible to schedule synchronisation events a-priori that match the timing of such occurrences. The correct frequency of synchronisation and thus of communication/information update among federates is always the result of a trade-off between the time spent on communication (too long if communication is frequent), and the likelihood of not sharing the occurrence of asynchronous events with other federates for too long a time (if communication is infrequent), which may invalidate large batches of simulated time. Ideally, the timing of federate synchronisation should reflect the characteristics of the simulated processes building from the most critical points, intended as the ones that are most likely and thus most frequently affected by asynchronous occurrences.

Prior research work by the authors developed a methodology to improve the performance of federation runtime infrastructure in the scheduling of manufacturing processes (Bandinelli et al., 2004) The methodology addresses the issue of communication delays among federates by introducing predicted failure events that are tailored to the process statistics of the physical system. Specifically, the methodology refers to the Mean Time between Failures (MTBF) distributions for the critical process components to generate histories of predicted failure events that can be fed to the federation control level to customise the timing of synchronisation. By these means, the impact of asynchronous events - generated locally at the individual federate level - on the time performance of the federation can be significantly reduced. Preliminary results for a simple manufacturing application case (Bandinelli et al., 2004), have shown a potential for the reduction of wasted simulation time up to 35%. Building from these results, the example analysis presented in this paper, establishes how the time-performance benefits accrued at the simulation level may improve scheduling and production performance in the physical system. With reference to the critical machines (i,e, the planning and drilling machines) a series of random extractions were made out of the corresponding MTBF distributions to obtain statistical estimates of their likely "next-failure" events. The timing of each predicted failure event was obtained comparing the average time to the next failure for each machine over a set of 20 extraction. The shorter value was then corrected adding a fraction of the corresponding standard deviation, as predicted failure events should follow the actual occurrence. A series of test runs were conducted to experimentally set the value of this fraction so as to minimise communication delays. Ideally, the objective is to schedule each predicted failure event right after the occurrence of an actual failure in the physical system, so that the occurrence can be seen by the federation with a minimal delay. The fraction of the standard deviation that is used to correct the average estimated time to next failure for the system is context specific, and for this application was experimentally set to 0.4. The process is iterated until predicted failure events have been scheduled to cover the entire simulation horizon.

EXAMPLE APPLICATION & RESULTS

For the purposes of this example application, the timing of federation synchronisation was customised using the process statistics identified in the previous section. By running the federation in the new condition it was observed that the percentage of on-time deliveries had increased by 40% (from over 35% late deliveries to less than 20%) and the cumulative delays in late deliveries has decreased by 28%, which show a relative improvement in the performance of remote scheduling with respect to the original federation.

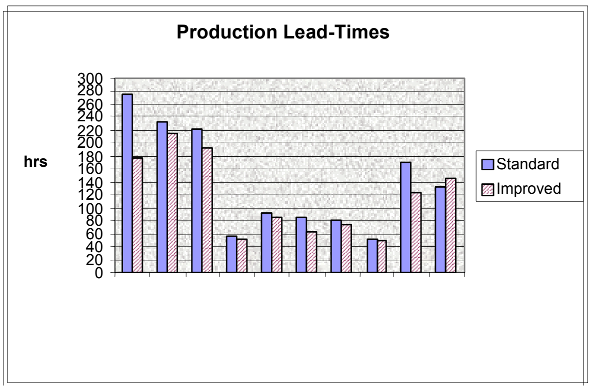

Figure 4: Improvements in production lead-times

A comparison between the production lead times observed in the physical system when scheduled using the standard and the improved synchronisation time management is presented in figure 4. The figure compares the lead-times for the main types of switch point assemblies produced by the company in the two cases.

Figure 5 presents a comparison between the percentage of late deliveries when scheduling production using the standard and the improved synchronisation time management approaches, respectively.

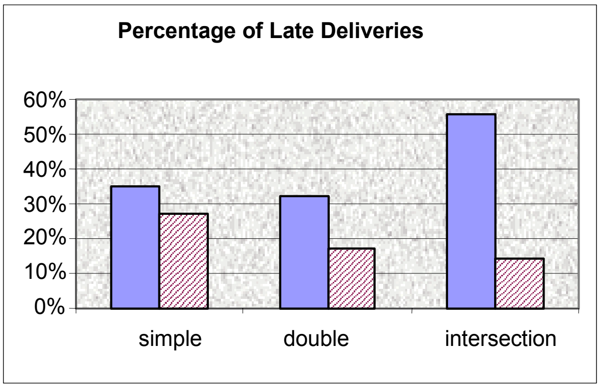

Figure 5: Reduction in the percentage of late deliveries

In this figure the types of switch point assembly are grouped into three main categories: single, double and intersection types. A relative improvement can be observed for each of these categories.

In summary, the analysis applied to the manufacturing and installation of railways switch point assemblies shows that the improved communication among simulation federates makes the scheduling tool more responsive to the dynamic needs of production and installation. Both scheduling and production performance are improved as indicated by the increase of on-time deliveries and by the reduction of the cumulative delays on late deliveries.

CONCLUSION

The availability of timely updates on process state variables makes scheduling of manufacturing and installation processes far more effective, as indicated by the relative increase in the number of on-time deliveries and by the reduction on cumulative delays for late deliveries.

The strength of the statistical inference method used to determine the appropriate timing of communications among federates is that it reflects actual process characteristics, which makes the timing of communication as responsive as possible to the occurrence of otherwise asynchronous events.

Future work will focus on the development of a detailed fault model to capture patterns of failures across production units and processes. AI techniques based on Artificial Neural Networks will be used to establish correlations between local failure modes and their impact on the productivity of other production units with the aim of supporting rescheduling activities around predicted failure events. Further research will also look at AI techniques as a more efficient way of generating histories of predicted failure events based on the characteristics of the MTBF distributions for the critical process components, and on the nature and location of the last failure event.

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