Developing a Discrete Event Simulation Methodology to support a Six Sigma Approach for Manufacturing Organization – Case study

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Abstract

Competition in the manufacturing industry is growing at an accelerated rate due to globalization trend. This global competition urges manufacturing organizations to review and improve their processes in order to enhance and maintain their competitive advantage. One of those initiatives is the implementation of the Six Sigma methodology to analyze and reduce variation hence improving the processes of manufacturing organizations. This paper presents a Discrete Event Simulation methodology to support a Six Sigma approach for manufacturing organizations. Several approaches to implement Six Sigma focus on improving time management and reducing cycle time. However, these efforts may fail in their effective and practical implementation to achieve the desired results. Following the proposed methodology, a Discrete Event Simulation model was built to assist decision makers in understanding the behavior of the current manufacturing process. This approach helps to systematically define, measure and analyze the current state process to test different scenarios to improve performance. The paper proposes a systematic process improvement approach which allows for constant refinement of a process until a state of perfection is achieved. It applies an action research strategy to develop and validate the proposed modelling methodology in a British manufacturing organization competing in global markets.

Keywords
Six Sigma, Discrete Event Simulation, Process Improvement, Action Research and Modelling

1 Introduction

According to The Engineer (2018), global manufacturing contributes to £6.7 trillion to the global economy. The UK automotive manufacturing industry turns over £80 billion year on year showing the growing competition for manufactures to implement process improvement techniques in order to stay competitive in local and global markets (SMMT, 2018). Initially developed as a methodology to measure defects and improve overall quality in manufacturing, Six Sigma in manufacturing seeks to reduce waste, improve quality of the product and in turn achieve more efficient operations.

Six Sigma originated at Motorola, where the process was focused on reducing variability in product and process in order to prevent defects (Sanders & Hild, 2007). The concepts underlying

Six Sigma deal with strong factors affecting manufacturing lead times, product and process costs, process yield, product quality and ultimately, customer satisfaction (Sanders & Hild, 2000). Six Sigma is made up of two methodologies, which are the Define, Measure, Analyze, Improve and Control (DMAIC) improvement cycle and Define, Measure, Analyze, Design and Verify (DMADV) method for improving new and existing products and processes.

This paper aims to develop a Discrete Event Simulation methodology to support a Six Sigma approach for manufacturing organizations. This methodology integrates the DMAIC improvement cycle, the Six Sigma technique to analyze and reduce variation, and the application of a Discrete Event Simulation approach to understand the behavior of processes and support improvement decisions. The proposed methodology is validated in the context of the manufacturing sector, specifically automotive. In this way, a model of a manufacturing process under study is constructed using a systematic approach for Discrete Event Simulation alongside the Define, Measure, Analyze, and Improve (DMAIC) improvement cycle. This approach will allow to understand the behavior of the current state process prior to simulate different scenarios to test the proposed solutions and implement changes for improvements. In this way, managers can be assisted in decision making to develop more effective improvement solutions aligned with strategic plans and goals.

The paper reviews relevant literature related to Six Sigma, Lean Thinking and the Discrete Event Simulation modelling technique. The paper continues with the development and implementation of Discrete Event Simulation methodology, including the application of process improvement techniques relevant to the DMAIC improvement cycle, the development of a cause and effect diagram, producing process decomposition maps and constructing the Discrete Event model. Finally, the paper presents the analysis of process variability and simulation of the model, outlining an action plan for future implementation. The model is simulated based on data collected from a manufacturing company in the UK. Applying simulation to action research have proven useful to companies to gradually implement changes to their processes. An action research strategy was established to support the development and implementation of the Discrete Event Simulation methodology in a British manufacturing organization competing in global markets.

2 Research Context

This research is conducted in a global manufacturing company with facilities worldwide. The organization is a leading supplier for combustion, hybrid and electric vehicles. The market is very demanding in terms of quality, responsiveness to orders and delivery times. With increasing change within the automotive industry, the organization aims to become more responsive and flexible by improving the performance of its manufacturing processes. The research was carried out in the UK facility of the global manufacturing organization. The manufacturing processes considered for this research included low volume/high variety products, with majority of the process heavily relying on skilled manual labor.

3 Research Methodology

Action research is an empirical research method concerned with the management of a change, solving real-world problems whilst simultaneously studying the experience of solving the problem (O'Brien, 1998) (Barber, et al., 2006). This research strategy involves close collaboration between practitioners and researchers, allowing the direct participation of problem owners. It is one of the ways of conducting research within an organization that can solve an immediate problem or a reflective process of a progressive problem. The action research strategy starts within a specific context of the problem to study and with a clear purpose. The action research strategy typically involves the following five stages in an iterative spiral (Rowley, 2003): (1) Diagnosis or fact finding and analysis, (2) Action Planning, (3) Decision about actions to be taken, (4) Evaluation of taken actions, and (5) Learning Specification (Susman & Evered, 1978). Action research involves actively participating in a change situation, often in a large organization, with the aim of improving strategies, practices and knowledge of the environment (Adelman, 1993). Once the initial research structure was outlined, an action research strategy was established to help defining the research objectives and to develop the Discrete Event Simulation methodology aligned with a Six Sigma approach. The research project involved working closely with managers and employees of the organization, which provided a greater understanding of the current state of the manufacturing process under study.

Following the first stage of the action research strategy to develop the modelling methodology, the diagnosis of the manufacturing process was carried out. This stage involved data analysis, conversations with managers and operators, Gemba walk and observations of the manufacturing process, including identification of the process flow. Several tools were used to support this analysis, such as cause and effect diagram and process flow. The conducted analysis lead to the identification of problems and selection and evaluation of key performance indicators (KPIs), such as work-in-progress (WIP), takt time, cycle time, setup time, productivity and skills of operators.

In the action planning stage of the action research strategy, meetings with production supervisors led to collaborate in producing ideas from different departments to consider potential courses of action. From this stage, a course of action is selected prior to collecting data. This included the selection of method to collect the data and to analyze this. This data will be used to populate the Discrete Event model and to simulate different scenarios to validate the proposed modelling methodology.

The evaluation stage and learning specification of the action research strategy was carried out systematically after each period of collection and analysis of data for different family of parts being produced in the manufacturing process under study. The action research strategy has been applied in a systematic and iterative manner during the development of the Discrete Event Simulation methodology.

4 Literature review

4.1 Six Sigma

In the early and mid-1980s, Motorola decided that traditional quality levels, didn’t provide an adequate solution. Instead they wanted to measure the defects per million opportunities. Motorola developed this new standard and created the new methodology associated with it (Hahn & Doganaksov, 2000). By 1988, they received the Malcom Baldrige National Quality Award, which lead to the use of Six Sigma in almost every industry.

Six Sigma is defined as a business process that follows companies to drastically improve their bottom line by designing and monitoring everyday business activities in ways that minimize waste and resources while increasing customer satisfaction by some of its proponents (Andersson, et al., 2006).

It is an highly disciplined approach that typically involves the five stages Define, Measure, Analyze, Improve and Control which is also known as DMAIC. These steps, in brief are (Kakkad & Makwana, 2017):

- Define (D) – Define the problem statement, goals and identify factors that are critical to quality.
- Measure (M) – Collect data for all the processes involved in achieving the goal. This data will be used to carry out comparative tests.
- Analyze (A) – Understand the root causes of why the defects occur; identify key process variables that cause defects.
- Improve (I) – Implement potential corrective and preventive measures, thereby reducing defect levels.
- Control (C) – Ensure the modified process now keeps the key improved variables within the acceptable limits, in order to maintain long term improvement.

While there are many definitions of the six concept, it is understood to represent a systematic approach to identifying and eliminating elements which do not add value to the product. The methodology describes 8 types of waste (Ghobadian, et al., 2018):

- Defects – Products that are out of specification
- Over Production – Producing too much of the product
- Waiting – For parts, information, instruction, equipment from previous workstation
- Skills – Underutilizing capabilities
- Transportation – Transporting items or information that is not required to perform the process from one location to another
- Inventory – Holding material or information ahead of requirements
- Motion – Moving people, products, and information more than required
- Over Processing – Performing any activity that is not necessary to produce a function product

4.2 Discrete Event Modelling and Simulation

The development of production systems is a complex task therefore strategies such as the use of Discrete Event Simulation (DES) makes it easier to find problems prior to making changes. Some authors applied animation resources integrated with DES models to make it easier to validate the process of the model under study to accomplish its credibility (Woo, et al., 2014), (Laurindo, et al., 2019).

Discrete Event Simulation (DES) is the process of defining the behavior of a complex system as an ordered sequence of defined events. Within this context, an event involves changing the system’s state at a specific point of time such as resources fail, operators take breaks, shifts change etc. (Rose, 2019). DES can statistically provide valid estimates of performance measures associated with these systems, such as the number of parts waiting in a particular queue or the longest waiting time a particular customer might experience (Sweetser, 1999). Therefore, DES methodology is disciplined in terms of capturing the structure of an existing or proposed system. The simulation will validate improving the process prior to implementation as this is often costly without the actual benefits difficult to justify prior to implementation (Heshmat, et al., 2013).

A major part of DES models are often build from process maps, or flow charts. These maps can also assist in clarifying important relationships and processes. Although there are exceptions, DES consists of a great deal of effort in capturing and analyzing process maps, variances and distributions, but once entered into the model these parameters remain fixed. The accuracy of historical data or estimates of future performance are required to populate the model and produce statistically valid results.

5 Building a Discrete Event Model for manufacturing process

The proposed methodology reflects on the following phases to develop the DES methodology to support a Six Sigma approach: (1) Define the purpose of improvement; (2) Fishbone diagram to understand the root cause; (3) Map the current state of the process; (4) Carry out a stopwatch analysis; (5) Construct the Discrete Event model; (6) Populate the model with accurate timings; (7) Analyze and simulate of the current state model; (8) Simulate different scenarios to test potential solution for improvement; (9) Produce an action plan to implement the proposed solution, and (10) Establish a continuous improvement approach. This systematical methodology is aligned with the DMAIC, Six Sigma approach. Section 5.1 of this paper explains the development of phases 1 and 2. Section 5.2 elaborate de development of phase 3, mapping the current state of the process. Section 5.3 includes the stopwatch analysis. Section 5.4 explains the construction of the Discreet Event model. The analysis and simulation of the current state of the manufacturing process are included in section 5.5. Phases 8 to 10 are beyond the scope of this paper and these will be addressed in a future paper.

5.1 Define the Purpose of Improvement and Understand Root Causes.

This phase of the DES methodology is aligned with the Define stage of the DMAIC improvement cycle. At this stage, it is important that the objective statement of the research defines, in measurable and time-bound terms, the target of performance to achieve in terms of improvement. In this case, the objective statement defines the purpose of the initiative to be the improvement of productivity by 5% of the specified manufacturing process. This statement can be adjusted once the root causes are determined during the analysis phase.

The Discrete Event Simulation methodology was started by using the DMAIC process. The Define stage of the Six Sigma approach is completed by using a fishbone diagram. This method is used to represent the different parameters that can be analyzed to improve the process. The cause and effect diagram will be validated by holding meetings with managers to measure a singular parameter. This tool provides a systematic way of identifying possible causes that create or contribute to the detected affect (Ilie & Ciocoiu, 2010). Thus, the fishbone is also beneficial to identify areas (root cause of a problem) to collect relevant data (Basic tools for process improvement, 1995). Figure 1 shows a fishbone diagram elaborated to identify the possible causes affecting the required level of productivity in the manufacturing process under study.

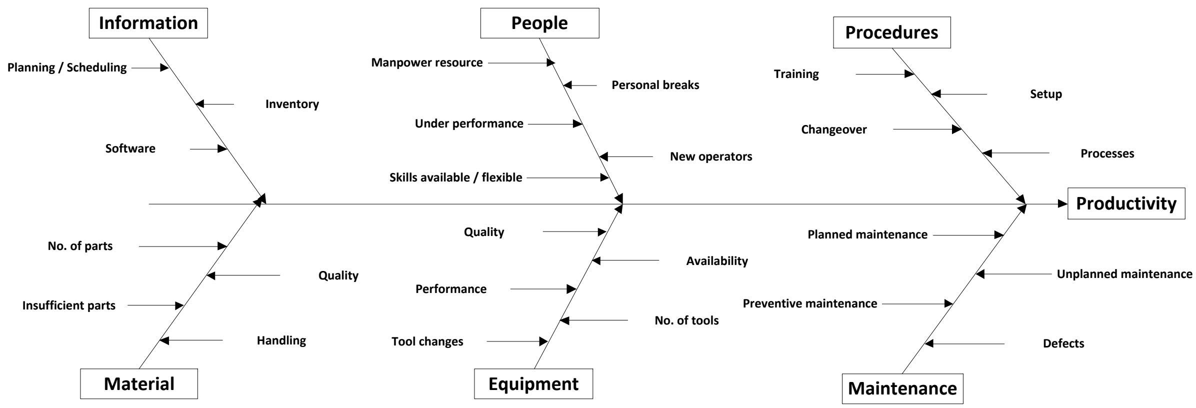

Figure 1. Cause and effect diagram

5.2 Mapping the Current State of the Manufacturing Process

From the cause and effect diagram, it was agreed upon to inspect the current state of the manufacturing process and observe any variations in its performance. Figure 2, shows a process map of the assembly line that is being analyzed. The process map, consists of 3 main process with queues in between them. It should be duly noted the maximum queue size in between each process is 3 and all the process have a singular operator. Figure 3, shows process 1 broken down into two separate workstations noted as WS1 and WS2. At each of the workstations there is 1 operator manually making changes to the product. At Process 2, there is 1 operator using a machine to add value to the product and Process 3 shows 1 operator manually adding value. This process flow diagram is used to analyze the system as it shows a simple diagram of the current process. This will be used to complete the next stage as the time measurements will be taken based upon deeper analysis of these processes.

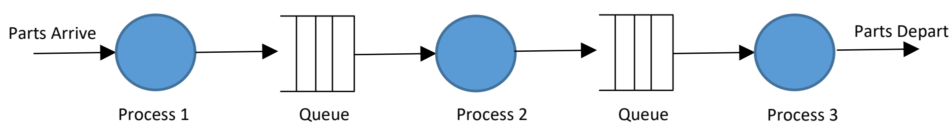

Figure 2. Graphical view of the manufacturing assembly line

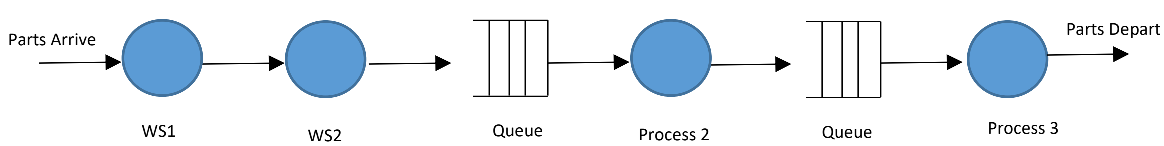

Figure 3. Process flow diagram

5.3 Stopwatch Analysis

The second phase within the DMAIC methodology is the measure phase. This section includes using a stop watch time study to measure the time taken by an operator. This time study is completed by the author measuring the time taken to complete a single processes over a period of 10 runs. The values contained in table 1, 2 and 3 show the average time. The stopwatch considers different operators using each machine and only takes into account model A. Table 1, shows there are 7 sub-process included within WS1 which are completed by a single operator. Table 2, shows there are 7 process included on this workstation 2 and is completed by a different operator. Table 3, shows the time taken for Process 2, which heavily relies on a machine. Table 4, shows there are 4 sub-process prior to the part leaving the assembly line.

Process 1 – WS1	
Process	Average time (seconds)
Sub-process 1	5
Sub-process 2	15
Sub-process 3	10
Sub-process 4	5
Sub-process 5	5
Sub-process 6	5
Sub-process 7	5
Total time	50

Table 1. Timings for process 1 – workstation 1

Process 1 – WS2	
Process	Average time (seconds)
Sub-process 1	55
Sub-process 2	10
Sub-process 3	5
Sub-process 4	45
Sub-process 5	5
Sub-process 6	10
Sub-process 7	5
Total time	135

Table 2. Timings for Process 1 – workstation 2

Process 2	
Process	Average time (seconds)
Sub-process 1	10
Sub-process 2	20
Sub-process 3	35
Sub-process 4	10
Sub-process 5	35
Total time	110

Table 3. Timing for process 2

Process 3	
Process	Average time (seconds)
Sub-process 1	5
Sub-process 2	35
Sub-process 3	15
Sub-process 4	10
Total time	65

Table 4. Timings for process 3

5.4 Construct and Populate the Discrete Event Model

This stage of the process allows to create a simple model based upon the current process map and stopwatch analysis. Within this stage, the model is created using Discrete Event Simulation to show how accurate the values are in comparison to reality. This is shown in Figure 4. The initial values of the model consisted of the parts arriving to the line:

- Random (exponential) value = 20.
- Maximum Arrivals = 20

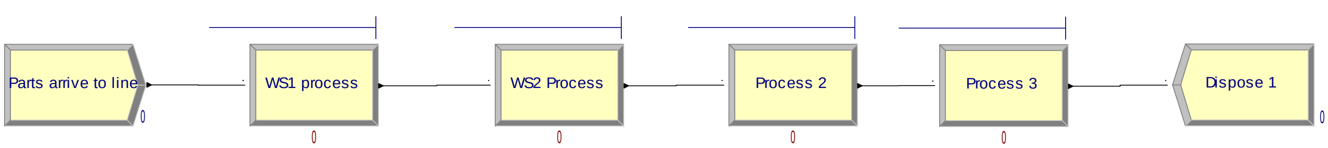

Figure 4. DSE simulation

5.5 Analyze and Simulate of the Current State Model

This section includes the Analyze phase of DMAIC. Within this phase, the simulation results are discussed and various conclusions are made. Within this phase key outputs are:

- Identification of key reasons for problems
- Identification of the difference between current and target performance
- Estimation of resources required to achieve target
- Identification of possible obstacles

The results from the Discrete Event Simulation model are shown in Table 5. To validate the model, the entire process was compared to that found on the assembly line. The analysis showed the current state of process including the total time to create 25 parts.

Using this data it is visible to show there is a large amount of wait time within the process. The process shows there is a high number of parts waiting in WS2. Figure 5, shows the utilization of resources within this process. This shows the part is spending a vast amount of time at workstation 2. Therefore, for the initial analysis it could be said the operator at Process 2 and Process 3 are idle and are not being used in the correct manner.

Type	**Average time (Minutes)**
Number In	25.00
Number Out	25.00
Total Time	28.01
Value-Added time	5.50
Wait Time	22.53
WIP	11.67
WS1 Queue	5.65
WS2 Queue	16.87
Process 2 Queue	0.00
Process 3 Queue	0.00
Number Waiting WS1	2.36
Number Waiting WS2	7.03
Number Waiting Process 2	0.00
Number Waiting Process 3	0.00

Table 5. Results from DSE

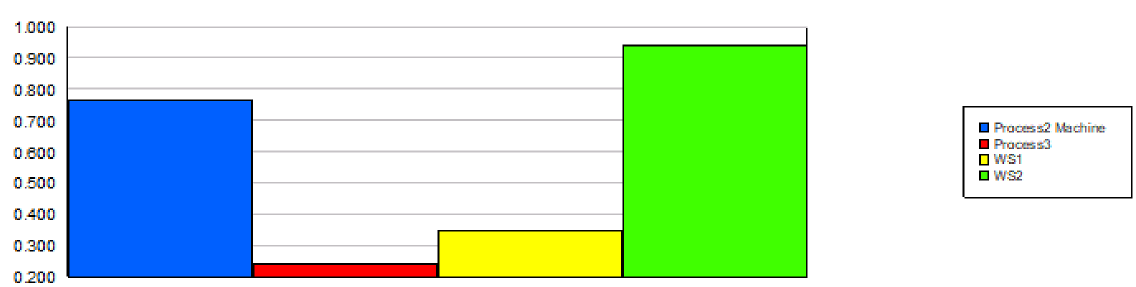

Figure 5. Utilization of resources

6 Conclusion and Future work

This paper presents a Discrete Event Simulation methodology to support a Six Sigma approach for manufacturing organizations.

The methodology includes the analysis and construction of a Discrete Event Simulation model to support decision makers, planners and managers in understanding the behavior of the current state of the manufacturing process under study. This will help them to be better informed to support their decisions in improving the manufacturing process. The DES model is constructed integrating the DMAIC improvement cycle, the Six Sigma technique to analyze and reduce variation, and the application of a Discreet Event Simulation approach.

The paper proposes a systematic process improvement approach which allows for constant refinement of a process until a state of perfection is achieved. The paper applies action research to validate the proposed methodology in a British manufacturing organization competing in global markets. Thus, the analysis, development and validation of a Discrete Event model of an assembly line of a British manufacturing organization in the automotive sector is described in the paper. The constructed model of the assembly line highlighted the need to improve the current state process due to high waiting time and queue time within the existing process.

This proposed systematic methodology could be implemented in manufacturing organizations to support the analysis and improvement of process performance and the successful implementation of their Six Sigma initiatives. The methodology can be improved further in the near future by addressing the following issues:

- Further action research is needed to analyze and implement the methodology in other assembly lines and collecting data considering a longer period of time.
- Combine the DES methodology with other modelling techniques (e.g. System Dynamics) to analyze the effect of strategic factors (internal and external) on manufacturing processes.
- Validate the DES methodology with data collected from other assembly lines.
- Create a detailed action plan for the implementation of improvements.

References

Adelman, C., 1993. Kurt Lewin and the origins of the action research. *Educational action research,* 1(1).

Andersson, R., Eriksson, H. & Torstensson, H., 2006. Similarities and differences between TQM, six sigma and lean. *The TQM Magazine,* 18(3), pp. 282-296.

Barber, K. D., Munive-Hernandez, E. J. & Keane, J. P., 2006. Process-based knowledge management system for continious improvement. *International journal of quality & reliability,* 23(8), pp. 1002-1018.

Basic tools for process improvement, 1995. *Cause and effect diagram.* [Online] Available at: https://www.balancedscorecard.org/Portals/0/PDF/c-ediag.pdf [Accessed 30 October 2018].

Corbett, S., 2007. *Beyond manufacturing: The evolution of lean production,* Dubai: Mckinsey's & company.

Garza-Reyes, J., Tangkeow, S., Kumar, V. & Nadeem, S., 2018. *Lean manufacturing adoption in the transport and logistics sector of thailand - an exploratory study.* Bandung, Indonesia, Proceedings of the Internation conference on industrial engineering and operations management, pp. 6-8.

Ghobadian, A. et al., 2018. Examining legitimisation of additive manufacturing in the inerplay between innovation, lean manufacturing and sustainability. *Internation Journal of Production Economics,* pp. 1-12.

Hahn, G. J. & Doganaksov, N., 2000. The Evolution of Six Sigma. *Quality Engineering,* 12(3), pp. 317-326.

Heshmat, M., El-Sharief, M. A. & El-Sabaie, M. G., 2013. *Simulation modelling of production lines: A case study of cement production line,* Assiut: Assiut University.

Ilie, G. & Ciocoiu, C. N., 2010. Application of fishbone diagram to determine the risk of an event with multiple causes. *Management research and practice,* 2(1), pp. 1-20.

Kakkad, G. P. & Makwana, H. H., 2017. Quality improvement in forging industry by using DMAIC process. *International Journal of Emerging Technologies and Innovative Research,* 4(6), pp. 54-58.

Laurindo, C. M. G., Túlio, P. A. & Rangel, J. J. d. A., 2019. Communication mechanism of the discrete event simulation and themechanical project softwares for manufacturing systems. *Journal of Computational Design and Engineering,* Volume 6, pp. 70-80.

O'Brien, R., 1998. *An overview of the methodological approach of action research.* [Online] Available at: www.web.ca/~robrien/papers/xx%20ar%20final.htm [Accessed 26 January 2019].

Rose, M., 2019. *Discrete event simulation (DES).* [Online] Available at: https://whatis.techtarget.com/definition/discrete-event-simulation-DES [Accessed 29 Jan 2019].

Rowley, J., 2003. Action research: an approach to student work based learning. *Education & Training,* 45(3), pp. 131-138.

Sanders, D. & Hild, C., 2000. A discussion of strategies for six sigma implementation. *Quality Engineering,* 12(3), pp. 303-309.

Sanders, D. & Hild, C., 2007. A discussion of strategies for six sigma implementation. *Quality Engineering,* 12(3), pp. 303-309.

Sarkar, D., 2009. *8 Wastes of Lean Manufacturing in a Services Context.* [Online] Available at: https://www.processexcellencenetwork.com/lean-six-sigma-business-performance/columns/8-wastes-of-lean-manufacturing-in-a-services-conte [Accessed 02 July 2018].

SMMT, 2018. *SMMT Motor Industry Facts 2018,* London, United Kingdon: The society of motor manufactures and traders limited.

Susman, G. I. & Evered, R. D., 1978. An Assessment of the Scientific Merits of Action Research. *Administrative Science Quarterly,* 23(4), pp. 582-603.

Sweetser, A., 1999. A comparison of system dynamics (SD) and Discrete event simulation (DES). *International conference of system dynamics society.*

The Engineer, 2018. *UK Manufacturing Statistics.* [Online] Available at: https://www.themanufacturer.com/uk-manufacturing-statistics/ [Accessed 16 December 2018].

Woo, J. H., Nam, J. H. & Ko, H. K., 2014. Development of a simulation method for the subsea production system. *Journal of Computational Design and Engineering,* 1(3), pp. 173-186.

Biographies

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