AN INDUSTRIAL CASE STUDY OF WEB-BASED SIMULATION-OPTIMIZATION

Anna Syberfeldt
Ingemar Karlsson
Amos Ng
Virtual Systems Research Center
University of Skövde
P.O. 408, 541 48 Skövde, Sweden
E-mail: anna.syberfeldt@his.se

KEYWORDS
Simulation, optimization, web, industrial case study.

ABSTRACT
This paper presents a web-based simulation-optimization system for improving production schedules in an advanced manufacturing cell at Volvo Aero Corporation in Sweden. The optimization aims at prioritizing components being processed in the cell in a way that minimizes both tardiness and lead times. Results from evaluating the implemented system shows a great improvement potential, but also indicates that further development is necessary before the system can be taken into operation.

INTRODUCTION
Web-based systems have been a strong trend the last few years and a great deal of classical desktop programs is now transformed into web versions. Also the simulation field has been affected by this trend and the term “web-based simulation” is now commonly used in the research community. “Web-based simulation” does not have an exact meaning, but is a broad term including various approaches to integrate the web with the field of simulation. Byrne (2010) states that web-based simulation “[…] can be defined as the use of resources and technologies offered by the World-Wide-Web (WWW) for interaction with client and server modelling and simulation tools”.

Although web-based simulation is a concept that has been discussed in the research community for 15 years (Fishwick, 1996), the area is still in its infancy (Byrne, 2010). During the last few years, the area has started to grow but there are still only a small number of real applications of web-based simulation (Byrne, 2010). This paper increases this number by presenting a case study of implementing a web-based simulation-optimization system for a real industrial problem. The case study was carried in cooperation with Volvo Aero Corporation, which develops and manufactures high-technology components for aircraft and gas turbine engines. The focus of the case study is on an advanced automated manufacturing cell that simultaneously processes a wide range of different engine components. The machines in the cell, as well as the components being processed, are capital-intensive and the aim of the optimization is therefore to achieve a maximum utilization of the cell.

The case study at Volvo Aero Corporation was carried out as part of a research project called “OPTIMIST” (OPTIMisation using Intelligent Simulation Tools). The overall aim of this multi-discipline (industrial engineering and computer science) research project is to leverage the effectiveness of the Swedish industrial sector by introducing intelligent simulation-based optimization to their daily operations. More information about this research project can be found in Ng et al. (2007).

The next section discusses the underlying reasons for using a web-based approach in the case study by presenting the advantages of web-based simulation-optimization in comparison to classical simulation-optimization systems that are installed on a local computer.

ADVANTAGES OF WEB-BASED SYSTEMS

Compared to classical simulation-optimization systems, several advantages of web-based systems can be identified:

Accessibility
A web-based system is accessible from anywhere with an internet connection, and not only from the specific computer having the simulation-optimization system installed. This also means that a web-based system allows access outside normal business hours.

Scalability
Web-based systems allow for dynamic provisioning of computing resources (Rabinovich and Spatscheck, 2002) and are thereby able to handle an increased number of simulation/optimization requests without performance degradation.

Portability
A web-based system can be run in any web browser on any operating system without requiring recompiling (Suh, 2005). It is not limited only to a traditional computer, but can be run on any device having a web browser (e.g. a mobile phone or an iPad).

Maintenance
Maintenance of web-based systems is easier since they do not have to be installed on each client’s computer. Updates are made through a server and reach the clients instantly, which eliminates virtually all on-site maintenance and allows for a frequent update scheme.
**Controlled access**

Through user logins, a web-based system allows for the configuration of user groups with different privileges based on work tasks. The privileges can be easily changed on the server instead of having the client computer updated.

**Licensing**

Simulation software licenses are often very expensive, and with a traditional simulation-optimization system it is often required to have one license installed on every computer that runs the system. With a web-based system, the number of licenses can be significantly reduced since the simulation is run on a centralized server.

Altogether, these advantages have motivated the use of a web-based, rather than a traditional local, simulation-optimization system for improving the manufacturing cell at Volvo Aero Corporation, which is further described in the next section.

**MANUFACTURING CELL**

Volvo Aero develops and manufactures high-technology components for aircraft and gas turbine engines. Today, more than 80 percent of all new commercial aircraft with more than 100 passenger capacity are equipped with engine components from Volvo Aero. Components manufactured at Volvo Aero can be found in military fighter aircraft as well, such as the F/A-18 E/F Super Hornet. As a partner of the European space program, Volvo Aero is also the primary supplier of nozzles and fuel pump turbines for the Vulcain rocket engine. Volvo Aero’s facilities are located both in Scandinavia and in the US, and has in total about 3 200 employees. In this work, a factory located at the headquarters of the Volvo Aero Corporation in Sweden is the subject under study.

More precisely, the focus of the study is on an advanced automated manufacturing cell comprising comprises five multi-task machines and five burring stations. The operations that are performed in a machine or at a station vary for different components. Instructions and tools are automatically set up in a machine for the component that arrives, which means that several different components can easily be processed in the cell at the same time.

The machines in the cell, as well as the components being processed, are capital-intensive and it is therefore important to achieve a high utilization of the cell. Finding an efficient processing schedule is, however, non-trivial due to the high complexity of the cell in combination with an unpredictable inflow.

The established method for creating schedules is currently a manual procedure based on trial and error. As there is no guidance on how to change input parameters between iterations, this approach is very time-consuming and requires many iterations and extensive effort by an expert for finding a satisfactory schedule. Furthermore, it does not guarantee that a valid schedule is found, but leaves the validation entirely in the hands of the expert, who is required to consider and carefully control all possible constraints. As there are multiple conflicting objectives to consider when creating a schedule, manual optimization is practically impossible – especially since explicit heuristics for finding a good schedule is missing. Therefore, an automatic simulation-optimization procedure has been identified by the company as necessary for improving the performance of the manufacturing cell. This procedure is presented in the next section.

**SIMULATION-OPTIMIZATION**

In parallel with the physical build-up of the manufacturing cell, a discrete-event simulation model of it was developed using the SIMUL8 software package. A screenshot of the simulation model can be found in Syberfeldt (2009, p. 73). The aim of building the simulation model was two-folded: 1) to perform what-if analyses aiding the production planning, and 2) to perform simulation-based optimizations. The simulation model has a front-end interface developed in Excel, which for the user facilitates entering input parameters into the model without the need to learn the simulation language. Due to the complexity of the manufacturing process and the various set-up configurations possible in the cell, the simulation model is quite complex. Validity tests, however, indicate that the simulation model represents reality well, and the model is generally accepted among operators working in the manufacturing cell.

When it comes to using the simulation model for optimizations, the main focus is on finding the best prioritizing of engine components being processed in the manufacturing cell. As previously mentioned, several different components are simultaneously processed in the manufacturing cell. In case two or more components arrive simultaneously at a machine or station, a priority number determines which component has precedence. The aim of the optimization is to set the priority numbers of the components in a way that 1) **minimizes tardiness** (overdue components), and 2) simultaneously **minimizes lead times** (the time between a components enters and exit the manufacturing cell). These two optimization objectives are identified by the company as most important to achieve a high utilization of the manufacturing cell.

For optimizing the priorities of components and thereby minimize tardiness of components while at the same time minimizing their lead times, a Hill Climbing algorithms is implemented. Hill climbing is an iterative algorithm that belongs to the family of local search (Russell and Norvig, 2003). The algorithms starts with a random solution to the problem, and attempts to find a better solution by mutating (changing) the solution (Figure 1). If the mutation produces a better solution, this new solution is kept and the procedure is repeated until no further improvements can be made.

```plaintext
currentNode = randomStartNode;
loop until termination criterion fulfilled{
    candidate = Mutate(currentNode)
    if (candidate is better than currentNode)
        currentNode = candidate;
}
return currentNode
```

Figure 1: Pseudo code for a general Hill Climbing algorithm.
Being a local search algorithm, Hill Climbing is good for finding a local optimum but it is not guaranteed to find the global optimum (that is, the best solution out of all possible solutions). Nevertheless, this algorithm has been used in the case study since it is simply to implement and considered to produce as good (or even better) results than other algorithms when the optimization time is limited. The latter is important since a new optimization is performed at every shift change in the cell, allowing the optimization to run for just a few minutes.

In the basic version, Hill Climbing allows only for a single objective to be optimized. In the case study, however, there are two optimization objectives and the basic algorithm has therefore been modified to allow for multiple objectives. This is done by optimizing one objective at a time without deterioration of the other objective. More precisely, the algorithm starts by optimizing objective 1 (tardiness) since this objective is considered most important by the company. When there have been 15 mutations without finding any better solution with respect to objective 1, the algorithm changes to optimize against objective 2 instead. The optimization of objective 2 is constrained in the sense that a solution improving objective 2 is only accepted if it does not deteriorate objective 1. The whole procedure is described with pseudo code in Figure 2.

```plaintext
obj = 1;
obj1Value = undef
numTries = 0;
current = randomSolution;
current.Evaluate();

loop until the user-defined time is up {
    candidate = Mutate(current);
candidate.Evaluate();

    if (obj is 1 AND candidate < current)
        current = candidate;
    else if (obj is 2 AND candidate < current AND obj1Value is preserved)
        currentNode = candidate;
    else
        numTries = numTries+1

    if(numTries > 15) {
        obj = 2;
        obj1Value = candidate
    }
}
return currentNode
Figure 2: Pseudo code for implemented Hill Climbing algorithm.
```

The simulation-based optimization is enabled using a web-based user interface, which is presented in the next section.

WEB-BASED USER INTERFACE

The user interface is in form of a web page, implemented using HTML, JavaScript and Ajax. When navigating to the web page, the user must first login in. Using a login in-system allows for the configuration of different user groups and the specification of privileges based on position in the company.

When logged in to the system, the first thing shown to the user is an information page describing the web-system and giving instructions about how to perform simulation-optimizations (Figure 4). The intention is that the information page should show not only static information, but also dynamic information about the manufacturing cell related to the current shift. Such information includes shift period, shift leader, operators working in the cell, and known disturbances.
Before starting a simulation-optimization process, the user must first specify the current status and configuration of the manufacturing cell (Figure 5). This data includes shift period, status of components currently under processing, list of entering components, availability of fixtures, availability of operators, and scheduled maintenance. All this data is necessary for the simulation model to be able to mimic the operation of the cell as close to reality as possible.

When the status and configuration of the cell has been specified, the user can initiate the simulation-optimization process. This is a simple procedure; the user just specifies at which point in time the results should be presented and then presses a start button (Figure 6). When the start button is pressed, a command is send to a web server to initiate a simulation-optimization process. Since the simulation-optimization is run at the server-side, and not on the client-side, the performance of the user’s computer is not affected at all by the simulation/optimization. In the current implementation, a single server is used and there can therefore only be one single simulation-optimization process active at the same time. To assure this, the start button is inactivated until the process is completed.

At the specified point in time, the outcome from the simulation-optimization process (that is, a prioritizing of components) is presented to the user. According to requirements specified by the company, the results are presented in form of a graphical production schedule (Figure 7). The graphical schedule specifies which component to process in which machine at each point in time. Along with the graphical schedule are details such as delayed components, periods of operator needs, and initial status presented. Altogether, this information supports the shift leader and the operators in managing the cell in an efficient way.

The next section describes how the web-based simulation-optimization system is evaluated.
EVALUATION

Evaluation of the web-based simulation-optimization system has been undertaken based on two criteria; 1) optimization performance, and 2) company benefits.

With respect to optimization performance, production schedules created by the simulation-optimization are compared to schedules created manually by a domain expert. As previously described, a manual procedure is the current approach for creating schedules. Comparing the schedules with respect to tardiness and lead times (the two optimization objectives) shows a great advantage of the simulation-optimization procedure. The simulation-optimization creates schedules with at least 20% improvements, and not seldom as much as 50% improvements or even more. This is no surprise, considering that the manufacturing cell is highly complex and that manual optimization is virtually impossible. Although it is obvious that the simulation-optimization performs better than a human, it is worth to notice that it is not clear how well the optimized solutions compare with the achievable values of the objectives, as the ideal values are not known. The combinatorial relationships, uncertainty factors, and non-linearities in the manufacturing process means that the problem is too complex to be modeled and solved analytically, and the true optimum therefore remains unknown. It is also important to notice that optimization results have so far only been verified in the simulation model. In future, the optimized production schedules can hopefully be implemented and evaluated also in reality.

With respect to the second evaluation criterion, company benefits, this is evaluated through thorough discussions with company representatives. These representatives include the operative manager of the cell, operators working in the cell, the head of logistics, and logistics engineers. Before the discussions take place, the web-based simulation-optimization system is first presented and demonstrated to the representatives. After that, they are given the opportunity to try out the system themselves. In the subsequent discussions, the representatives were asked about their opinions about the system. All of them rose that they see a great potential in the system when it comes to improving production schedules of the future, especially at high workloads. Also, they see an advantage in that the system heavily reduces the human effort associated with creating production schedules. All representatives agreed that the system is worth trying in real production, but that an additional feature must be implemented before this can take place. This feature is a real-time integration with the manufacturing cell that reduces the need to specify the current status and configuration of the cell before an optimization is started. With such integration, the optimization can be fully automatic and run more frequently. Since the manufacturing cell is relatively new, is has modern, built-in computer systems that make it possible to achieve status information in real-time. A discussion is currently undergoing at the company about how use and integrate these systems with the web-based simulation-optimization system.

CONCLUSIONS AND FUTURE WORK

This paper presents a web-based simulation-optimization system for improving production schedules in an advanced manufacturing cell at Volvo Aero Corporation in Sweden. The optimization aims at prioritizing components being processed in the cell in a way that minimizes both tardiness and lead times. The production schedules being the outcome of the optimization is evaluated by the company and the results look very promising. In comparison with production schedules created manually by domain experts, the optimization is able to find solutions with at least 20% improvements according to validations using the simulation model.

To improve the optimization results even further, future work includes evaluating more sophisticated optimization algorithms. The current Hill Climbing algorithm works well, but is reasonable to expect that improved performance can be achieved with a more advanced algorithm. The algorithm currently under consideration for replacing the Hill Climbing algorithm is a new evolutionary algorithm called Cuckoo Search (Yang and Deb, 2009). Cuckoo Search is inspired by biological mechanisms and mimics the breeding behavior of some cuckoo species that lay their eggs in the nests of other birds. In the algorithm, each egg in a nest represents a solution, and a cuckoo egg represents a new solution. The aim is to use the new and potentially better solutions that are cuckoos, to replace worse solutions in the nests. Initial studies reports that Cuckoo Search is efficient for both engineering optimization problems and for scheduling (Yang and Deb, 2010; Tein and Ramli, 2010), and its original structure make it interesting to take a deeper look at the algorithm.

Besides the potential optimizations possible with the developed web-based system, there is also another important advantage pinpointed by the company. This is the possibility to share results in real-time among stakeholders without additional efforts. With locally installed programs, the results can only be viewed on the specific computer unless they are not printed or e-mailed. This overhead is completely eliminated with a web-based system which allows everyone that has access to the system to view the results simultaneously. This aspect was actually considered the most important advantage of a web-based system according to the company. From the universities perspective, we thought before starting the project that the main advantage of a web-based system would be the obvious benefit of having access to the system from anywhere with an internet connection. But it turned out that this was incorrect, and we learned that this possibility to easily share results is an important selling point when creating new projects with other companies in the future.

Besides advantages, it should also be mentioned that the company also raised an important disadvantage with the web-based system, namely security vulnerability. In comparison to a locally installed program, a web-based system is considerably more vulnerable to malicious attacks. This is not only a risk in itself, but there is also a risk that the system is never adopted due to this aspect. Volvo Aero Corporation, similar to many other companies, has a strict IT
policy and very high security regulations, meaning that the system might not be accepted if not “fully” secure. For succeeding in introducing web-based systems in industry we therefore emphasize that it is of critical importance to put lots of efforts on security issues.

An additional disadvantage with a web-based system, not mentioned by the company but by the software developer, is limitations in the graphical user interface. The possibilities to create advanced graphical features in the web browser are complicated compared to desktop applications. It might therefore not be possible to achieve a perfect graphical look in a web-based system. However, along with more and more applications being made web-based this will start to change and the problem will most probably be non-existing in the future.

REFERENCES


AUTHOR BIOGRAPHY
ANNA SYBERFELDT is a senior researcher at the University of Skövde, Sweden. She holds a PhD in Computer Science from the De Montfort University, UK and a Master’s degree in Computer Science from the University of Skövde, Sweden. Her research interests include soft computing techniques and simulation-based optimization. Her e-mail address is <anna.syberfeldt@his.se>.

INGEMAR KARLSSON is a senior system developer at the University of Skövde, Sweden. He received his BSc degree in Computer Science from the University of Skövde. His main research interest is simulation-based optimization. His e-mail address is <ingemar.karlsson@his.se>.

AMOS NG is an Associate Professor at the University of Skövde, Sweden. He holds a B.Eng. degree and a M.Phil. degree, both in Manufacturing Engineering from the City University of Hong Kong and a Ph.D. degree in Computing Sciences and Engineering from De Montfort University, Leicester, U.K. He is a member of the IEE and a Chartered Engineer in the U.K. His research interests include production simulation, simulation-based optimisation, multi-objective optimisation, decentralised (agent-based) machine control systems. His e-mail address is <amos.ng@his.se>.