Application of the quick scan audit methodology in an industrial filter production process

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Abstract: The quick scan audit methodology (QSAM) is an established investigative tool to assess the health of business processes and supply chains within short schedules. This study extends the standard QSAM procedure to include the simulation step. It also extends the QSAM to a wider industry platform by applying it into the precision mechanical engineering industry, where managers have been under competitive pressure to reduce an industrial filter production lead time. Following a review of the relevant literature, this paper presents the research design adopted in the study. The QSAM has been conducted using various data collection techniques (such as observations, process activity mapping, interviews, questionnaires, brainstorming and access to company documents) and data analysis methods (including cause and effect analysis, Pareto analysis and time series plot). This is followed by the development of a set of improvement strategies, namely direct information sharing, priority planning, and additional data recording and analysis. In addition to testing the potential benefits of changing scheduling approaches for the paint plant, simulation has been utilised in this study as a communication means to increase employee participation in the QSAM process and enhance the audit accuracy. It has also provided the case company with a better understanding of the behaviour and characteristics of the system under study, thus facilitating more thoughtful decisions to improve the system. The paper concludes with further research opportunities derived from this study.

1. Introduction

Operations and supply chain improvement approaches have developed widely over the years, ranging from Total Quality Management (TQM) and Business Process Reengineering (BPR) to lean and agile concepts (Salama *et al.*, 2009; Hopp and Spearman, 2008). However, there is a key component often missing from all this - a framework that can make sense of the underlying operations (Hopp and Spearman, 2008). This is further complicated by today's operating and supply chain systems, which are often complex, multi-functional and multi-organisational in nature. The size and complexity of such systems, their stochastic nature, the inter-relationships between system components, and human bounded rationality make system behaviour counterintuitive and difficult to predict or manage (e.g. Surana *et al.*, 2005; Wycisk *et al.*, 2008). The practical context of these systems is also affected by the social setting, political landscape and industry norm (Chillderhouse and Towill, 2011b). However, to embark on business improvement initiatives, an important pre-requisite is to fully comprehend the current state of business processes and supply chains (Naim *et al.*, 2002). Therefore, there is a need for a systematic and holistic audit methodology to conduct a comprehensive assessment of a complex phenomenon. This study focuses on such an investigative technique, namely the Quick Scan Audit Methodology (QSAM). The QSAM has been applied in a wide range of industrial sectors (including automotive, dairy, electronics, retailer, timber, steel and utilities) and organisational settings (including global, medium, SME and family-run businesses) (e.g. Childerhouse and Towill, 2011a &b). Furthermore, it has been used ranging from a single focal organisation to a multi-echelon supply chain (Childerhouse and Towill, 2011b). This study further extends the QSAM to a wider industry platform by applying it into the precision mechanical engineering industry. This opportunity for a QSAM audit arose when the case study company (hereafter called Company X) sought guidance on improvement possibilities for reducing lead times. Among other improvement recommendations, the audit over a short timescale has led to the identification of the process improvement initiative of reducing changer-over time. This confirms Schmenner's (1988) view that lead time reduction does not necessarily mean operating the fastest machines or having the most automation, but it can mean designing and organising the factory so that materials are moving forward through well-maintained equipment with short change-over times.

Company X is a manufacturer of filtration and separation products based in the UK. It is one of the principle operating divisions of a world-leading firm of motion control technologies and systems, with over 300 manufacturing locations around the world. Company X operates in a high product variety, low volume environment and its customer base is wide and includes oil and gas drilling, medical, industrial construction and aerospace markets. In this highly specialised, precision-engineering oriented industry where reliability and safety is synonymous with the importance of the product, an emphasis has been long placed on product quality according to industry standards. However, Company X has been faced with increasing amounts of pressure from customers and competitors over the past two years. The case company needed to address lead time issues to compete in market and the management team identified the need for reducing production lead time. Following the merging of production lines across the two plants, Company X had applied lean tools to tackle the issue of eliminating waste, however lead time was still a barrier for improving business performance and enhancing customer satisfaction. The management team thus decided to have an external look at their operation. We obtained a mandate to perform a diagnostic study of the case company's operations and supply chain system and identify potential improvement opportunities. In particular, Company X expressed its desire to improve the process in order to increase the efficiency of its plant in the short term, while considering heavy investment on automating the production line in a long

term. Therefore, this project was initiated, with team members consisting of researchers in collaboration with the company's lean team and production planning manager.

The project is oriented around conducting a "health check" of Company X's production process using a QSAM procedure. The QSAM is aimed at understanding and documenting all or parts of the supply chain and associated material, information, cash and resource flows and then to identify improvement opportunities (Lewis *et al.*, 1998). Data extracted from the QSAM process is analysed using systems thinking principles (Böhme *et al.*, 2013), to ensure that the causes of uncertainty are addressed in a holistic way. The company was also attracted by QSAM's capability to develop "quick-hit" solutions and short-term benefits, and identify medium- and long-term improvement opportunities, which can provide various components for a business process improvement (BPI) programme. Therefore, this project provided the researchers with the opportunity: (1) to apply the QSAM to identify the main constraints and gaps along the industrial filter production process, and make recommendations for improvements; and (2) to explore whether any adaptation of the QSAM is required to fit the demands of auditing this specific case company in a new industry setting. This paper proceeds by reviewing the relevant literature on the QSAM in Section 2. Section 3 discusses the research design and particularly the procedure involved in conducting the research, while Section 4 presents data analysis and findings including improvement recommendations. This is followed by the discussions of the findings in Section 5. Section 6 concludes with possible opportunities for further research.

2. Literature Review

This section provides a review of the relevant literature on the QSAM. It also explores the applicability of the QSAM to our project with Company X compared to other possible diagnostic approaches.

2.1 Operations and Supply Chain diagnostic Tools

Any improvement project must start with an evaluation of the current state of practices and performance (Watson, 1994; Christopher, 1998; Hopp and Spearman, 2008), laying a foundation for pointing out which best practices are to be pursued. Various tools and frameworks have been developed to diagnose specific business areas such as inventory management, demand forecasting, production and distribution, and logistics (e.g. Hax *et al.*, 1980; De Vries, 2007; van Landeghem and Persoons, 2001). However, as competition has increasingly become supply chain vs. supply chain (instead of individual company vs. company) (Christopher, 1998), the migration from single businesses with functional units towards supply chain wide processes is a common theme in current management paradigms such as business process re-engineering, lean thinking and agile production (Naim *et al.,* 2002). Major opportunities for improvements often lie at the interfaces, e.g. between sales and manufacturing, or between product development and manufacturing (Hopp and Spearman, 2008). Therefore, there is a need to understand the total business system behaviour particularly within the context of the supply chain. Recent years have seen a range of different operations and supply chain auditing tools that have been developed to address this (for a review see Foggin *et al.*, 2004; Salama *et al.*, 2009).

Most supply chain diagnostic approaches reported in literature require a significant investment in time to complete, and some need detailed and precise quantitative data (Gardner *et al.*, 2005; Foggin *et al.*, 2007). However, in addition to the lack of quantitative data in practice, it may not be feasible to undertake both resource and time-consuming diagnostics particularly when there is considerable pressure to solve the audit problem as an urgent priority, which is indeed

the case for our project with Company X. There is thus a need to provide an insight into a company's operations over a relatively short timescale. Foggin *et al.* (2004) developed the Diagnostic Tool, which assists a third-party logistics (3PL) provider in obtaining critical information regarding the state of a client's supply chain operations within 2 hours, such as in a sales call. Based on a qualitative questionnaire (with a total of 140 questions), the Diagnostic Tool aims to identify potential problems that the 3PL provider can cover for its clients. Similarly, Netland and Alfnes (2011) proposed a quick maturity test to assist the development of a company's supply chain operations strategy. While providing an invaluable quick initial assessment, such diagnostics offers low level of data detail and limited opportunity for information validation. Furthermore, no audit can be considered successful unless it provides a thorough understanding of how the constituent elements of an organisation interact with one another (Salama *et al.*, 2009). Such interactions of people, processes and technology frequently constrain the system's performance (Towill, 1997).

With a quick but accurate assessment of the company's current situation being one of the main objectives, Salama *et al.* (2009) developed a methodology which uses predefined master causal relationship maps based on best practices from the Supply Chain Operations Reference (SCOR) model and leading industry companies. The SCOR model is the most widely used reference model which integrates the concepts of business process engineering, benchmarking, process measurement and organisational design into a cross-functional framework (SCC, 2010). The SCOR model can serve as a diagnostic tool for supply chain management. It can facilitate the evaluation and comparison of supply chain performance across companies or industries, and help managers identify opportunities for improvement. However, Lambert *et al.* (2005) have called for the further assessment of the performance benchmarking data used in the SCOR, in view of the scepticism of the value of benchmarking data collected by survey. Furthermore, in addition to the perils of benchmarking (Denrell, 2005), it is important to acknowledge that, when seeking to identify top-performing organisations with a view to adopting their best practices, context impacts organisational performance (Böhme *et al.*, 2014). As well as the industry context, the motivation of the respondent has a direct effect on the accuracy and meaning of any data collected (Childerhouse and Towill, 2011b). To fully appreciate the social context, observation-based on-site research that triangulates data from different sources and collection methods is essential (Childerhouse and Towill, 2011b). This has motivated the development of an on-site audit tool, so called quick scan audit methodology, which will be the focus of the next sub-section.

2.2 Quick Scan Audit Methodology (QSAM)
The QSAM was developed in the 1990s by Cardiff University's Logistics System Dynamics Group to assess the health of business processes and supply chains within short schedules (Naim *et al.*, 2002). It has been specifically designed to minimise the disturbance to the target organisation(s) (Childerhouse and Towill, 2011b). The scope of this diagnostic approach can vary from company to company depending upon the issues encountered by each company and the relative complexity and size of their operations and associated supply chain capabilities. Typically, the QSAM consists of a preliminary presentation (half a day), on-site data collection (two days), data analysis (three days), a single feedback presentation to management (half a day), followed by the report write-up phase (three days). It is important to note that the QSAM is a team-based approach involving "players" from the host organisation (ensuring investigator triangulation). This is coupled with a verification feedback presentation, thus enhancing the reliability of the audit. The data is collected during the QSAM using observation, questionnaires, process mapping, interviews, and review of archival information (Naim *et al.*,

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2002). In addition to this data source triangulation, the combination of quantitative and qualitative QSAM data provides further methodological triangulation.

An important feature of the QSAM is that the issues identified during the audit process are analysed using systems thinking in order to yield a cause-effect diagram (Naim *et al.*, 2002). The theoretical basis for this QSAM analysis is system-engineering principles which involve feedback thinking and process control theory (Parnaby, 1979; Childerhouse and Towill, 2011a), as illustrated in Figure 1. Consequently, those issues encountered by a business in the supply chain are categorised into four uncertainty areas, namely supply side, process side, demand side and control side. For example, a business may find uncertainties associated with excessive downtimes of its manufacturing equipment (process), changing customer schedules due to poor voice of the customer data capture and erratic demand profiling (demand), poor supplier delivery performance (supply), and inaccurate and distorted process control. The degree of uncertainties identified in the QSAM has been found to be highly correlated with the levels of supply chain integration and maturity (Lockamy *et al.*, 2008; Childerhouse *et al.*, 2011). The resultant output of the QSAM uncertainty analysis is targeted at unearthing causal relationships (Naim *et al.*, 2002). Salama *et al.* (2009) have revealed that lack of the identification of causal relationships during the diagnostic stage represents a major threat to a business improvement project's success. In addition to the identification of short-term improvements actions ("quick hit"), the QSAM is also capable of defining longer-term action plans for the supply chain (Naim *et al.*, 2002; Childerhouse and Towill, 2011b).
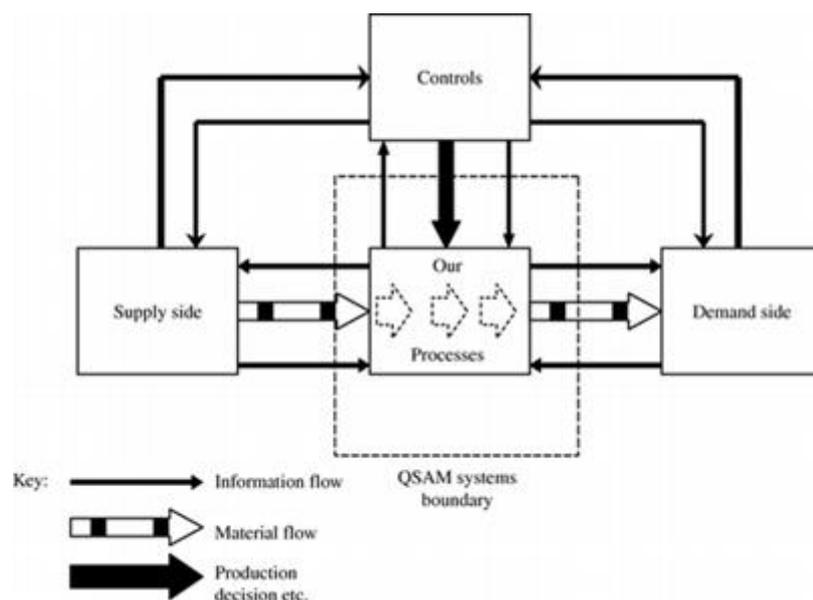

Figure 1. Systems view of QSAM (*Source: Childerhouse and Towill, 2011a*)

2.3 Evolution and adaptation of QSAM

Over the years QSAM has been refined in light of experience (Towill and Childerhouse, 2006), e.g. with shorter cycle time and increased research intensity (Böhme *et al.*, 2008). Its application in SME settings has further broadened the scope of inquiry to include strategic management and human resource consideration in order to comprehend the business imperatives and staffing issues (Böhme *et al.*, 2013). Furthermore, Böhme *et al.* (2013) have adapted the QSAM to a public (healthcare) sector. Meanwhile, the weaknesses of the QSAM have not gone unnoticed in literature. They include that it (1) offers limited opportunity for the

business employees to participate as team members, (2) requires a considerable amount of tacit knowledge from the team members, and (3) is not easily transferable to businesses as a change management tool (Naim *et al.*, 2002). In diagnosing problems and developing improvements to production planning processes, Atilgan and McCullen (2011) have adapted the QSAM to include some change management practices. They have related how a company's dissemination feedback sessions and implementation team-work added value to the QSAM. For example, a feedback session not only increased "buy-in", but provided enhanced verification of the QSAM results, as the presentation audiences also included the interviewees.

In its original form, QSAM addresses supply chain improvement through the identification of short-term actions, which target non-value adding activities typified in lean thinking (Childerhouse *et al.*, 2010). The mapping of a value stream has been used as a starting point for identifying improvement opportunities and supported the initial processes of QSAM (Childerhouse and Towill, 2011b). The main focus of value stream mapping (VSM) is on differentiating between value-adding and non-value-adding activities in processes, and tracking wastes towards making process improvements (Hines and Taylor, 2000; Seth and Gupta, 2005). VSM is also well recognised as a functional method to reorganise manufacturing structure with a vision of eliminating waste and leading to the achievement of leanness in practice (Hines and Taylor, 2000; Serrano Lasa *et al*., 2009). Thomas and Barton (2011) have further proposed the use of QSAM as a precursor to the implementation of Lean Six Sigma (LSS) projects in small and medium manufacturing enterprises. Through a case study, they have shown how the implementation of the QSAM into the design, development and early stage implementation of a LSS project has provided a simple yet effective method to achieving improvements in the project performance. While identifying opportunities for improvement in many aspects of businesses (Naim *et al.*, 2002; Childerhouse *et al.*, 2010; Atilgan and McCullen, 2011; Childerhouse and Towill, 2011a), the QSAM also yields rich empirical data to test and further investigate various issues including supply chain integration, time compression, the bullwhip effect and simplified material flow (Potter *et al.*, 2009; Childerhouse and Towill, 2011b).

To sum up, QSAM is an established tool for accurate assessment of production processes within a short timeframe, resulting in a wide range of improvement opportunities. The systems perspective embedded in QSAM ensures that the causes of uncertainty are addressed in a holistic way thus yielding the identification of the cause and effect nature of business processes and supply chains. Since its inception, QSAM has evolved and adapted over time. This study is further to (1) examine its application in the precision mechanical engineering industry; and (2) identify what refinement is required in this new industrial setting.

3. Research Design

This study investigates a production process in a UK manufacturer of industrial filter products, where managers have been under competitive pressure to reduce production lead time. To evaluate the production process and recommend opportunities to reduce lead time, an adapted QSAM was adopted. An overview of the major steps involved in conducting the audit is shown in Figure 2. The buy-in obtained is a matter of outlining the perceived problem and the QSAM. In their previous attempt to reduce production lead time, the management team conducted initial research and chose Product A to focus on, as it contributed the highest profits to Company X. After Product A had been identified for improvement, VSM was adopted to give an overview of the flows of both material and information within the overall supply chain. While this mapping had been conducted before this project started, the management team was

keen to involve academic assessment to ensure that their mapping was observed objectively. Therefore, the project team accomplished the VSM from scratch (see Figure 3), which also defined the scope of the process mapping later in the QSAM. It is also worth noting that, as a result of the initial lean project, the culture for improvement at Company X was strong, and staff were willing to go an extra mile to help improve processes.

As can be seen from Figure 2, this study has largely followed the standard QSAM procedure (Naim *et al.*, 2002; Childerhouse and Towill, 2011b). However, as well as benefiting from the previous lean project at Company X, the application of simulation in this study also represents something of a departure from the standard QSAM. While it might be possible to experiment with the actual physical system, in many cases, it is just too difficult, costly, or impossible to do physical studies on the system itself (Pidd, 2004). Considered against real experimentation, simulation is (1) less costly. Real experiments may turn out to be extremely expensive particularly if something goes wrong; and (2) time efficient. It is possible to simulate weeks, months or even years in seconds of computer time. Hence a whole range of policies may be properly compared (Pidd, 2004; Kelton *et al.*, 2014). More specifically, we have used a discrete-event simulation (DES) model for this study. We have chosen the DES as we are interested in (system) behaviour changes at an instant of time (an event) with constant behaviour between the events. By contrast, continuous models represent continual changes, often using differential equations, so that the behaviour in the model is always altering. In business systems it is usually unnecessary to model changes continuously and often the important aspects of the system do change in a discrete way (Brooks and Robinson, 2001). DES has long been a tool for analysis of operations and supply chain systems and it is capable of stochastic situations and the inter-relationships between system components (Manuj *et al.*, 2009; Jeon and Kim, 2016). This level of insight may not be evident within the VSM and process mapping, both of which tend to be static representations of the system, e.g. focusing on the average time duration of each activity (Potter and Lalwani, 2007). In conjunction with computing simulation, variability and dynamic changes in system parameters can be effectively captured (Parthanadee and Buddhakulsomsiri, 2014). This insight, as well as the quantification of potential benefits in the simulation, has further increased buy-in of improvement recommendations developed from the QSAM, thus lowering resistance to change needed for their implementation.

In the context of this study, employees were actively involved in the development of the simulation model, which forms part of validation and verification of the simulation model (Kleijnen, 1995; Kelton *et al.*, 2014). To verify and validate the simulation model, we developed an animation to visualize all types of scenarios we considered in our analysis. We then showed the animation to the employees who are the most familiar with the actual system and obtained their acceptance of our model as an accurate representation of their system. Where accurate records on the actual system (e.g. cooling time) do not exist, we have used the best judgement of the employees. In this context, the key for the verification and validation process has been that both the QSAM team and the employees have confidence in the results from the simulation model. Company X also found this involvement and participation of their employees to be very useful, providing a better understanding of the behaviour and characteristics of their system and thus facilitating more thoughtful decisions to improve the system.
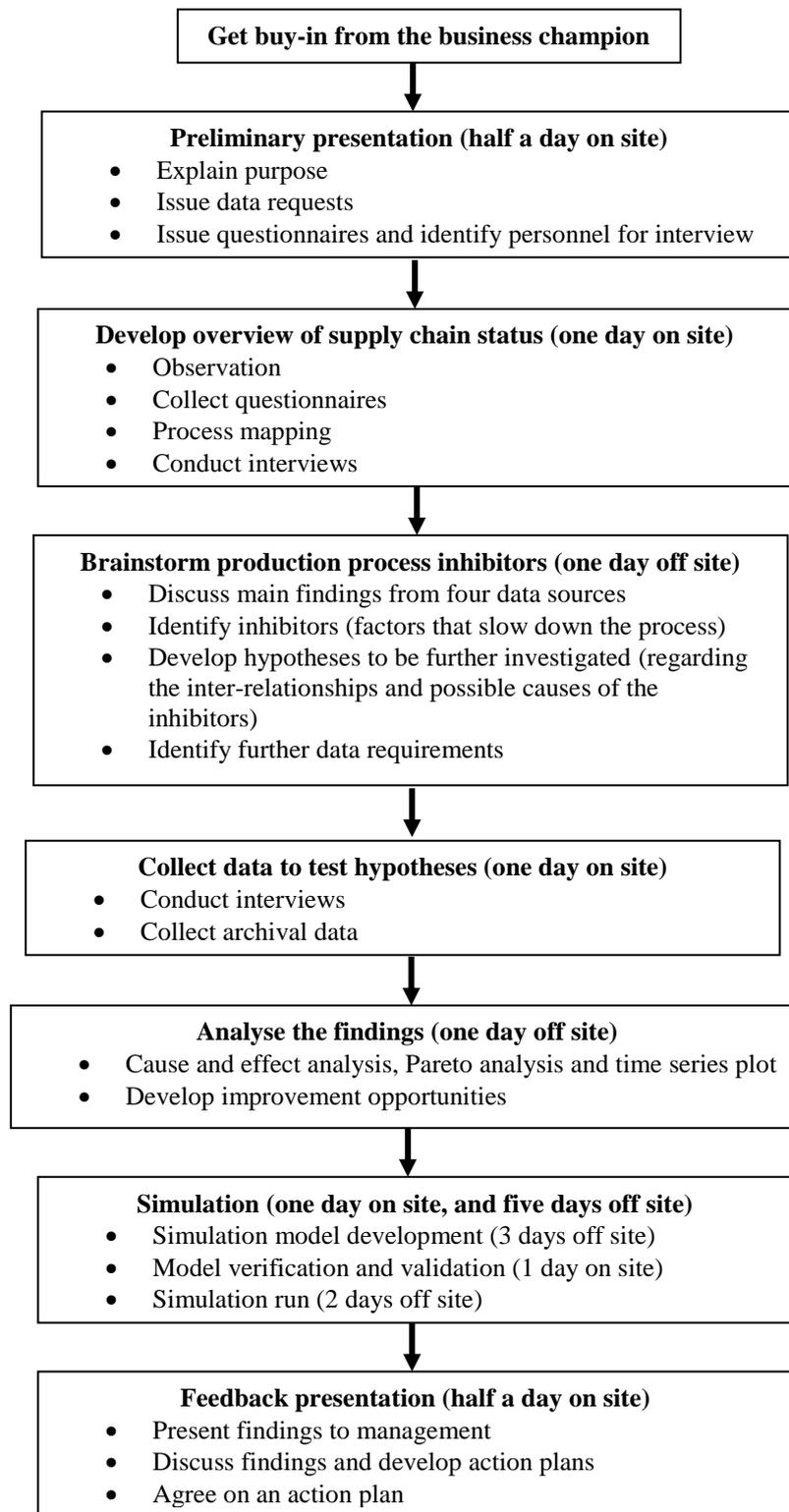
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│    Get buy-in from the business champion      │
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┌─────────────────────────────────────────────┐
│   Preliminary presentation (half a day on site)│
│     •  Explain purpose                         │
│     •  Issue data requests                     │
│     •  Issue questionnaires and identify personnel for interview │
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┌─────────────────────────────────────────────┐
│  Develop overview of supply chain status (one day on site) │
│     •  Observation                             │
│     •  Collect questionnaires                  │
│     •  Process mapping                         │
│     •  Conduct interviews                      │
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│  Brainstorm production process inhibitors (one day off site) │
│     •  Discuss main findings from four data sources │
│     •  Identify inhibitors (factors that slow down the process) │
│     •  Develop hypotheses to be further investigated (regarding │
│        the inter-relationships and possible causes of the │
│        inhibitors)                             │
│     •  Identify further data requirements      │
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│   Collect data to test hypotheses (one day on site) │
│     •  Conduct interviews                      │
│     •  Collect archival data                   │
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│      Analyse the findings (one day off site)   │
│     •  Cause and effect analysis, Pareto analysis and time series plot │
│     •  Develop improvement opportunities       │
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│  Simulation (one day on site, and five days off site) │
│     •  Simulation model development (3 days off site) │
│     •  Model verification and validation (1 day on site) │
│     •  Simulation run (2 days off site)        │
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│     Feedback presentation (half a day on site) │
│     •  Present findings to management          │
│     •  Discuss findings and develop action plans │
│     •  Agree on an action plan                 │
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Figure 2. The QSAM process (adapted from Naim *et al.*, 2002 and Childerhouse and Towill, 2011b)
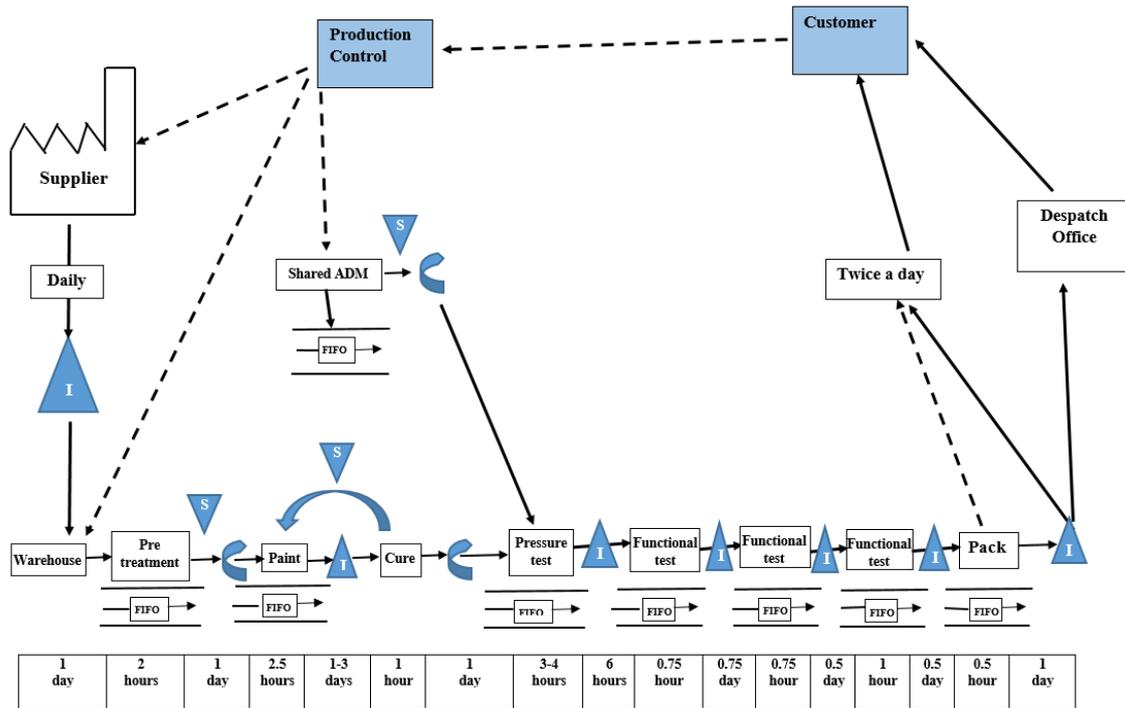
Figure 3. Value stream map of the case study company

1 day	2 hours	1 day	2.5 hours	1-3 days	1 hour	1 day	3-4 hours	6 hours	0.75 hour	0.75 day	0.75 hour	0.5 day	1 hour	0.5 day	0.5 hour	1 day

4. Data Analysis and Results

During the course of this research, various data collection techniques have been adopted such as observations, interviews, questionnaires, brainstorming and access to company documents. The data collected were analysed using standard techniques including cause and effect analysis, Pareto analysis and time series plot. A detailed process activity mapping (Hines and Rich, 1997) of the Product A production was also carried out, providing a step-by-step analysis of the activities for the entire production process (see Appendix A & B). It highlighted a sub-assembly process, namely Absorption Paint Plant (APP), as the major constraint to the whole supply chain. Interviews were conducted with company staff in the mapped process to further verify this (i.e. slowing down the whole process). It was also found that APP was responsible for painting 80% of all components/parts to be assembled in the product line cell assembly. Simulation was further utilised to test the potential benefits of our improvement recommendations. In addition to a way of extracting company data, it was also applied as a communication platform for the QSAM.

4.1 Identification of gaps

Following the VSM and the process activity mapping, the project team brainstormed inhibitors for the Product A production, their inter-relationships and possible causes. Empirical data was requested to validate the interrelationships and possible causes of inhibitors stated. Interviews were also conducted where necessary to validate the mapped process and enable identification of gaps. It is evident from Table 1 that main weaknesses pointed not only to the process within the APP, but also information flow along the overall Product A production process. They include indirect information sharing, no priority planning, absence of replenishment rule, variances in component colours and sizes, and frequency in changeover times.

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Gap	Causes
Gap 1 – Communication	Production order unit workers wait for confirmation from DSO regarding feedback from the customer on whether the order should be produced.
Gap 2 – Communication	Workers assigned to creating work order form part of the production order by investigating production orders regularly via the JD system.
Gap 3 – No replenishment rule	In the case where all the parts are not available, a trigger card indicating the required part and quantity is prepared and placed at an assigned column of the cell for pick-up.
Gap 4 – Occasional changes in work order	Instructions from the works order unit for certain products to be made before others are also given on a regular basis.
Gap 5 – Communication	The trigger card is picked up and parts indicated are checked at stores for availability. If a part is available, it is collected. In the case where the part is not available, an instruction is sent for the part to be ordered.
Gap 6 – Assigning responsibility for decision making	When parts are collected from the stores a decision is made on whether the parts have to be painted before sending them to the cell.
Gap 7 – "first come first serve" (FIFO) method	The paint plant operator paints using the FIFO method. The FIFO will yield a highly predictable and easily manageable output stream for a simple flow line, however, it tends not to work well in a complex situation with many constraints such as on changing of colours, quantity and size of component parts and overall capacity in our case (Hopp and Spearman, 2008). Unsurprisingly, it was found that the APP operator encountered delays when adhering to an FIFO rule.
Gap 8 – No data on cell assembly	Estimated time for painting parts varies due to the sizes of the parts. This includes load number, computer number (part number), description, colour, painter, quantity, date, repaint and issue.
Gap 9 – Inadequate information for planning	Request for parts to be painted are from different cell assemble units.

Table 1. Gaps and causes along the Product A production process

4.2 Improvement opportunities developed from VSM and process activity mapping
Based on the gaps and causes presented in Section 4.1, further information was collected and then analysed for the potential improvement opportunities. An initial summary of improvement recommendations included direct information sharing, priority planning, and addition data recording and data analysis.

Direct Information Sharing. Lack of direct information sharing was found to be the main reason for the identified communication gaps (Gap 1, 2 & 5). This can be further attributed to over-reliance on the company's Job Descriptor Entry (JDE) system. Therefore, direct information sharing between production order unit, work order unit, cell assembly, treatment plant and APP would lead to enhanced planning at the treatment plant and APP. For example, they can better forecast the component parts needed instead of having to wait for data from the cells to start a process. Also, when messages are sent electronically from DSO to production order unit regarding customer confirmation, work order unit should be copied in the email. This allows stock query to be easily made for replenishment purposes, so if needed request for components parts will be sent out straightaway.

Priority Planning. The delays exhibited at the APP operator when adhering to the FIFO method (Gap 7) is attributed to constraints such as changing of colours, quantity and size of component parts and oven capacity. An attempt to fulfil certain customers requested by allocating earlier delivery date was found to be the main reason for occasional changes in work order. A priority

scheduling (e.g. based on order value and quantity instead of the FIFO method) can help achieve a smooth running of the paint plant process thus reducing delay time (Gap 4). This makes sense also because requests for parts to be painted are from different cell assembly units.

Additional Data Recording and Analysis. To address Gap 8 and 9, Company X was advised to constitute an update of paint plant data to include information on cell assembly providing information on transfers from the paint plant to cell assembly. This requires to record cooling time. During the QSAM, it was also observed that the painted parts are kept in the oven for about an hour (regardless of parts size) to dry the paint, before removed from the oven and pulled to the cooling area. Additional data analysis is also needed to carry out from the view of cell assemblies.

While further data analysis related to the APP is needed to identify areas for improvement which may not be evident within VSM and process activity mapping, this level of insight was found to be extremely useful for the case company and provided "quick wins". Those changes such as information sharing (regarding customer confirmation) between units via e-mail were even made during the auditing process. After having the management team review the improvement recommendations, it was agreed to implement all the rest of them immediately and evaluation of the effect of recommendation will follow.

4.3 Data analysis and simulation

It became apparent from the proceeding analysis that the slowing down of the APP processes was mainly attributed to: 1) number of different colours used, and 2) variances in size of component parts. Currently the component parts painted at APP was on a "first come first serve basis" (FIFO). The mixing of different colours in a load required the APP operators' expertise in order to determine which painted parts could be put in the oven as a load. In addition to fixed oven capacity, light and dark colours could not be put in the oven at the same time. In light of these constraints, therefore, lead time reductions particularly in changeover times for APP process were prioritised for process improvement.

Identifying priority colour

Company X has ranked top ten colours used at APP by counting the frequency of colour descriptors in its yearly data sheet. This has provided an important baseline for determining colour priority. On a closer examination, it was revealed that the existing ranking of colours based on counts was different from those based on quantity or batch size (i.e. by counting the quantity of component parts painted in a specific colour against its specific description of colour in a data set only). Using existing yearly colour data which was based on counting the frequency of colour description, analysis of ranking colours based on quantity or batch size was carried out. Table 2 clearly shows the differences in percentages between counting on colours and those on quantity/batch size. For year 1 it appears that the existing method will suggest "a make" of 7.03% less than it should for dryer grey and 8.38% less than it should for black semi. For year 2 it appears that the existing method will suggest a make of 3.76% less than it should for dryer grey and 8.70% less than it should for black semi. For year 3 it appears that the existing method will suggest a make of 6.34% less than it should for dryer grey and 8.48% less than it should for black semi. Table 2 shows the summary of top two colours derived from the recommended method (using quantity / batch size), i.e. dryer grey and black semi with its usage rate. It indicates that the usage of both priority colours attributed to over 80% of usage rates.

	Ranking	Colour	Counts on colour	Total	Counts on Quantity/ Batch Size	Total
Year 1	1st	Dryer Grey	42.63	66.07	49.66	81.48
	2nd	Black Semi	23.44		31.82	
Year 2	1st	Dryer Grey	46.21	70.67	49.98	83.14
	2nd	Black Semi	24.46		33.16	
Year 3	1st	Dryer Grey	45.31	67.35	51.65	82.17
	2nd	Black Semi	22.04		30.52	

Table 2. Summary of Top Two Colour Usage

Identifying priority component part in sizes

After the main colours were identified, the focuses were moved to component parts that were painted by the main colours in an attempt to simulate results for planning and scheduling at APP. During the QSAM, it was found that the component part requested to be painted varied in sizes, which inevitably affected process and changeover time. It was also revealed that there was always the need to get to a certain quantity for an oven load in order to maximise the oven capacity. The oven capacities for small, medium and large component parts are 60, 24 and 15 respectively. Analysis was then undertaken using three sizes of component part painted in dryer grey (i.e. small, medium and large), based on the fixed oven capacity and the full loading of different parts. Figure 4 shows time series analysis comprising component part sizes painted in dryer grey. It shows that smaller component part sizes were highly ranked followed by large component part sizes and then medium component part sizes. The time series plot indicates a substantial rise in the month of October for each component part size, varying from 1926, 601 and 115 in terms of quantities/batch size respectively.
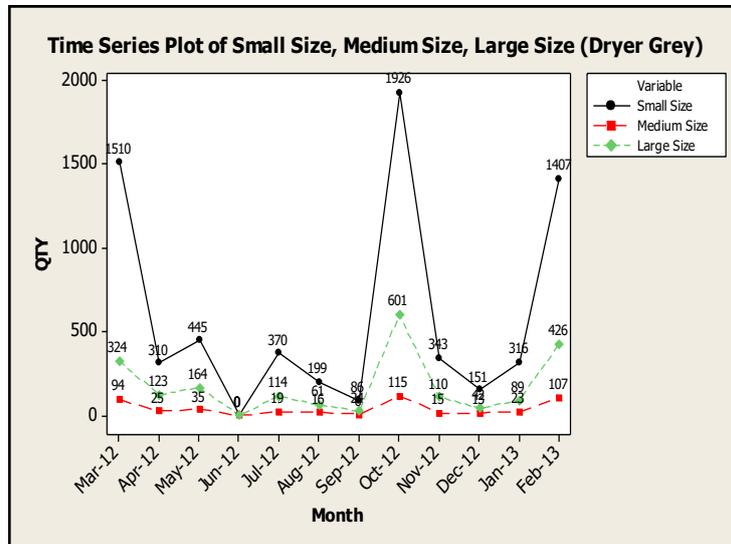

Figure 4. Time Series Plot of Parts Sizes by Month

The aforementioned analyses have indicated that the focus for lead time reduction should be on component parts painted with dryer grey. To evaluate potential gains based on identification of priority colours and priority size a simulation model was further developed using software package Arena 14. The model was based around the process activity mapping, and subsequently verified and validated (e.g. comparing the output of the model with known output values based on manual calculations, and comparing outputs of the simulation to those from

the actual system). The verification and validation process has also involved substantial employees' participation. We have utilised built-in facilities in Arena for an animated display of our simulation model. As pointed out by Brooks and Robinson (2001), the visual display (showing what the simulation model is doing) can act as a powerful communication tool. We have shown it to those employees who are knowledgeable about the system being modelled and obtained their confirmation that the model is a sound representative of their real production system. This provides a greater understanding of the simulation model, and aids model verification and validation (Kleijnen, 1995; Manuj *et al.*, 2009). The data over the course of a month (i.e. October) were used to demonstrate the potential benefits. The prioritised work schedule planning was based on utilizing full capacity of the oven with the optimal choice of component part sizes. Simulation results of work scheduling in APP between existing and suggested approach are compared. It is shown that by prioritising dryer grey work schedule amongst small, medium and large component parts, changeover of dryer grey could be reduced to zero, resulting in changeover reduction in other colours too. Consequently the changeovers in October can be reduced from 220 changeovers with associated 660 minutes changeover time to 158 with 474 minutes, as shown in Table 3. The new schedule would provide a systematic order of scheduling paint at APP. A smooth flow of the paint plant process would reduce changeover time, and increase the number of component parts painted.

Month (in weeks) Quantity/Time		Week 1 (1st-6th)	Week 2 (8th-12th)	Week 3 (15th-18th)	Week 4 (22nd-28th)	Week 5 (29th-31st)	Total
Current System							
Quantity of component parts	Small-size Parts	318	331	358	459	460	**1926**
	Large-size Parts	173	77	101	160	90	**601**
	Medium-size Parts	29	6	23	49	8	**115**
No. of Changeover		39	59	57	42	23	**220**
Changeover time (in minutes)		117	177	171	126	69	**660**
Suggested New Approach							
Quantity of component parts	Small-size Parts	462	385	308	539	231	**1926**
	Large-size Parts	144	120	96	168	73	**601**
	Medium-size Parts	28	23	18	32	14	**115**
No. of changeover		24	40	45	35	14	**158**
Reduction in changeover no.		*15*	*19*	*12*	*7*	*9*	***62***
Changeover Time (in minutes)		72	120	135	105	42	**474**
Reduction in changeover time (in minutes)		*45*	*57*	*36*	*21*	*27*	***186***

Table 3. Simulation Results on Potential Benefits of the Suggested Improvement Approach

5. Discussion

This research has demonstrated the benefits of applying QSAM in a production process of a UK industrial filter manufacturer in terms of identifying the causes of delays and providing

recommendations for improvements. The QSAM's strengths are evident in the research: (1) it is a relatively quick and efficient process; (2) as well as investigator triangulation, QSAM provides methodological triangulation using different data collection pathways (Childerhouse and Towill, 2011b); and (3) it gives a holistic perspective of the case company, particularly within the context of the supply chain (Naim *et al.*, 2002). In addition, direct involvement of practitioners during the data collection and analysis coupled with the verification during the feedback presentation also greatly enhances the reliability of the audit. The great interactive collaboration between a researcher and members of the organisation has been highlighted in action research (Coughlan and Coghlan, 2002). Indeed, Salama and Towill (2005) have demonstrated that the QSAM follows the seven stages of action research sequentially. From a theoretical standpoint, the QSAM advocates systems approach ensuring that each element of the uncertainty source is addressed (Böhme *et al.,* 2013). This also ensures that the auditor is aware of the cause and effect nature of business processes and supply chains.

In terms of research design, the combination of VSM, process mapping and simulation in this study is similar to the methodology developed by Potter and Lalwani (2007). Since the implementation of improvement recommendations is likely to be both expensive and time-consuming, a simulation model has often been utilised to quantify the benefits gained from the recommendations prior to their implementation (e.g. see Abdulmalek and Rajgopal, 2007; Potter and Lalwani, 2007). According to Abdulmalek and Rajgopal (2007), managers may be reluctant to implement improvement strategies derived from lean tools such as VSM due to a lack of quantifiable evidence needed to convince them. Companies are keen to consider only improvements of production and logistics related performances, which are usually quite easy to quantify (Salama *et al.*, 2009). In this context, a DES model has been developed in this study to test the potential improvement strategies and quantify the benefits they deliver within a dynamic environment. Results from the simulation can facilitate and validate the decision to implement the improvement recommendations.

The adoption of the adapted QSAM process (to include simulation) is also aligned with the case company's specific context. While providing improvement suggestions within a short period of time, the audit has benefitted from Company X's initial lean initiative. Company X had previously identified the activities in a given business process and categorised them as either value added activities or waste. However, Hopp and Spearman (2008) warned that, while tools such as VSM and DMAIC (Define, Measure, Analyse, Improve and Control) are a useful first step, they are not a substitute for a general, systematic diagnostic. The QSAM in this study thus provides a holistic approach to conducting a further business health check. Additionally, to enhance the feasibility check for the "future state" in VSM, simulation has been proposed in literature to facilitate and validate the decision to implement lean initiatives. In this context, it is thus understandable that, on completion of the QSAM audit, the management team pointed out that the QSAM audit has not been a diversion from their previous lean project, but may enhance the achievement of their overall lean practice.

Furthermore, as well as a way of extracting company data, simulation has been utilised in this study as a communication platform to increase employee involvement in the QSAM process and enhance the audit accuracy. This tends to be an additional benefit of simulation so that, for example, as well as helping a decision to be made, the model also helps all those involved to understand the basis on which it is being taken (Brooks and Robinson, 2001). This is also in support of Van Der Zee and Van Der Vorst (2005), arguing that a visual interactive simulation model presents an important communicative means for obtaining oversight with regard to

alternation scenarios. The involvement of employees in the simulation model development and analysis increases employee involvement in the QSAM process, which has been acknowledged as one of the QSAM's main weaknesses (Naim *et al.*, 2002) as mentioned in Section 2.2. This is also in line with the computing simulation literature. For example, Robinson (2002) suggested that, when its primary aim is to better understand the nature of the organisation's problems and to identify actions that lead to probable improvement, a DES project requires high levels of customer involvement. It is also worthy of noting that, in addition to the feedback presentation, simulation provides a further opportunity to improve QSAM accuracy during the verification and validation of the model.

It is important to point out that simulation is capable of understanding and analysing the behaviour and dynamics of systems (Jamalnia and Feili, 2013; Jeon and Kim, 2016) such as the build-up of queues, and interaction between different system components and elements. In this context, it is not surprising that Company X found it very useful to get their employees involved in the simulation model development and analysis. This has provided them a better understanding of the behaviour and characteristics of their system, thus facilitating more thoughtful decisions to improve the system. As Brooks and Robinson (2001) pointed out, while there are many different applications of simulation, one objective of building and using a simulation model should always be to improve the understanding of the way the system works. Kelton *et al.* (2014) further revealed that some managers requested that simulations be constructed but did not really care about the final results, as their primary goal was to focus attention on understanding how their system worked. However, simulation models do not provide optimal results, but rather are best for comparing a fixed number of alternatives (Law, 2006). Simulation is usually not appropriate when an analytical solution is possible or even preferable (Banks, 1998). Furthermore, the availability of relevant quantitative data is important for both developing and validating a simulation model. Simulation model development and analysis can also be time consuming (Banks, 1999; Jahangirian *et al.*, 2010). It should thus be noted that two researchers in our audit team have a background in business simulation or computational modelling.

6. Conclusion

This paper has investigated a production process in a UK manufacturer of industrial filter products, where managers have been under competitive pressure to reduce production lead time. For this research, it was deemed crucial to provide improvement suggestions within a short period of time. Building on the case company's previous lean initiative, the project team decided to adopt the QSAM to facilitate the improvement of the production lead time. Largely following a standard QSAM procedure including obtaining buy-in, the identification of a value stream and mapping out the process, conducting questionnaire surveys and interviews, and brainstorming, direct information sharing, priority planning, and additional data recording and analysis were then suggested. The case company has implemented all of these improvement suggestions during the QSAM process. Further data analysis indicated that analysis by use of quantity/batch sizes is more accurate in decision making for planning than that of count (i.e. the existing method in Company X). Also, a suggested approach by way of scheduling of the paint plant using prioritized colour and component parts was tested using simulation. The simulation results indicated that it would significantly reduce the number of changeover by 62 (i.e. a changeover time savings of 186 minutes). Following this, the case company has made a plan to pilot our proposed priority scheduling. More importantly, a foundation for future analysis and improvement has been laid. The case company intends to utilise simulation to test the impact of automation on all the value streams involved to further weigh up automation

benefits versus investment. The other outputs of the QSAM audit will also be embedded into the case company's future improvement initiatives. This is evident in the comment by the production planning manager at Company X: "It is always good to bring on board a fresh pair of eyes when conducting such projects. Information gathered and documented serve as a foundation for further analysis and documentation for future research".

While extending the QSAM to a wider industry platform, simulation in this study has also been utilised as a communication means to increase employee participation in the QSAM process and enhance the audit accuracy, which should further provide the incentive and motivation for the case company to make the initial commitment to improvement suggestions. This is in support of Salama *et al.* (2009), who argued that methodologies and tools used in improvement projects shall not be perceived as means on how to achieve improvement but rather as a collection of concepts to facilitate communication and consensus building. While acknowledging that benefits from improvement recommendations do not always lend themselves to quantification using computing simulation, it is hoped that this study will advance the use of simulation in the QSAM. While providing specific guidance to company X, it is possible to apply the method in this study more widely to other similar production processes, because of the general nature of the techniques adopted. As mentioned in the Discussion section, the case company's previous lean initiative has facilitated the implementation of the adapted QSAM audit in this study. While this has demonstrated the relevance of this study to those companies who have lean initiatives in place, we also believe that the QSAM audit can be adapted to suit the diverse organisational needs as it is a collaborative exercise between the academic researchers and members of the host organisation.

A key QSAM element that results in a successful audit is the verification during the feedback presentation. Atilgan and McCullen (2011) have demonstrated that extending feedback stages through wider dissemination has increased audit accuracy. It appears from this study that the validation and verification of the simulation model can be used to further verify the accuracy of the QSAM outputs. Further research could investigate how verification of the QSAM results can be enhanced by further participant validation which involves taking or sending research data (including researcher interpretations of participants' data) back to participants to allow them to confirm its accuracy. Furthermore, to our best knowledge, this study represents the first effort to add the simulation step to the standard QSAM procedure. However, from a modelling perspective, the inclusion of DES in the QSAM is unsurprising. The initial stage of any QSAM involves undertaking a detailed process map of value stream operations. The resultant representation of activity selection and process sequence is very helpful in setting up DES. More importantly, system dynamics (SD), which is the central aspect of systems theory as the basis for the QSAM, can gain holistic and strategic perspectives and policy analysis about the system while relying less on hard data (compared to other simulations techniques such as DES). Unlike SD that is capable of capturing long-term effects of policy and strategy development, DES generally provides detailed analysis of shorter-term decisions and actions at operational or tactical levels. Scholars have frequently made explicit calls for the increasing use of the combination of SD and other simulation techniques such as DES and agent-based simulation, in order to cope with increasingly complex operation and supply chain systems (Jahangirian *et al.*, 2010; Jeon and Kim, 2016). In this context, it would thus be advisable to explore the possibilities of utilising other analytical tools such as agent-based simulation to further leverage the rich data generated by the QSAM.

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Appendix A
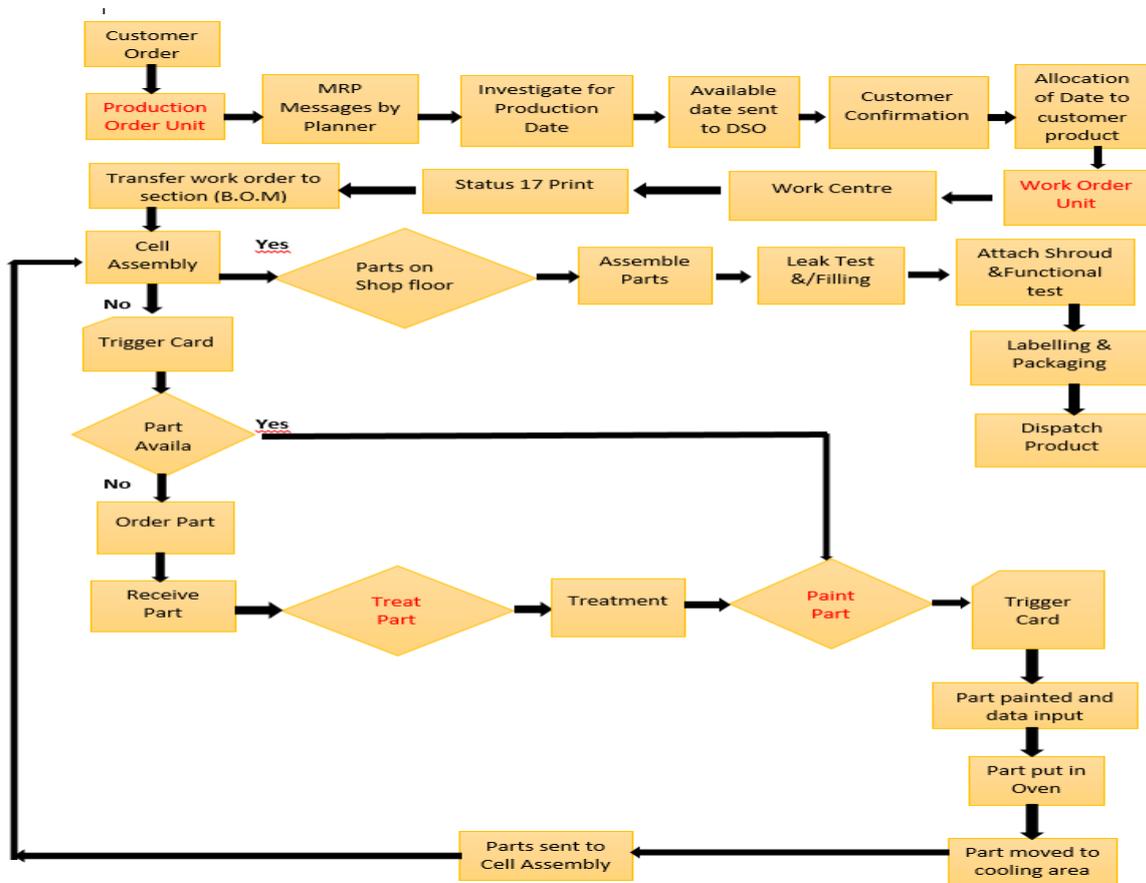
Appendix B

Production Order Unit Process After a customer order is received by the DSO, it is logged in the company's JDE system and then sent to the production order unit. After checking daily update from the company's MRP Messages, an available date for production slot is sent back to the DSO who then confirms with the customer. Upon receiving confirmation from DSO, the production order unit allocates the date to the customer product (Gap 1 in Table 1). In case of prolonged delayed feedback from a customer where the available date slot for production is within the same month, the product is assigned to production date slot. This is because Product A has a standard quantity to be produced as per working day.

Work Order Unit Process The personnel assigned to creating work order investigates production orders regularly via the company's JDE system (Gap 2). The identification code for the type of product ordered is generated by the MRP this overnight. The process follows Status 17 print and Transfer to Section/Cell assembly (B.O.M). It is important to note that the work order is updated as and when production orders are received.

Cell Assembly Process The cell assembly receives work order on a daily basis and uses the FIFO method to assemble parts. After receiving the work order drawings (MRQ) are printed and then checked to see if all the parts required for assembling the product are available on the shop floor. If available, these parts are assembled then sent for leak testing and or filling. Products are labelled after meeting specification and then packaged to be dispatched. If not, a trigger card indicating the required part and quantity is prepared and placed at an assigned column of the cell for pick-up. The work order received by the cell assembly is often updated more than once in a day. Instructions from the work order unit for certain products to be made before others are also given on regular basis (Gap 4).

Intermediate processes (Treatment inclusive) The trigger card is picked up and parts indicated are checked at stores for availability. If part is available it is collected. Otherwise, an instruction is sent for part to be ordered (Gap 5). After parts are received from supplier and conforms to requirements, a decision is made whether the part has to be treated or sent straight into stores. If the parts need to be treated, they go through aluchroming. If not then it goes straight to stores. When parts are collected from the stores a decision is made on whether the parts has to be painted before sending it to the cell. In the case where parts have to be painted it is sent to the absorption paint plant with its trigger card. Otherwise, it is sent to the cell.

Paint Part process Component parts to be painted at the absorption paint plant are to be received with trigger cards. The paint plant operator paints using the FIFO method (Gap 7). Estimated time for painting parts varies due to the sizes of the parts. Data were computed after parts have been painted. This includes load number, computer number (part number), description, colour, painter, quantity, date, repaint and issue (Gap 8). The parts are put in an oven at full capacity after painted. The painted parts are kept in the oven for an hour (regardless of the size of the parts) to dry the paint, before removed from the oven and pulled to the cooling area. Then the parts are sent to the cell assembly after cooling. It is vital to note that not only product A's component parts are painted at the absorption paint plant. Request for parts to be painted are from different cell assemble units (Gap 9).