Implementing Self-Service Business Analytics in Support of Lean Manufacturing Initiatives

by

Simon LIZOTTE-LATENDRESSE

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Department of Mechanical Engineering, École de technologie supérieure

Mr. Lucas Hof, Member of the jury
Department of Mechanical Engineering, École de technologie supérieure

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This past year and a half has felt like a blur to me; a good kind of blur. I have made so many memories, and learned so much about myself and the world, it feels like I have just started truly living. I have so many people to thank for it – mentors, family, and friends. Undertaking this master's was a big part of this journey, and I would therefore first like to express my gratitude towards Mr. Yvan Beauregard for having seen the potential in me, given me opportunities for growth, and steered this research towards academic rigor and industrial impact – something we can both be proud of.

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Implémentation d'analytiques d'affaire libre-service pour supporter les initiatives en opérations épurées dans les environnements manufacturiers

Simon LIZOTTE-LATENDRESSE

RÉSUMÉ

Les programmes d'amélioration continue tels que Lean Six Sigma (LSS) sont les pierres angulaires de nombreuses cultures d'entreprise à haute performance. Toutefois, plusieurs obstacles peuvent se dresser quand vient le temps d'implémenter et de pérenniser des amélioration – de hauts taux d'échec sont rapportés en amélioration continue. La mise à profit des systèmes d'information (SI) existants peut se révéler être un obstacle dans les environnements où les données sont fragmentées entre les multiples bases de données des progiciels de gestion intégrés et des systèmes d'exécution de la production.

Les analytiques d'affaire libre-service (AALS) offrent la flexibilité requise pour unifier de telles données fragmentées avec des temps de cycle minimaux, ce qui en fait la classe de logiciel idéale pour les gestionnaires pilotant des projets d'opérations épurées en milieux manufacturiers. Les AALS peuvent permettre aux gestionnaires de concevoir et réajuster des métriques convenables tout au cours de la durée typique de trois à six mois d'un projet LSS.

Le but principal de cette étude est de proposer un cadre pour l'implémentation d'AALS supportant les initiatives d'opérations épurées en milieux manufacturiers. Ce cadre de nature prescriptive est conçu pour guider les gestionnaires en ce qui a trait à maximiser les résultats et minimiser les délais – faire du projet un succès.

Pour atteindre ce but, une méthodologie de sciences de la conception impliquant une étude de cas industrielle est réalisée. En un premier temps, une revue de littérature systématique est exécutée, établissant une base pour la recherche et mettant en évidence les lacunes dans l'état de l'art. Puis, un modèle d'implémentation est conçu pour les AALS. Ce modèle est appliqué et évalué à l'usine partenaire, division canadienne d'une entreprise internationale fabriquant des pièces d'acier et disposant d'environ 15000 employés à travers le monde. Les leçons apprises sont ensuite étayées et intégrées pour produire un cadre d'implémentation généralisable appuyé par l'étude empirique en milieu manufacturier.

Les résultats quantitatifs du sondage d'évaluation sont supérieurs au seuil initialement défini. Des observations qualitatives en entreprise révèlent les impacts positifs de l'utilisation d'AALS supportant les opérations épurées dans les environnements manufacturiers – une communication interdépartementale accrue améliorant la prise de décision opérationnelle.

Mots-clés: Étude de cas, Conception de systèmes d'information, Analytiques d'affaire libre-service, Implémentation, Opérations épurées, BPMN, Sciences de la conception.

Implementing Self-Service Business Analytics in Support of Lean Manufacturing Initiatives

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ABSTRACT

Continuous improvement (CI) programs such as Lean Six Sigma (LSS) are the cornerstones of many high-performance corporate cultures. However, numerous obstacles can arise when comes the time to implement and sustain improvements – high failure rates are reported for CI programs. Leveraging existing information systems (IS) can be an obstacle for lean manufacturing initiatives in environments where data is fragmented across multiple databases of Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES).

Self-service business analytics (SSBA) provide the flexibility required to unify fragmented data with minimal turnaround, which makes this class of software ideal for managers piloting lean manufacturing initiatives. SSBA can enable the managers themselves to design and redesign suitable metrics throughout the typical three to six months duration of LSS projects.

The main goal of this study is to propose an implementation framework for SSBA supporting lean manufacturing initiatives. This prescriptive framework is designed to guide managers in maximizing results and minimizing delays – making the project successful.

To achieve this goal, a Design Science Research (DSR) methodology involving an industrial case study is carried out. First, a systematic literature review is conducted, which establishes a research base and highlights research gaps. Then, an implementation workflow is designed for SSBA. Next, this workflow is applied and evaluated at the case company – the Canadian division of an international steel parts manufacturing company with about 15000 employees worldwide. Lessons learned are then outlined and integrated to yield a generalizable implementation framework backed by empirical evidence in manufacturing.

Quantitative evaluation survey results for the implementation case study were above the threshold set. Qualitative observations reveal positive impacts of SSBA supporting lean manufacturing through improved inter-departmental communication leading to better operational decision making.

Keywords: Case study, Information system design, Self-service business analytics, Implementation, Lean manufacturing, BPMN, Constructive Research.

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LIST OF ABREVIATIONS

AATP	Advanced Available-To-Promise
BA	Business Analytics
BPMN	Business Process Modeling and Notation
CNC	Computer Numerical Control
COMS	Customer Order Management System
DAQ	Data Acquisition
DBR	Drum-Buffer-Rope
DSR	Design Science Research
ERP	Enterprise Resource Planning
IoT	Internet of Things
IRL	Integrated Risk Likelihood
IS	Information Systems
IT	Information Technology
KPI	Key Performance Indicator
LSS	Lean Six Sigma
MES	Manufacturing Execution System
MOC	Manufacturing Operations Cockpit
MSFIS	Mamdani Style Fuzzy Inference System
OEE	Overall Equipment Effectiveness
OFPPT	Order Fulfillment Progress Projection Tool
PO	Purchase Order
PSI	Production Sales Inventory

QFD	Quality Function Deployment
RMT	Risk Mitigation Tool
RPA	Robotic Process Automation
S&OP	Sales and Operations Planning
SSBA	Self-Service Business Analytics
TI	Total Impact
ToC	Theory of Constraints
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TPM	Total Productive Maintenance
VBA	Visual Basic for Applications
WIP	Work In Progress

INTRODUCTION

For manufacturing companies, developing and keeping a competitive edge has become more important than ever. In an increasingly global supply chain, pricing considerations for suppliers are often superseded by that of flexibility and dependability. Indeed, customers are now very much aware of the cost of holding inventory to compensate for a supplier's low ability to react to fluctuating demand. As supply chains become leaner, push dynamics between various stages switch to pull, and the system becomes more vulnerable to effects such as bullwhip (Ivanov, 2018).

Information systems (IS) play a key role in enabling the improvements required upon manufacturing companies by this new reality of the market. The data stored in those can be leveraged to increase awareness of manufacturing capacity and demand, bolstering the all-important communication channels between sales and production. However, the information relevant to improvement projects can be fragmented between multiple databases of Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES) implementations. The data wrangling required to turn this fragmented data into valuable information such as metrics has traditionally been time consuming for both managers and IT specialists (Lohr, 2014). This can limit the ability of IS to support lean manufacturing projects with fast-evolving requirements, particularly within the typical three to six months timeframe of a Lean Six Sigma project. Self-Service Business Analytics (SSBA) expand perspectives for managers through a new class of software able to connect to a wide range of IS to combine and process fragmented data into information with minimal turnaround. With SSBA, managers therefore benefit from increased flexibility to dynamically tailor suitable sets of metrics and tools in support of improvement initiatives.

Nevertheless, challenges arise from the implementation of SSBA to support improvement projects within a three to six months timeframe. While best practices are well documented for implementing IS such as ERP in manufacturing environments, SSBA implementations can be seen as a form of corporate entrepreneurship (intrapreneurship). As autonomy and ambiguity tolerance are present to various degrees in companies, implementation strategies must account for cultural specificities. The SSBA implementation project can stall at different stages, for instance if no link can be established with existing IS.

The primary objective of this research is to propose manager-oriented guidelines for SSBA implementation in support of lean manufacturing. Those guidelines are designed to increase project quality for both SSBA implementation and the lean manufacturing improvement initiative it supports. The goal for this resulting project is to finish on time, on budget, and with the desired outcomes. This is measured through a satisfaction survey involving key stakeholders, as well as qualitative observations.

The methodology selected for this research is Design Science Research (DSR), as it is an answer to the dilemma between rigorous theoretical contributions and action research yielding industrial impacts. For this research, literature review findings are integrated in an implementation workflow – the first iteration of the DSR artifact. This workflow is then applied by developing an implementation for SSBA at the case company for which the core business is thermal cutting of sheet metal. This implementation is then evaluated, which leads to lessons learned. These lessons learned are used to improve the artifact, yielding a comprehensive framework – the second iteration of the artifact.

This thesis begins with a general literature review on the continuous improvement, operations & change management methodologies used in this research. An overview of the methodological approach follows. Then, the integrated article is detailed through the steps of the DSR methodology, yielding an implementation framework. This integrated article is an extension from the conference paper presented at the 2018 IFAC Symposium on Information Control Problems in Manufacturing (Lizotte-Latendresse & Beauregard, 2018). The extended article was submitted to the International Journal of Lean Six Sigma October 4th 2018; it was under review with no feedback which could be accounted for at the time of completion of this thesis. Lastly, results are discussed, and a general conclusion summarizes contributions of this research & key opportunities for future work.

Supporting materials are provided in appendixes: evaluation survey & results (see Table-A II-1), code excerpts, INCOM 2018 paper & presentation, ethics committee approval, and integrated article proof of submission.

CHAPTER 1

LITERATURE REVIEW

1.1 Background

Continuous improvement is an essential component of high-performing corporate cultures. Without it, organizational success eventually becomes solely dependent on the market's reaction to companies' offerings. Improving the offering itself in a mature market poses several challenges (Cooper, 2011), and several organizations which do not succeed with bold innovation reach a plateau and eventual decline after growth periods. While it is possible to reshape business processes – clear and out-of-the-box thinking yielding breakthroughs (Goldratt & Goldratt-Ashlag, 2010) –, quantum leaps can become increasingly harder to achieve as the low hanging apples become exhausted. To net a significant and sustainable impact on large organizations' long-term performance, sparse improvement projects cannot be solely relied upon. That is where improvement programs such as Lean Six Sigma (LSS) come in. With such programs, business objectives set by top management are disaggregated into specific targets for incremental improvements throughout the organization. This collaborative process is known as Catchball (Sunder M, Ganesh, & Marathe, 2018).

Rigorous improvement methods are then leveraged to progress towards those targets and achieve durable results. There are however numerous obstacles to the sustainability of improvements, with reported failure rates of up to 60% (McLean & Antony, 2014) – project management and implementation approaches have been additionally been reported as recurrent themes for organizational failure. As the focus of this thesis is supporting LSS projects with IS, this literature review includes an overview of Gemba walks and mind mapping, two of the LSS techniques used in this research. Since the industrial implementation case relates to the Theory of Constraints (ToC), the concept will be introduced next. Then, sales and operations planning (S&OP) techniques and metrics will be outlined. Lastly, stakeholder-oriented change management will be presented as a building block of the framework developed, and linked to Quality Function Deployment (QFD).

1.2 Lean Six Sigma tools and techniques

1.2.1 Gemba walk

The concept of Gemba walk refers to the act of spending time on site with the stakeholders involved in the process to develop an understanding of its ramifications. Gemba is the Japanese word for “the actual place”, which is where the work is carried out (Tyagi, Choudhary, Cai, & Yang, 2015). There are limitations to the understanding of a process which can be developed without leaving a manager’s office, as can be depicted by this quote:

“The knowledge of the world is only to be acquired in the world, and not in the closet” (Philip Chesterfield)

An important philosophy behind the Gemba walk is to look up to the people doing the actual work. Those people often have considerable experience in doing what they do; they are best placed to advise of subtleties in the process, and even opportunities for improvement. They may very well simply not have had the time or tools to implement those changes themselves. A Gemba walk can additionally give a good feel of the general climate in an industrial setting with factors such as cleanliness, which can modulate a change agent’s approach.

1.2.2 Mind mapping

Mind mapping is a visual tool for brainstorming and problem solving. This representation was first promoted by Buzan (1976) and then Russell (1979) for its ability to boost creativity and learning, believed to stem from its stimulation of both the hemispheres of the brain – creative and logical. This tool differs from concept mapping (Novak & Gowin, 1984) in that there is necessarily a hierarchy of ideas, with one concept at the center and the others branching out. Keywords can be associated with the revolving concepts to further detail the mind map. As all the information radiates logically from the potentially complex central concept, its understanding is simplified.

This technique can be used as a LSS tool, for instance to brainstorm on opportunities for application of LSS method such as setup time reduction at a specific company. Areas where much time is wasted due to setup could be marked around the central concept of setup reduction, which could then lead to a Pareto analysis. An example of a mind map is shown at Figure 1.1; it integrates basic Lean Six Sigma techniques in a high-level representation.

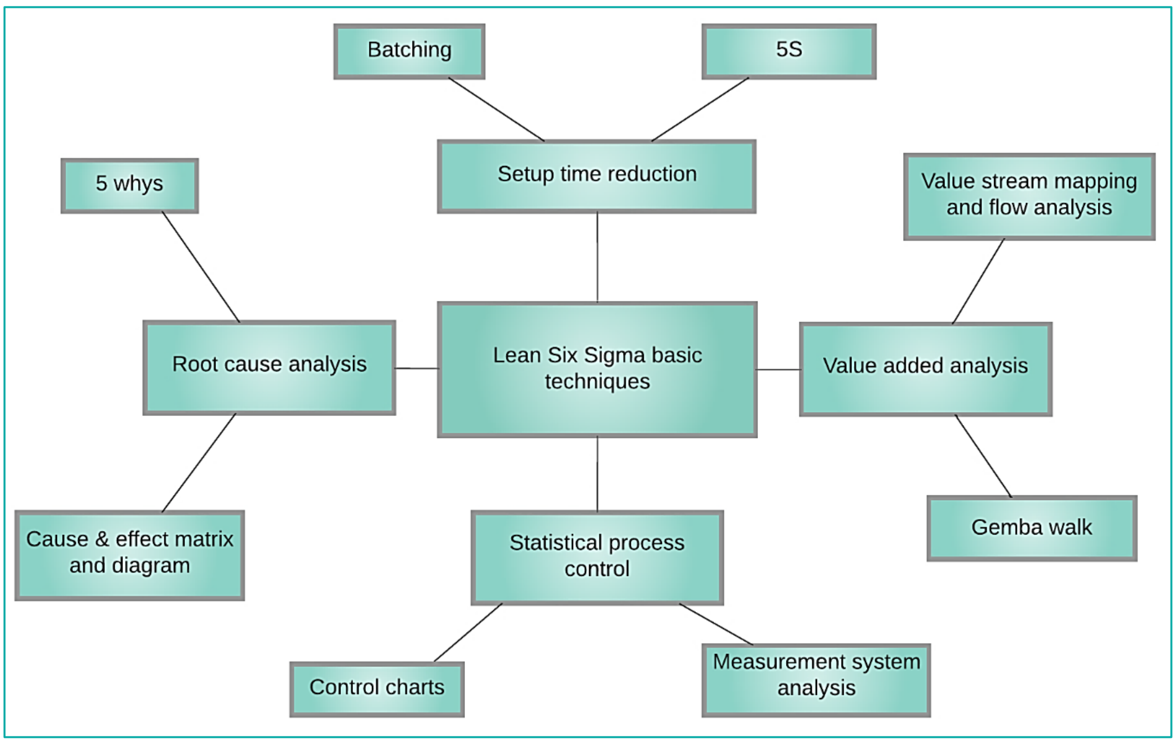

Figure 1.1 High-level mind map for Lean Six Sigma techniques

1.3 Theory of Constraints

The ToC is an improvement methodology which was defined in *The Goal* by Goldratt and Cox (1984). It rests upon assumptions about what drives the long-standing profitability of a company – throughput accounting. While it was first coined for manufacturing, ToC has been successfully applied to other sectors such as service (Pacheco Lacerda, Augusto Cassel, & Henrique Rodrigues, 2010), healthcare (Garza-Reyes, Villarreal, Kumar, & Diaz-Ramirez, 2018; Taylor & Nayak, 2012), and even cloud storage (Chang, Chang, & Chang, 2017).

Key elements of this theory are core assumptions, the five focusing steps, and the Drum-Buffer-Rope (DBR) model – a simplified representation of effective production management. Assumptions include that profitability is highly correlated to the metrics of throughput (i.e. cash flow), inventory, and operational expenses. The five focusing steps are used to increase flow through the constraint (i.e. bottleneck) restricting throughput by subordinating considerations of lesser importance. The DBR model is of high relevance to this research, as the production capacity management system developed with SSBA for the case company is based upon this model.

In a DBR system, the *drum* is defined as the resource which is the most constrained in the system (Darlington, Francis, Found, & Thomas, 2015). In throughput accounting according to the ToC, the *drum* is effectively what restricts cash flow, limiting profitability. In the context of the case company for which the core business is cutting steel, the *drum* can be identified as the most loaded cutting line at a given moment. One option to reduce demand on the *drum* is to leverage redundant production line capabilities and spread the load. However, this strategy is only effective up to the point where all compatible lines have been overbooked, which is why sales have to be kept in the loop. That is where the *rope* comes in, which encompasses both direct sales-production communication and visual analytics. While there are challenging orders which command discussion between sales and production, it is with regular production that visual analytics can have the highest impact serving the purpose of *rope*. If peaks in capacity utilization are communicated, it is possible for sales to focus on under-utilized capacity – a pull dynamic is enacted. This dynamic helps to maintain a *buffer*, which is the safety margin to deliver orders to customers at the dates promised. This *buffer* is further secured through the integration of dynamic lead times communicated to sales. While simplicity is a good starting point with ToC, state-of-the-art algorithms such as advanced available-to-promise (AATP) algorithms can be leveraged to further secure the *buffer* based on stochastic simulations (Rabbani, Monshi, & Rafiei, 2014).

1.4 Sales and operations planning techniques and key metrics

S&OP is the process through which strategic objectives are linked to integrated plans for the sales and production departments (Thomé, Scavarda, Fernandez, & Scavarda, 2012). It is performed at least once a month with regard to both aggregated and long-term forecasts and shorter-term tactical plans – the associated hierarchical planning level can vary depending on the industry. The primary goal for this process is to ensure that there are sufficient resources allocated to the departments to support the company's objectives. The process being integrated, alignment is ensured for the plans of the individual departments – imbalances can be detected and corrected at early stages.

The S&OP process can be supported by several metrics depending on the industry. Thomé et al. (2012) split those between six categories: plan, source, production, delivery, S&OP dashboard, and end-results. In a production system well modeled by DBR like the case company, the most relevant metrics are "capacity utilization", "production lead-time", "on-time delivery of goods", and "adherence to sales, marketing and operations plan".

By maximizing capacity utilization across the schedule, more can be produced with the initially allocated resources. This ensures that no capacity is wasted. Wasted capacity has the potential to cause unnecessary and costly overtime down the road during peak demand periods, as getting ahead of schedule increases the buffer to absorb peaks which would have otherwise required allocation of additional resources. This capacity utilization also has to be leveled, as utilization spikes increase the risk for late deliveries. The production lead time has a regulating effect on demand, and should therefore be neither too short or long to help with staying on track of the sales, marketing, & operations plans.

1.5 Stakeholder oriented change management & QFD

The stakeholder theory integrating all groups and interests impacted by activities was defined by Freeman (2010), originally in 1984. Application of this theory implies identifying key stakeholders, and analyzing their characteristics. Important characteristics for change management include interest and influence; sorting stakeholders in a table and a quadrant can be particularly useful in some projects (Project Management Institute Inc, 2013). Additional factors include expectations, autonomy, and levers of power.

In the case of technology-driven change, the need to account for stakeholders is very high because of the potential for a disconnect between non-technical stakeholders and the design intent (Long & Spurlock, 2008). It is possible to go further than to simply account for or even involve stakeholders – a practice coined "stakeholder shaking" goes beyond this by enabling co-creation of solutions (Sulkowski, Edwards, & Freeman, 2017). For a manufacturing company, a good example of stakeholder shaking is communicating the impact of late deliveries on customer satisfaction. Even if some departments are affected more directly than others by customer dissatisfaction, increasing awareness of the systemic perspective can increase cooperation, in turn leading to ideas for improvement projects.

Stakeholder oriented change management relates to QFD defined in the ISO 16355 standard (International Standards Organization, 2015) in that the focus is working towards the benefit of the stakeholders. QFD emphasizes actively listening to the voice of stakeholders and includes Gemba visits to help in discovering unknown requirements. At the core of QFD is identification of requirements – which could be feature requests in the case of this study –, and prioritizing those requests to achieve maximum stakeholder satisfaction with the available resources. The ISO 16355 standard includes tools and techniques to aid stakeholder communications, requirements prioritization, scope delineation, and ultimately stakeholder satisfaction.

CHAPTER 2

METHODOLOGY

2.1 General research methodology

Since this research has the double aim of contributing to the body of knowledge of SSBA and improving the processes of an industrial partner through development of a SSBA tool, a practical research methodology is required. The selected methodology is DSR as represented in Figure 2.1, as this approach bridges the gap between theoretical and action research.

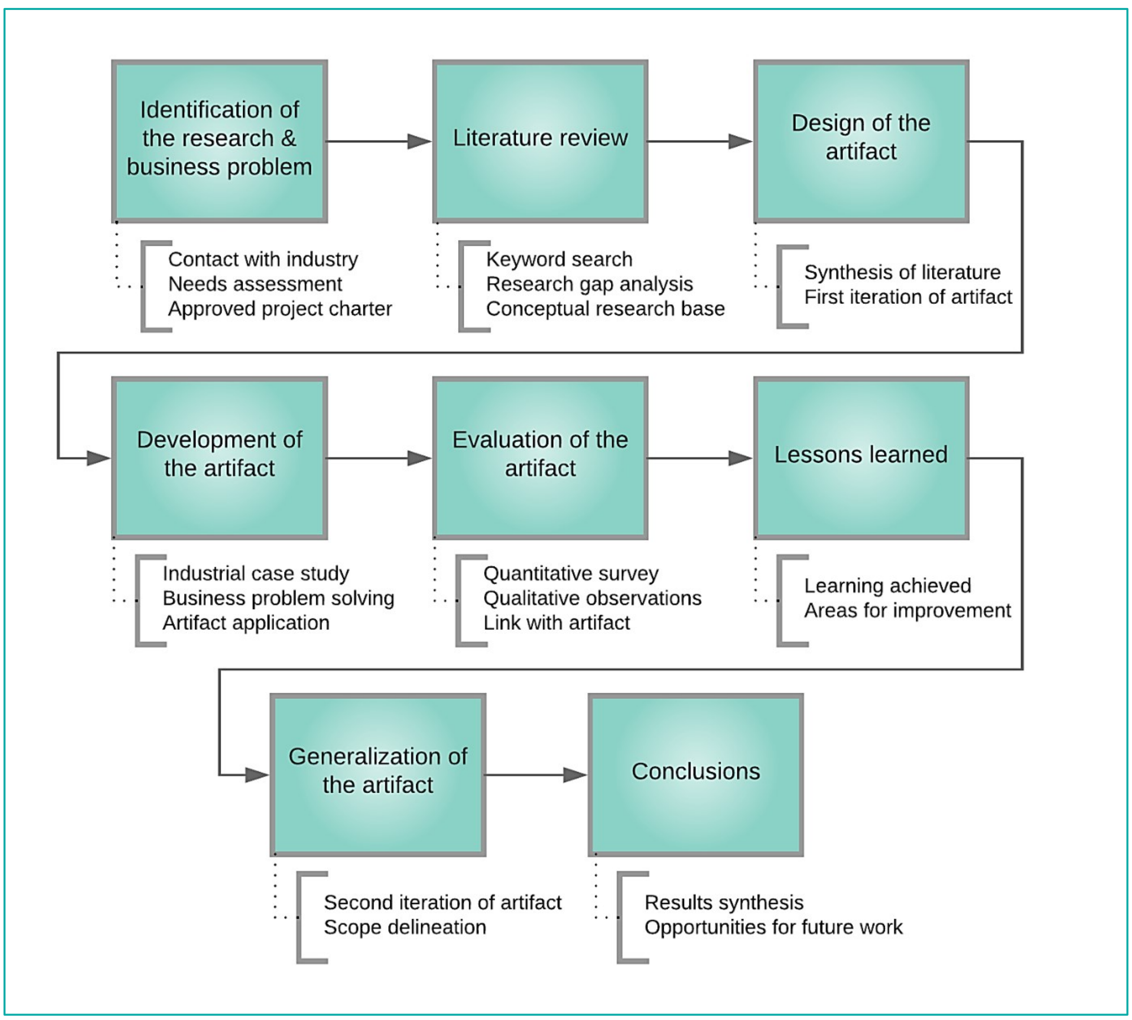

Figure 2.1 Thesis methodology, adapted from Dresch, Lacerda, and Antunes Jr (2015)

Fitness of the research project for the DSR methodology is detailed in Table 2.1. The general research methodology and its instantiation are further detailed in the integrated article sections 3.2.6 Producing and presenting information systems research and 3.3 Methodology.

Table 2.1 Research fitness for DSR; criteria adapted from Dresch et al. (2015)

Criterion	Criterion description	Research adequation to criterion
1 – *Design* as artifact	DSR must produce an artifact which can be a construct, model, method or instantiation	An implementation methodology for SSBA is designed
2 – Problem relevance	The purpose of DSR is to develop solutions to solve important and relevant problems for organizations	SSBA implementation is relevant to the industrial partner, and can be generalized to similar organizations
3 – *Design* evaluation	The utility, quality and efficacy of the artifact must be rigorously demonstrated via evaluation methods	A survey evaluates stakeholder satisfaction resulting from SSBA implementation, which is complemented by field observations
4 – Research contribution	DSR must provide clear and verifiable contributions in the areas of the developed artifacts and present clear grounding on the foundations of design and/or design methodologies	The designed implementation framework is grounded in the literature review results; it constitutes a first proposal for SSBA implementation guidelines supporting lean manufacturing
5 – Research rigor	Research should be based on an application of rigorous methods in both the construction and the evaluation of artifacts	The systematic literature review is the first step in rigorous artifact construction. An anonymous survey supports minimally biased evaluation
6 – *Design* as a research process	The search for an effective artifact requires the use of means that are available to achieve the desired purposes, while satisfying the laws governing the environment in which the problem is being studied	The industrial case study gathers empirical evidence regarding the laws governing a manufacturing ecosystem, and the way to effectively implement SSBA
7 – Communication of the research	DSR must be presented to both an audience that is more technology-oriented and one that is more management-oriented	A journal article was submitted for this research study. The *International Journal of Lean Six Sigma* targets a broad audience of practitioners and academics

2.2 Ethics assessment

The research involves an industrial partner, which made ethics and confidentiality an important aspect. The case company has opted to remain anonymous. Managers were given the opportunity to provide comments on manuscripts before those were submitted for publication. The evaluation survey was additionally designed to preserve the anonymity of the participants. Given those measures, ethics approval was obtained; this authorization is provided in APPENDIX VI.

2.3 Industrial case study

While the research & business problem definition was performed in collaboration with the industrial partner, the industrial case study is also very important to the research. It provides an opportunity to develop the artifact, and validate it empirically. The general workflow of the industrial case study is therefore the first iteration of the artifact, which is presented in Figure 3.9; it is grounded in the integrated article literature review at section 3.2.

The main steps of the industrial case study are therefore obtaining stakeholder support (executive, most importantly), assessing information systems, mapping processes, selecting SSBA software, developing a change management plan, deploying & continuously improving SSBA. The final stage of continuous improvement is iterative and incremental; it does not cease until empirical saturation is reached, meaning in this context that there are little new feature requests over time from stakeholders – a plateau is reached. This condition is not expected to be reached within the timeframe of this research, as it is geared towards LSS projects with a 3-6 months duration, hence the duration of the case study itself. There are countless new features which could be added to SSBA over time to better support the sales and production departments, but in this approach, feature requests must emerge from the stakeholders themselves to ensure that all those implemented add value. New feature requests are gathered via meetings and Gemba walks.

2.4 Evaluation methods

The evaluation approach selected is both quantitative and qualitative. A survey was designed to assess stakeholder satisfaction towards the tool based upon criterions from Hommes and Van Reijswoud (2000), which are further detailed in the integrated article section 3.3. This survey is provided in APPENDIX I. It was disseminated via Google Forms to five employees from the sales and production departments, which is most of them – some were on vacation. Additionally, a data-logging feature was added in the SSBA implementation at the case company with the aim of supporting and assessing the impact of the SSBA tool on the manufacturing ecosystem; this production capacity management tool is shown in Figure 3.16, with the enabling VBA code provided in APPENDIX III. With this feature, it is possible to see if the calculated lead times are being respected to improve S&OP, and increase profitability as per the DBR model.

Qualitative observations complement quantitative evaluation methods. Indeed, LSS and QFD approaches both include Gemba visits or walks. This is because, while data-driven assessments are essential, those do not always tell the full story. Time is to be spent in the field with the sales and production departments to gather qualitative empirical evidence towards the industrial impacts of SSBA. The evaluation survey in APPENDIX I additionally includes a text field for anonymous feedback on the SSBA tool.

CHAPTER 3

INTEGRATED ARTICLE: AN EMPIRICAL FRAMEWORK FOR IMPLEMENTING SELF-SERVICE BUSINESS ANALYTICS SUPPORTING LEAN MANUFACTURING

Simon Lizotte-Latendresse[1], Yvan Beauregard[1]

[1]École de technologie supérieure, Department of mechanical engineering, 1100 rue Notre-Dame Ouest, Montréal, QC, Canada, H3C 1K3

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Abstract

Purpose – Managers driving lean initiatives in the manufacturing industry need to set up metrics to support changes with limited time and resources. Relevant data is often fragmented across multiple information systems. Self-Service Business Analytics (SSBA) can be leveraged to convert this data into useful information. The aim of this paper is to develop an empirically supported framework to guide SSBA implementation within the typical 3 to 6 months timeframe of a Lean Six Sigma project.

Design/methodology/approach – The study as described in this paper adopts a Design Science Research (DSR) methodology. A systematic literature review is conducted to identify gaps in current literature and establish a research base. Then, a workflow is designed to solve the implementation problem. This model then is applied at a case company for empirical evaluation. Lessons can then be learned from the case and integrated into a generalizable framework.

Findings – This paper identifies guidelines for successful SSBA implementation in the manufacturing industry, which are synthetized in a framework. This framework stems from an implementation workflow and its evaluation in supporting the implementation of SSBA at the Canadian division of an international steel parts manufacturing company with about 15000 employees worldwide.

Originality/value – The main contribution of this paper is a framework designed to guide managers in implementing SSBA to support fast evolving improvement initiatives in the manufacturing sector. Grounded in a theoretical research base and empirically validated, this framework bridges the gap between theory and practice as a first proposal for guidelines to implement SSBA supporting lean manufacturing.

Keywords Case study, Information system design, Self-service business analytics, Implementation, Lean manufacturing, BPMN, Constructive Research

Paper type Research paper

3.1 Introduction

As the boundaries of inventory reduction are being pushed increase profitability, expectations towards suppliers are increased. It is not merely about pricing or even quality anymore, but also fast and reliable deliveries. While this wave of change can and must be a win-win situation for both suppliers and customers (Goldratt & Goldratt-Ashlag, 2010), it also brings about several challenges. A particularly important one for manufacturing companies is improving the ability to quickly react to fluctuating demand. This requires keen awareness of production capacity, as well as solid inter-departmental communication. Numerous information systems (IS) are available to assist production managers with these challenges for both the analytic and communication dimensions of planning. However, investing in powerful software does not guarantee the desired improvements. While several ERP systems and modules are marketed as polyvalent, implementation in specialized manufacturing environments will sometimes require compromise, even with subsequent investments. Managers navigating such environments to drive positive change – lean initiatives – must adapt to the IS landscape with limited time and resources.

With successful implementation, ERP neutral self-service tools can help managers bridge the gap between IS-native features and their lean manufacturing requirements. A literature review is conducted, which supports design of an implementation methodology for self-service business analytics (SSBA). The methodology is then applied to develop an implementation of SSBA at a case company in the manufacturing industry. This development is then evaluated, and lessons learned enable incremental improvements on the implementation methodology itself.

Initial order management processes for the case company are represented at Figure 3.1 with the standardized approach of Business Process Model and Notation (BPMN) by the Object Management Group (2013). Lead times whiteboard (see Figure 3.2) & ad-hoc production impact assessments are central in the pre-SSBA workflow.

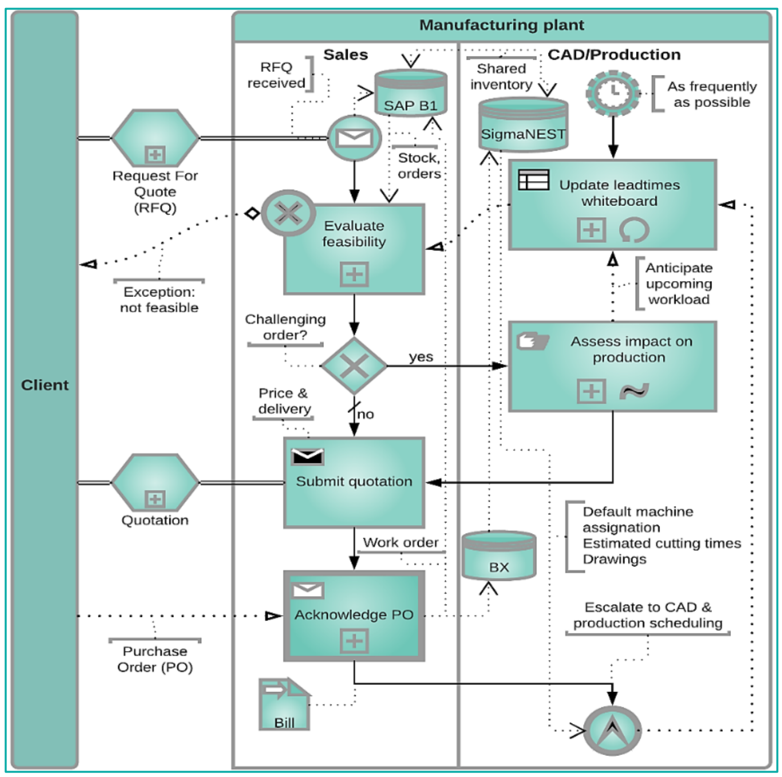

Figure 3.1 Case company present state BPMN
(Lizotte-Latendresse & Beauregard, 2018)

For the case manufacturing plant, the core business is thermal cutting of parts out of sheet metal, with plasma for fast cuts and oxyfuel for thick material. Plasma melts steel with an electrical arc, and oxyfuel is propane burned with oxygen. While the decades old company has as much as 15000 employees worldwide, the plant studied has 50-100 employees. From an IT perspective, SAP Business One (B1) enhanced by the BX Manufacturing module is adopted as corporate ERP, while the SigmaNEST software package is leveraged to program CNC plate processing machines. From a supply chain perspective, it should be noted that this plant also manufactures welded assemblies, and that a portion of orders require outside processing for operations such as bending or machining. Lean manufacturing projects impacted by the developed SSBA information system include improving lead time estimation with live update, increasing plasma/oxyfuel cutting torch time percentages by showing sales under-utilized machine capacity, and maximizing on-time delivery by detecting at risk orders. Figure 3.3 represents SSBA integration with the whiteboard superseded.

This paper begins with a presentation of the background in the fields of business analytics and lean manufacturing. Then, selected state-of-the-art literature is further detailed. Next, the selected Design Science Research (DSR) methodology is presented. An implementation workflow can then be designed, which is the initial methodological artifact in this DSR study. Application of the implementation workflow at the case company for development of an implementation of SSBA is subsequently documented and evaluated. Lessons learned from this development enable incremental improvements upon the initial artifact, and confer it a degree of generalizability. A key contribution of this paper is the resulting artifact – a prescriptive framework applicable to the SSBA implementation class of problems –, which fills a gap identified in current literature (Lizotte-Latendresse & Beauregard, 2018). As a result, conclusions can be drawn regarding both academic and managerial implications.

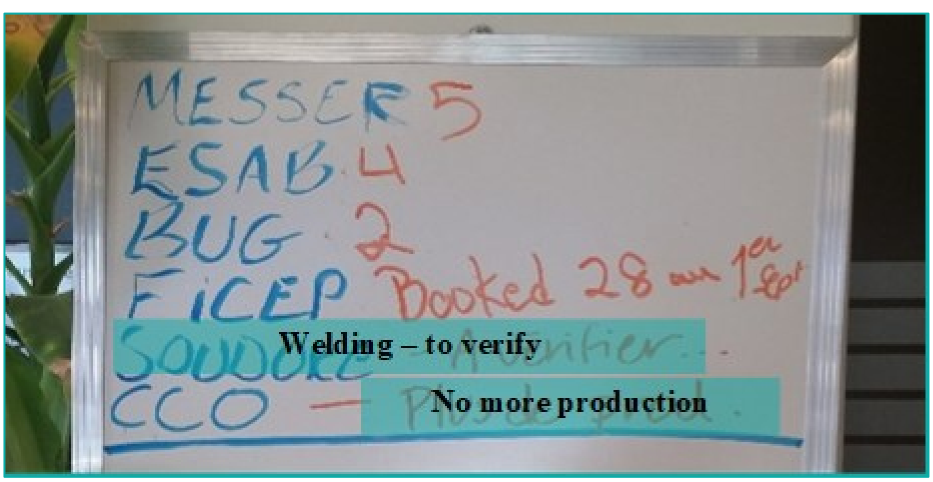

Figure 3.2 Lead times whiteboard

This research is an extension from the conference paper presented by the authors at the 2018 IFAC Symposium on Information Control Problems in Manufacturing (Lizotte-Latendresse & Beauregard, 2018).

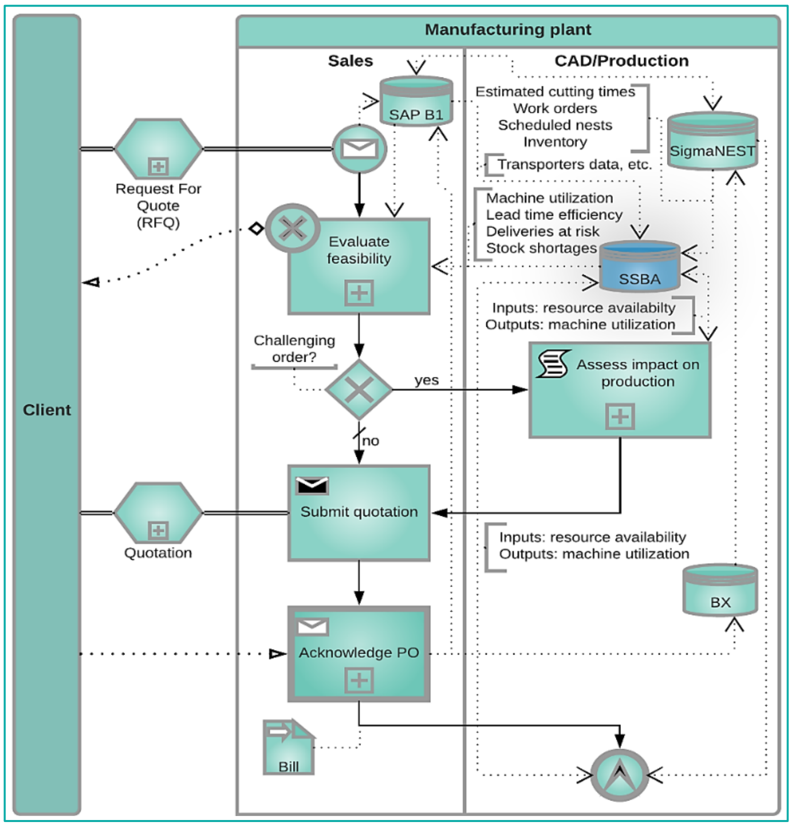

Figure 3.3 Case company desired state BPMN
(Lizotte-Latendresse & Beauregard, 2018)

3.2 Literature review

3.2.1 Background

A fundamental principle in Lean is that we need to measure if we are to improve. The more mature the lean organization, the harder the bottlenecks are to find and improve (Sims & Wan, 2017), and doing so will more often than not require gathering data. As in any science, data quality must be considered – cleansing big data is a major challenge today's organizations face (Sadiq, 2013). Robotic process automation (RPA) tools such as Blue

Prism can improve the flow of data (Forrester Research, 2018). Still, data by itself is not enough to drive improvement, as it needs significance before it can be translated into accurate and timely control decisions (G. Meyer, Buijs, B. Szirbik, & Wortmann, 2014). Business Analytics (BA) address turning valid data into valuable insight for managers (Unver, 2012); this discipline adds the past and future dimensions (Calfa, Agarwal, Bury, Wassick, & Grossmann, 2015) to Business Intelligence (BI), which tracks real-time status (Unver, 2012).

The impact of Lean management initiatives (e.g. standard work) on key performance indicators (KPI) such as Overall Equipment Effectiveness (OEE) can then be tracked (Unver, 2012). With recent advances in the internet of things (IoT) yielding tools such as Worximity (2017), data acquisition (DAQ) can be performed from virtually any industrial equipment. Still, care must be taken to avoid pitfalls in defining KPIs, for instance setting the bar too low to make ourselves look good (Hammer, Haney, Wester, Ciccone, & Gaffney, 2007).

On the other hand, analytic tools such as Bayesian networks can assist decision makers by effectively processing highly complex datasets to forecast Engineer-to-Order (ETO) project workloads (Eickemeyer, Herde, Irudayaraj, & Nyhuis, 2014), helping reduce bottom-line uncertainty (Kogan & Tell, 2009). Analytics can also interface with Enterprise Resources Planning (ERP) systems, modulating sales-production interactions, which in turn correlate with higher customer satisfaction (de Vries & Boonstra, 2012; Parente, Pegels, & Suresh, 2002), all the while enabling dynamic pricing strategies (Özer & Uncu, 2015).

A new, disruptive trend in BA is self-service. Over the last decade, an increasing number of companies have opted for software such as Tableau, Microsoft Power BI, and IBM Watson Analytics (Alpar & Schulz, 2016; Dinsmore, 2016). Microsoft is positioned to the furthest for Completeness of Vision in the Leaders quadrant in the Gartner (2018a) Magic Quadrant for Analytics and Business Intelligence Platforms. Although having different feature sets when compared to leading data science and machine-learning platforms like RapidMiner (Gartner, 2018b), these tools target end users instead of experts (Dinsmore, 2016).

As a result of the shorter design cycles these decision support tools facilitate, time-sensitive decision making can be improved (Mayer, Hartwig, Roeder, & Quick, 2015). Managers quickly get actionable intel – the edge to effectively adapt in fast-changing environments (Balogun & Tetteh, 2014; Monostori et al., 2015). Visual analytics can now be updated real-time (Selvaraju & Peterson, 2017), and multi-database query mashups modified in a few clicks – minimal "data-wrangling" (Lohr, 2014) is required. Another benefit of SSBA is it requires managers to frame their requirements. Traditionally, resorting to Business Intelligence specialists without sufficient attention to requirements engineering (RE) could induce delays of weeks (Dinsmore, 2016), impacting long-term usability in notorious cases (Schlesinger & Rahman, 2016). Self-service attempts – even failed – can help mitigate such risks, as requirements are better framed should there be need for experts.

Table 3.1 Systematic literature review summary [a]

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<tr><td rowspan="7">AND</td><td colspan="2"></td><td>Framework</td><td>Model</td><td>Procedure</td><td>Process</td></tr>
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<tr><td colspan="2"></td><td>Support*</td><td>For</td><td>Sustain*</td><td>Enabl*</td></tr>
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a. Strategy executed 02/10/18 in Scopus, Engineering Village, and Web of Science

b. The only hit is Lizotte-Latendresse and Beauregard (2018) if the "Lean" keyword is included

There is limited research on the relatively new topic of SSBA, particularly regarding the implementation dimension. In fact, the only two relevant hits in our systematic literature review at Table 3.1. (Olavson & Fry, 2008; Schuff, Corral, St. Louis, & Schymik, 2016) are not directly related to manufacturing. Since end-user software is involved, some improvisation is expected, which may explain in part why such implementations have been scarcely documented. This appears particularly true for the case of make-to-order (MTO) dominant manufacturing sites, where weak matrix project management support structures are frequent (Project Management Institute Inc, 2013). Nevertheless, a need is to be addressed for implementation guidelines to maximize results and minimize delays with respect to the project manager's triple constraint (see Figure 3.4).

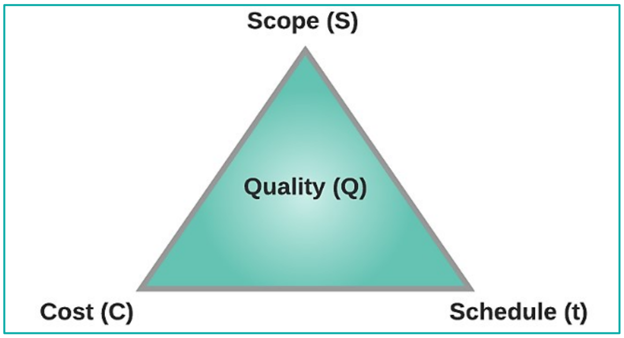


Figure 3.4 Project management triangle
(Project Management Institute Inc, 2013)

While project management best practices drive project team overall effectiveness to implement traditional ERP systems in manufacturing environments (Boykin, 2014), overemphasis on traditional project planning techniques may actually burden SSBA implementations. This is analogous to the plan-centric and agile approach dichotomy in software development (van Waardenburg & van Vliet, 2013). Some implementations of SSBA can also be seen as form of corporate entrepreneurship (intrapreneurship) initiative, for which autonomy and organizational ambiguity tolerance are key enablers – maturity factors (Elia, Margherita, & Petti, 2016). Furthermore, corporate culture factors such as workplace attitude and commitment should be taken into account in the implementation strategy, as they bear strong influence on long-term sustainability (Glover, Farris, Van Aken, & Doolen, 2011). Guidelines such as the MIT Lean Enterprise Self-Assessment Tool (LESAT) enable characterization of current versus desired states, as well as a Lean transformation roadmap (Lean Advancement Initiative, 2012).

Our contribution to the BA body of knowledge is through development of a methodology to implement SSBA in lean manufacturing environments with regard to current IS, sales and operations planning (S&OP), and workplace culture – the systemic perspective. This state-of-the-art review constitutes the foundations for the framework designed and developed through the Design Science Research methodology (Dresch et al., 2015). This framework is incrementally improved with lessons learned throughout SSBA implementation in the steel industry.

Related state-of-the-art literature addresses several problems associated with design and implementation of intelligent systems supporting lean improvement programs in multiple industries. Selvaraju and Peterson (2017) present critical socio-technical factors of success for analytics in a lean context. Unver (2012) introduces a manufacturing intelligence (MI) system assisting lean continuous improvement by contextualizing shop floor data. Saha, Aqlan, Lam, and Boldrin (2016) develop an expert system to help prioritize customer orders. Urabe, Shuangquan, and Munakata (2016) attempt to solve KPI conflicts between sales and production by means of better communication with the help of an inter-departmental cockpit – improved S&OP. Dresch et al. (2015) produce a comprehensive guide to Design Science Research (DSR) in management and engineering, effectively synthetizing key advances such as those from Peffers et al. (2006) in information systems (IS) research.

3.2.2 Critical factors of success for analytics in a lean context

The first step in Selvaraju and Peterson's research is developing a framework to assess the organization's maturity for technology-supported Lean (Selvaraju & Peterson, 2017). A second goal of the authors is defining technology-supported business problem solving best practices. Thirdly, the authors wish to use analytics to monitor the lean transformation, as well as technology adoption rates. The framework aligns with Balanced Scorecard metrics: "Customer value, Financial excellence, Culture growth, and process excellence" (Selvaraju & Peterson, 2017).

The developed methodological artifact is based on existing state of the art models. First of all, an Organizational Culture Inventory (Human Synergistics International) is employed to characterize the organization's culture for key behavioral styles such as Constructive or Passive/Defensive. Secondly, this analysis is combined with a lean technology and process maturity assessment. The technology and process assessments are out of the article's scope.

Then, BA are integrated in a decision-making methodology throughout the lean transformation. Here, BA enable managers to quickly identify improvement opportunities from dynamic performance measurements. The visual analytics process feedback loop enables continuous improvement of problem solving and decision-making processes (see Figure 3.5).

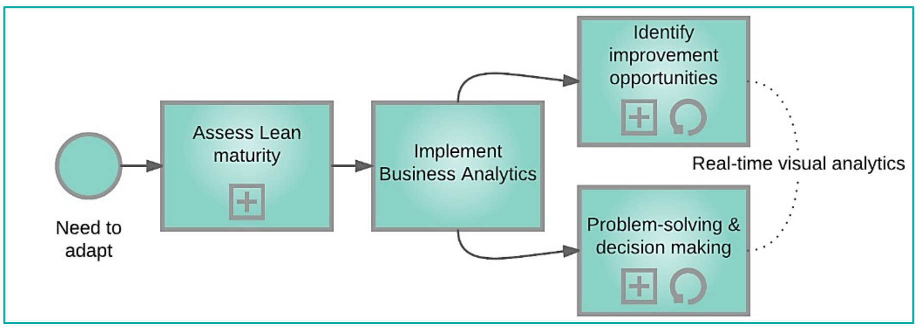


Figure 3.5 BPMN for the Selvaraju and Peterson (2017) framework

Application of this methodology yields an "Information Delivery Management Tool". The resulting dashboard-based application is designed to gauge the effectiveness of organizational lean measures. The dashboard is deployed online with the help of IBM supply chain manufacturing. Selvaraju and Peterson (2017) conclude that the framework has been successfully validated for implementation in a complex manufacturing environment. Authors foresee application of the framework to other fields.

3.2.3 Contextualization of shop floor data with ERP systems

Unver (2012) aims to develop a framework for BA in the form of a manufacturing operations center (MOC) following guidelines of the International Society of Automation's ISA-95 standard. Another requirement for the framework is to support implementation of the Lean philosophy, namely measures such as total productive maintenance (TPM) (Unver, 2012). As a major improvement over current tools and techniques, the author wishes to address the disconnection problem between shop floor systems and corporate-level ERP.

The author's methodological approach is mainly one of software architecture. He is part of a team of developers at Oracle. The software architecture team starts by assessing the shortcomings of current ERP-integrated production support systems. Design requirements are outlined; for instance, the possibility for the system to bring relevant KPIs to both plant managers and cross-plant vice-presidents. An ERP-agnostic concept is then developed with numerous industry partners to support shop floor integration. The neutral design, bound by the ISA-95 standard, is meant to be sufficiently generic to harness components from various industries. Two use cases are presented, which are examples of lean transformations where the software helps.

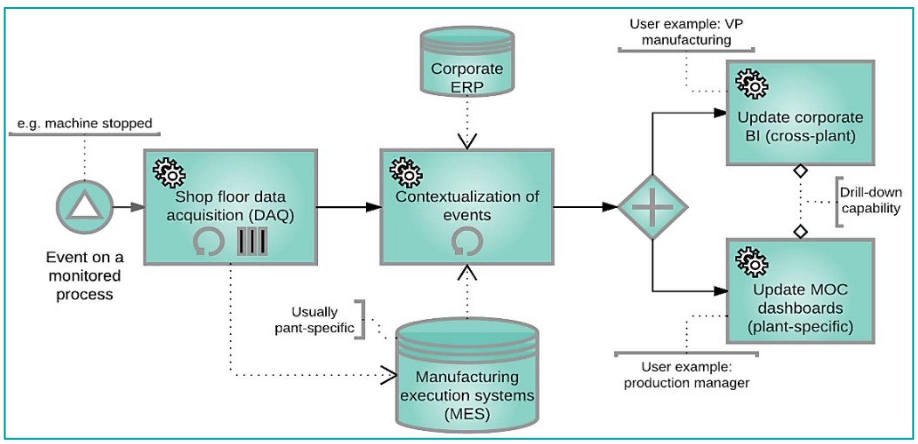


Figure 3.6 BPMN for the MOC from Unver (2012)

Unver's research yields a MOC (see Figure 3.6) which works by converting real-time data from shop floor equipment into business events, aggregating these events with context data acquired from ERP systems, and then generating relevant KPIs. A cornerstone of the system is hierarchical drill-down capability, which enables corporate-level managers to investigate otherwise superficial plant KPI components – disaggregate performance metrics down to problematic machine shifts to outline possible root causes. Use cases include TPM (i.e. OEE), as well as live production line status dashboards to improve incident response delays. The Oracle MOC offering is Oracle BI Enterprise Edition (OBIEE). Future work includes adding other important metrics such as work in progress (WIP) and manufacturing lead times.

3.2.4 An expert system to help prioritize work orders

Saha et al. (2016) endeavor developing an End-to-End (E2E) Customer Order Management System (COMS) composed of three integrated tools and a real-time dashboard. The problem researchers mean to tackle is quantification of strategic and operational impacts of expert system assisted order prioritization decisions. Authors wish to assist the prioritization decisions, but also track order progression and late delivery risk.

The methodological approach employed by Saha et al. starts by a characterization of the system for which a COMS will be developed, and performing a diagnosis of areas where decision support is most needed. A set of assumptions is derived from the supply chain assessment, and the three-module decision support system is designed. The order prioritization tool relies on the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) as a multi-criteria decision-making model. Then, an order fulfillment progress projection tool (OFPPT) is developed. It utilizes a Mamdani Style Fuzzy Inference System (MSFIS) to simulate subject matter expert (SME) judgement. Finally, a risk mitigation tool (RMT) is developed to draw a risk criticality matrix by aggregation of order parameters and context into the Integrated Risk Likelihood (IRL) and Total Impact (TI) variables. Interactions between these systems and work in progress (WIP) are represented in Figure 3.7.

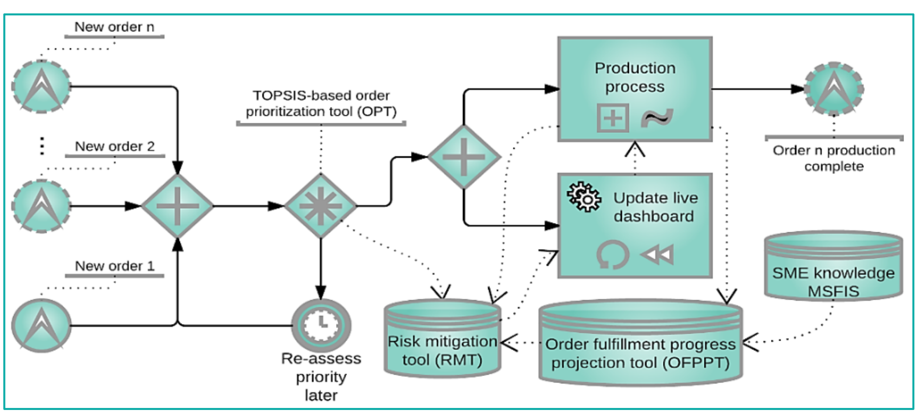


Figure 3.7 BPMN for the expert system from Saha et al. (2016)

Evaluation of the system is possible with an application at a server manufacturer in combination with criterions derived from Hommes and Van Reijswoud (2000): expressiveness, effectiveness, suitability, comprehensibility, coherence, completeness, and efficiency. An order management dashboard is implemented. The system performs well with regard to the evaluation criterions (Saha et al., 2016). The RMT could be improved by incorporating very low likelihood yet massive impact risks like terrorism.

3.2.5 Dashboards to help solving departmental KPI conflicts

Urabe et al. (2016) wish to address the problem where some departments will jeopardize other departments KPI to maximize their own. Low synergy and chronic finger-pointing are ultimately detrimental to the company's bottom line. The authors wish to develop a strategy to better manage this issue, and then implement it through an automated tool.

From a methodological standpoint, authors start by highlighting the issues with traditional methods for supply-demand planning. KPI conflict patterns are outlined. Then, a visualization system is developed to provide a communication-based solution.

In their diagnostic, authors emphasize a recurring KPI conflict pattern: if sales focus on fast-selling products to catch up on their KPI goals rather than to try selling overstocked items, not only will the overstock be detrimental to supply chain management (SCM), which is penalized by excess inventory, but the sales surge will also force the production department to utilize more resources than initially allocated to maintain on-time delivery rates. This is the production sales and inventory (PSI) problem. A communication-based strategy is then prescribed to help overcome the issue. It integrates the three departments affected by the diagnosed pattern: production, sales, and SCM. Where PSI problem-solving used to be done by individual departments – often neglecting the systemic perspective –, it should now be accomplished through inter-departmental cooperation. To implement a PSI-Cockpit supporting this strategy, two main features are selected: drill-down and alert. Drill-down enables involved departments to quickly identify item-level parameters which cause KPI conflicts, modify these in a tabular interface, all the while simulating the impact on KPIs real-time. The alert feature displays a notification when a departmental KPI reaches a critical threshold. Problem solving following an alert is performed through what-if analysis with the simulation feature (see Figure 3.8). The simulation feature can be seen as a digital twin, as changes made are only theoretical until those have been applied. Future research will evaluate the impact of this tool on the manufacturing ecosystem.

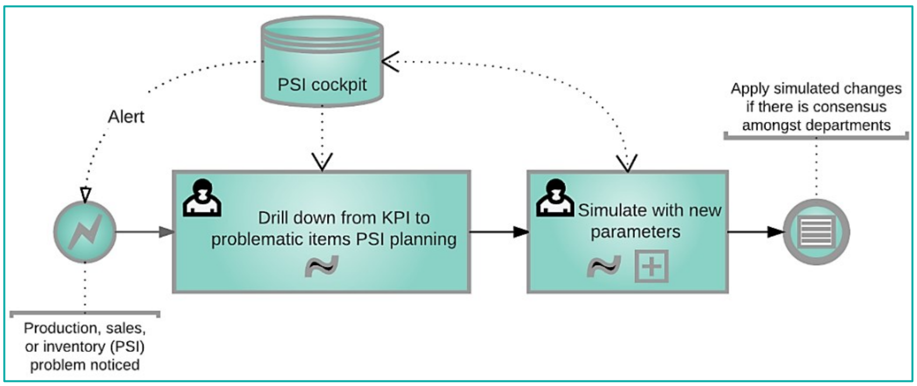


Figure 3.8 BPMN for Urabe et al. (2016) PSI problem solving

3.2.6 Producing and presenting information systems research

Dresch et al. (2015) perceive a lack of systematization and consolidation of the concepts of DSR in current literature, particularly for application in management and engineering. To address this, authors wish to contextualize the foundations of Design Science, DSR, and synthetize a method for DSR.

The authors build upon pioneering work from Peffers et al. (2006) for DSR adapted to IS. Peffers et al. addressed a shortcoming in DSR (Dresch et al., 2015) methodological guidelines as to application to information systems research. Although DSR had existed for over a decade, very little research had been published following this method which effectively bridges the gap between rigorous research and prescriptive applications. Indeed, action research and case studies seldom focus on rigorous science fundamentals such as experimental repeatability and hypothesis falsifiability. Emphasis is put on designing artifacts which are consistent with current literature, and building upon those to expand the body of knowledge. The process is iterative in its nature, as initial requirements only lead to a proposal for a solution and the formalization of construction heuristics. It is through iterative simulation and evaluation that construction and contingency heuristics can be refined to clearly define a satisfactory artifact and its limitations.

Design Science research in IS involves (Peffers et al., 2006):

- Identifying the problem and the research motivation, and defining objectives for a solution;
- Designing and developing an artifact;
- Demonstrating effectiveness of the artifact in problem-solving along with thorough evaluation, documenting lessons learned from the demonstration, and
- Communicating results.

As the development of DSR guidelines was done following the DSR methodology, the author's recommendations will be validated by upcoming Design Science Research papers which are successful with application of the methodology.

3.3 Methodology

The design science research methodology is selected for this research. As summarized in the literature review, this methodology structures rigorous practical research. The methodology is a good fit for information systems design, where it has been successfully applied (G. Meyer et al., 2014). DSR aims to design and recommend, while the general scope of pure case studies and action research would be to explore, describe, explain, and predict (Dresch et al., 2015). The key steps are literature review, artifact design, artifact development, artifact evaluation, clarification of learning achieved, generalization to a class of problems, and conclusion.

A systematic literature review was conducted. This literature review is then leveraged for design of the artifact, which in this case is an implementation methodology for SSBA. It is the step where construction heuristics are defined. While the artifact design itself is a largely abductive process, as it stems from creativity guided by state-of-the-art practices, the subsequent steps add scientific value to it – application makes it possible to gather empirical evidence. Artifact development is the phase where the construction heuristics are applied. In this research, it is the phase where the SSBA is implemented in an industrial setting.

This development is then documented, and empirically evaluated. In this research, empirical evaluation is achieved through a survey disseminated in both the sales and production departments. The survey is distributed electronically with Google Forms. It is based on the evaluation criterions used by Saha et al. (2016), originally developed by Hommes and Van Reijswoud (2000): expressiveness, effectiveness, suitability, comprehensibility, coherence, completeness, and efficiency. For combined departments, an average score of 4 out of a maximum of 5 for those criterions is set as the threshold for satisfactory implementation. An opportunity is also given for anonymous commentaries through the survey form. Field observations of the impacts of the tool on the manufacturing ecosystem are also reported.

The next step is outlining lessons learned. This clarifies the learning achieved in the artifact development and validation steps. In this phase, the goal is to reflect on the strengths and weaknesses of the artifact in its current state. It makes a feedback loop possible towards the artifact design stage. Lessons can be learned from the industrial implementation case documented through the steps of the designed implementation methodology. The dual purposes for studying the case are thus to evaluate the construction heuristics used to develop the SSBA tool, and also evaluate the fitness for use of the tool itself. The goal of this research is to develop a prescriptive framework applicable to the SSBA implementation class of organizational problems. Recommendations are to be formulated for conducting the identified key steps of the implementation: IS assessment, process mapping, software selection, change management, SSBA deployment and continuous improvement.

From the scope of the artifact development, it is then possible to generalize the methodological artifact improved by the lessons learned to a class of problems, which is the goal of this research.

3.4 Design of the artifact

Key SSBA architecture findings can be summarized:

- The Hierarchical drill-down capability can facilitate PSI problem investigations, S&OP, and helps scalability;
- An alert feature can be integrated in order to notify stakeholders that a problem is to be addressed, especially in cases where timely action is needed;
- Simulation can improve the decision-making process. Predictive analytics leveraging statistics or machine learning can ultimately help modulate KPI outcomes with improved operational decision-making;
- Tracked KPIs must be chosen carefully, as people will attempt to improve those if they are compensated to do so, even if the outcome is unproductive.

Implementation methodology has additionally been reviewed. Assuming sufficient stakeholder strategic involvement, best practices are split between the phases of planning and execution in the MIT LESAT. Best practice highlights as to planning are the following:

- Assess available information systems, data accessibility;
- Determine areas of possible improvement in current processes, preferably with a structured approach such as process mapping. Establish current versus desired;
- Evaluate data quality, for instance the standard times used to estimate production throughput;
- Adapt to corporate culture factors such as openness to change and inter-departmental power dynamics.

The mental model presented in Figure 3.9 integrates these literature review findings into a high-level implementation workflow – the first iteration of the artifact. The SSBA implementation framework presented at Figure 3.10 is the second iteration of this artifact; it integrates lessons learned throughout SSBA implementation at the case company.

3.5 Case study of the artifact development

3.5.1 Assess available information systems

Assessment of the available information systems with the partner company was not a structured process. No need for a standardized assessment such as object-oriented analysis with data flow diagram (Repa, 2013) was established, since it was clear which program fulfilled the role of MES and which one fulfilled the role of ERP. The MES database structure could be understood by inspection with the database management program bundled with it, and a connection was established. Stakeholder support was required to acquire a connection file for the ERP SQL database.

3.5.2 Map current versus desired processes

By walking the process through a “Gemba walk” (Camuffo & Gerli, 2018), an understanding of the general workflow was developed. The standardized notation of BPMN was then used to represent the different steps of the process. This mapping was then validated with the people involved in the process.

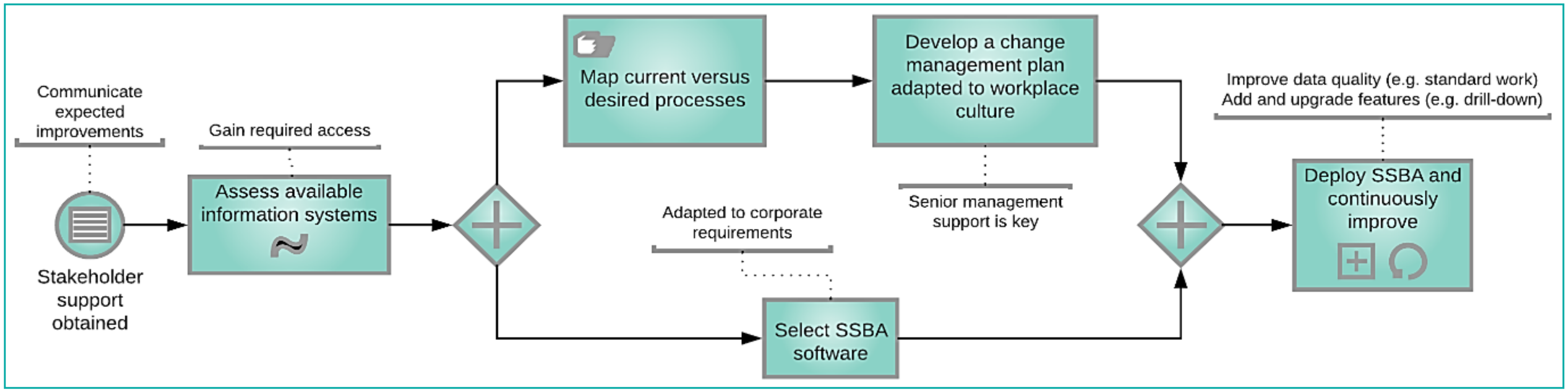


Figure 3.9 Lean manufacturing SSBA implementation workflow (Lizotte-Latendresse & Beauregard, 2018)

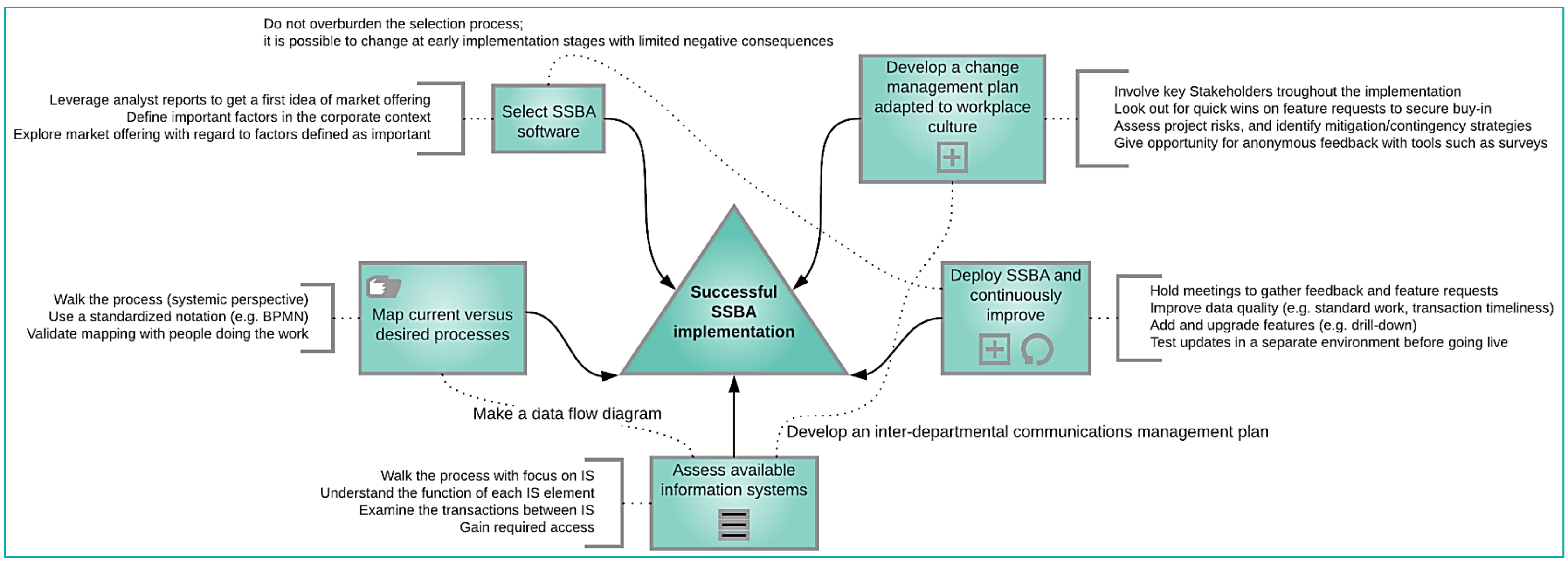


Figure 3.10 Lean manufacturing SSBA implementation framework

3.5.3 Select SSBA software

For SSBA software selection, a qualitative approach was used. The first tool that was used to help with selection was the research report from the Gartner (2018a) analyst firm. This helped by giving a first idea of the most reputable solutions available in terms of completeness of vision and ability to execute. From that point, additional attributes were included based on corporate requirements. Considered factors are accessibility, flexibility, as well as scalability.

Accessibility in this context is having the software pre-approved by IT and already packaged for simple deployment on any company machine. This is considered an important factor given the short timeframe, and much weight was given to the availability of Power Query through the company's System Center (Microsoft, 2018) platform for free on any computer with the Office suite. The querying feature is even built-into newer versions of the software. Power BI is also readily available. Other options would have required an approval workflow.

Flexibility is defined as the ability to implement changes quickly in the tool, for instance slight adjustments to the way calculations are performed to generate a dashboard. This was also deemed a very important aspect, as it was planned to hold meetings at the company to gather feature requests from stakeholders. With the help of Visual Basic for Applications (VBA) in Excel plus M and R languages for Power Query, it was possible to go beyond built-in capabilities and better articulate the solution to corporate requirements. Those programming languages are very well documented given the strong user base involved in developer forums; documented similar cases can be leveraged to significantly reduce troubleshooting time for non-experts.

Scalability as the ability to accommodate increases in scope is an important aspect, as what saves time for initial experimentations may not necessarily be viable for cross-plant deployment. While Power Query may seem at first like it is just an Excel plugin, query mashups designed with it can actually be imported into Power BI, which is a much more scalable software. Data gateways can enable the cloud-based software to query enterprise databases remotely to create dashboards available via web browser.

3.5.4 Develop a change management plan

The change management plan developed here was based on the Stakeholder Theory by Freeman (2010). Meetings have been held with those stakeholders which would be most impacted by the adoption of the SSBA tool. The main objectives were to gathering suggestions and getting a chance at better communicating the vision behind the project. Benefits of this strategy are twofold, as it not only contributes to the continuous improvement of the tool, but also fosters the ownership and buy-in critical for convergence towards empirical saturation – stakeholder satisfaction. As opposed to change management models like that of Kotter (1995), this approach is a better fit, as stakeholders are involved in designing the change to be achieved right from the start. There is no need to create a sense of urgency, as stakeholders will buy-in and contribute to requirements definition if they are allowed to see the benefits for them early on.

3.5.5 Deploy SSBA and continuously improve

The SSBA deployment and improvement phase was composed of several subprocesses. First, main queries had to be designed through Power Query. Secondly, the dashboard had to be designed and linked to the query results. Automated refresh routines were subsequently implemented to enable unattended dashboard updating. The tool was then physically deployed. Meetings were organized to gather stakeholder feedback and new features requests – features which were then gradually implemented. The cumulative number of improvements over time is shown at Figure 3.11; those improvements are summarized in Table 3.2. Given the trend of cumulative continuous improvements, empirical saturation has not been reached for the iterative improvement process within the timeframe of the project. Several additional features from the literature review could be deployed incrementally to tackle additional problems such as order prioritization (Saha et al., 2016).

Initial query design was a straightforward process thanks to the step-by-step design tool of Power Query. Connections were established with the help of the Office Data Connection (.odc) files. Mashup capabilities were leveraged when came the time to combine data from MES and ERP, which had databases operating on two separate SQL servers. Not only did the tabular interface enable merging and formatting data, but the built-in M language was used to apply logic on entire rows in a much faster and cleaner way than would have been possible in Excel. This capability was leveraged to account for oxyfuel multi-torch cutting, which depends on part size and plate thickness. Multi-torch cutting can make a big difference when it comes to estimating cutting times for large orders of an item: up to eight parts can be cut in parallel on the Esab machine of the case company.

Output from these queries was then linked to Excel formulas in another worksheet to turn data into information. At this point, there was a lot of reflection as to the way that this information should be displayed, and the decision was that order volume should be shown with two levels of aggregation – one per month and one daily.

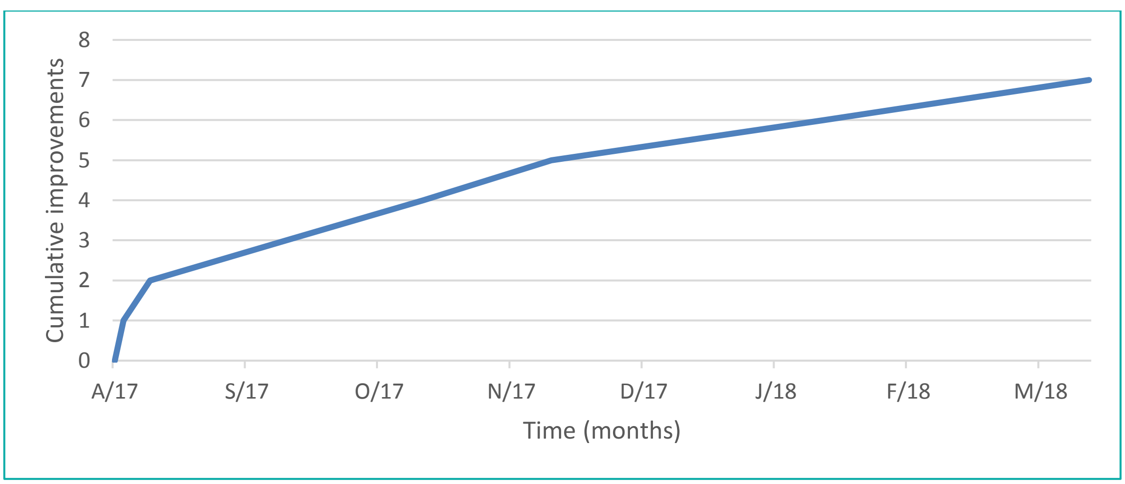


Figure 3.11 Count of improvements to the SSBA tool over the duration of the project

Table 3.2 Evolution of requirements over the project duration

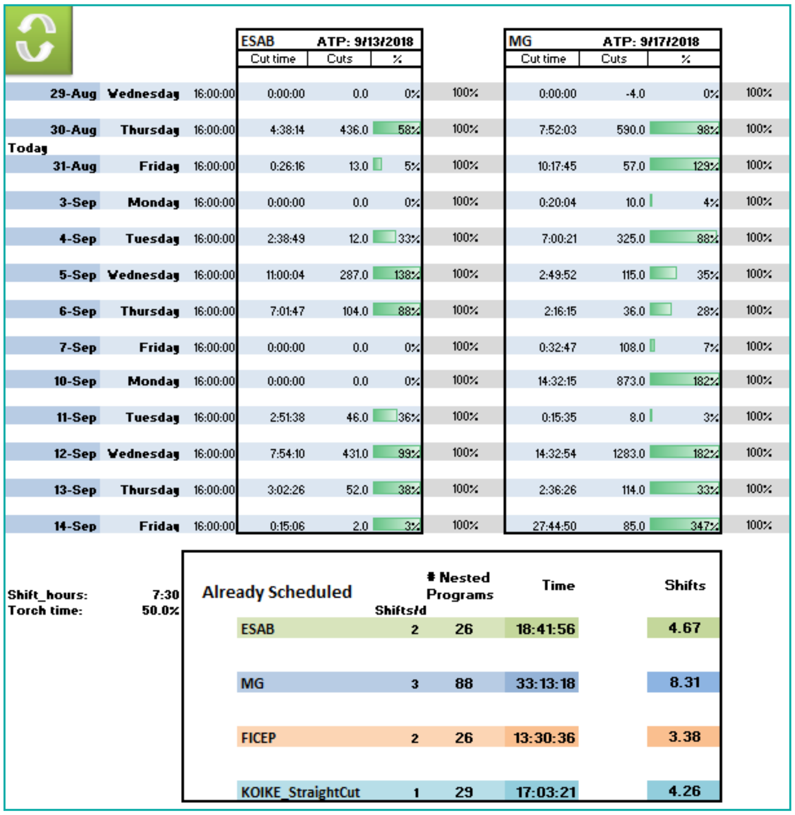
Requirement	Completion date
Initial deployment	08-07-17
Increase font size	08-09-17
Hide weekends to display more business days	08-15-17
Drill-down feature	09-15-17
Multi-torch time calculations	10-16-17
Data logging	11-14-17
Lead time calculations	01-15-18
Account for outside processing	03-16-18
RPA for order releasing [c]	Not yet complete
RPA to account for shop floor improvisation [c]	Not yet complete

[c.] Enabling data quality project

Each line on the dashboard then corresponds to a day from the last two (late orders) to the next 10 business days. Sum of the processing times for orders due this day is then converted to a percentage of the daily capacity. This is represented in equation (3.1), where t_{ijk}^{c} is the cutting time estimate for an item $i \in I$ due for a day $j \in J$ on a production line $k \in K$, P_{jk} is the capacity utilization percentage for a given day and line, n_k^s is the number of shifts in a day on a given line, d^s is the duration of a shift, and A is the target availability percentage. $j = 0$ corresponds to the current day. Items marked as complete in the IS are excluded from calculations.

$$P_{jk} = \frac{\sum_{i \in I} t_{ijk}^{c} * 100}{n_k^s * d^s * \frac{A}{100}} \qquad \begin{cases} \forall j \in J \\ \forall k \in K \end{cases} \tag{3.1}$$

Since orders are produced in advance whenever possible, this disaggregated representation is not always an accurate barometer of the situation in terms of production. There is however a second aim to it. Creating a pull dynamic towards days with low capacity utilization spreads out deliveries to customers, and helps to take some pressure off the shipping department. The factory has a single bay to load trucks, and having too much to ship on a given day can have adverse effects such as requiring production employees to join in to help shipping, lowering line throughput.



			ESAB Cut time	ESAB Cuts	ESAB %		MG Cut time	MG Cuts	MG %	
			ATP: 9/13/2018				ATP: 9/17/2018			
29-Aug	Wednesday	16:00:00	0:00:00	0.0	0%	100%	0:00:00	-4.0	0%	100%
30-Aug	Thursday	16:00:00	4:38:14	436.0	58%	100%	7:52:03	590.0	98%	100%
Today										
31-Aug	Friday	16:00:00	0:26:16	13.0	5%	100%	10:17:45	57.0	129%	100%
3-Sep	Monday	16:00:00	0:00:00	0.0	0%	100%	0:20:04	10.0	4%	100%
4-Sep	Tuesday	16:00:00	2:38:49	12.0	33%	100%	7:00:21	325.0	88%	100%
5-Sep	Wednesday	16:00:00	11:00:04	287.0	138%	100%	2:49:52	115.0	35%	100%
6-Sep	Thursday	16:00:00	7:01:47	104.0	88%	100%	2:16:15	36.0	28%	100%
7-Sep	Friday	16:00:00	0:00:00	0.0	0%	100%	0:32:47	108.0	7%	100%
10-Sep	Monday	16:00:00	0:00:00	0.0	0%	100%	14:32:15	873.0	182%	100%
11-Sep	Tuesday	16:00:00	2:51:38	46.0	36%	100%	0:15:35	8.0	3%	100%
12-Sep	Wednesday	16:00:00	7:54:10	431.0	99%	100%	14:32:54	1283.0	182%	100%
13-Sep	Thursday	16:00:00	3:02:26	52.0	38%	100%	2:36:26	114.0	33%	100%
14-Sep	Friday	16:00:00	0:15:06	2.0	3%	100%	27:44:50	85.0	347%	100%

Shift_hours: 7:30
Torch time: 50.0%

Already Scheduled	Shifts/d	# Nested Programs	Time	Shifts
ESAB	2	26	18:41:56	4.67
MG	3	88	33:13:18	8.31
FICEP	2	26	13:30:36	3.38
KOIKE_StraightCut	1	29	17:03:21	4.26

Figure 3.12a Production-side dashboard part 1

On the top of each column, there is however a fully aggregated representation in the form of a lead time per machine (see Figure 3.12 a & b). Those available to promise (ATP) dates – akin to the lead times shown on the whiteboard at Figure 3.2 – are computed by summing up cutting time estimates for all orders which require the machine in the upcoming month, and dividing by the effective daily machine torch runtime to net a number of business days (lead time) which is input in the Excel Workday function. Lead time calculations are represented in equation (3.2), which adds a second sum to equation (3.1); L_k is the computed lead time for a production line $k \in K$.

$$L_k = \frac{\sum_{j=-2}^{30} \sum_{i \in I} t_{ijk}^c}{n_k^s * d^s * \frac{A}{100}} \qquad \forall k \in K \qquad (3.2)$$

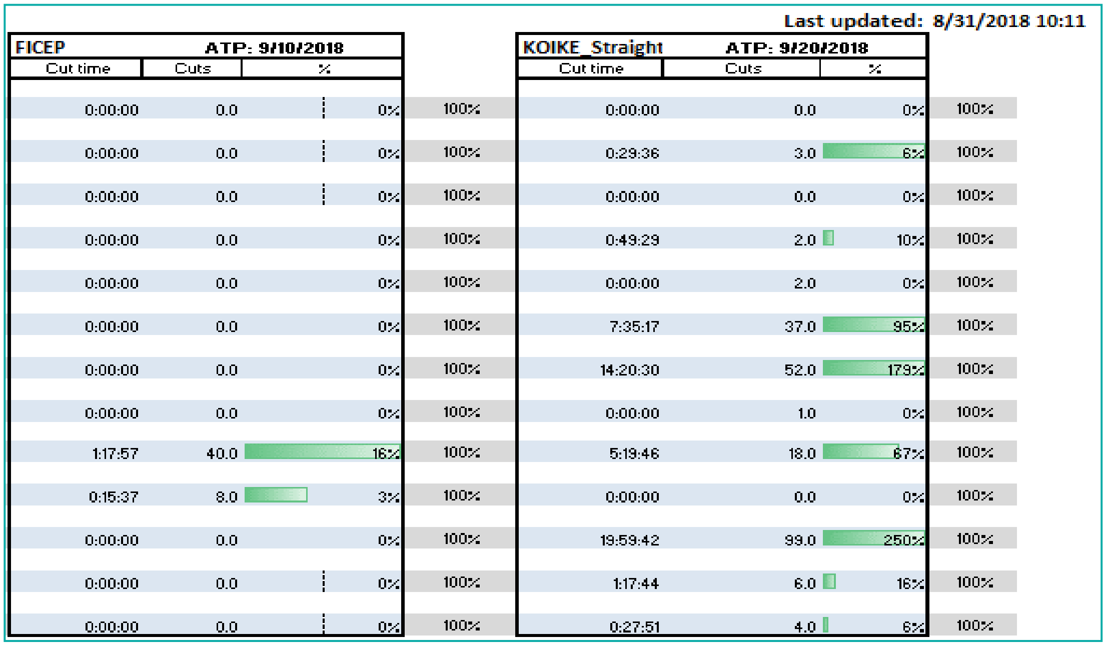


Figure 3.12b Production-side dashboard part 2

Such lead times are prescribed mainly to avoid overbooking on the short term with general production – premium orders are possible though the ad-hoc communication channels shown in Figure 3.3.

The production-side dashboard shown at Figure 3.12 a & b is subject to input from the production management team as to planned downtimes. A streamlined version was therefore developed to run unattended in the form of an “airport view” dashboard for the sales department (see Figure 3.15 and Figure 3.18). This sales-side dashboard queries the “master” – which is shown in Figure 3.12 – through Power Query.

Those two files needed to be able to run unattended. For the production workbook, the initial requirement was that it refreshes itself every two minutes, and then autosaves for the changes to be made accessible to the querying sales workbook. The sales-side dashboard had to cycle between the machine capacity utilization and the ready to ship orders worksheets (see Figure 3.15 and Figure 3.17) automatically, and also needed to query the master workbook every few minutes for updated information. This was implemented with Excel VBA add-ins which generate dropdown menus in the ribbon (see Figure 3.13).

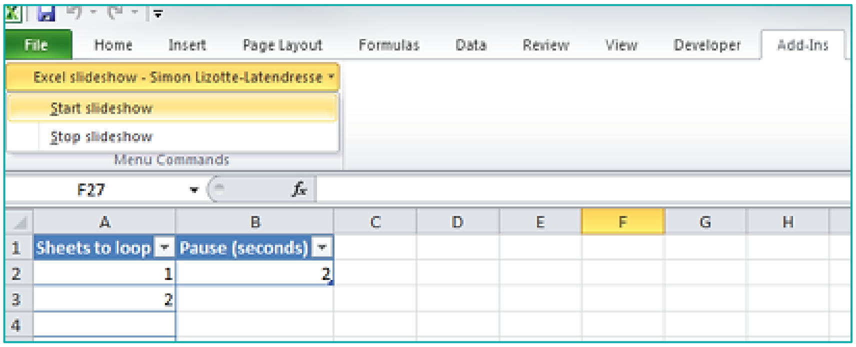


Figure 3.13 Add-in user interface for the sales-side dashboard

While the production workbook runs on the production planner's computer, the goal with sales was to have the information accessible without requiring a workbook to run on everyone's computer, a bit like the old whiteboard. To accomplish this, the production planner's computer was connected to a wall-mounted TV via HDMI, and the sales workbook was moved to this additional screen (see Figure 3.15).

Meetings were held to spark continuous improvement of the tool. While first requests had to do with formatting of the dashboard, such as increasing font size and displaying only business days, there were then several additional feature requests.

Two feature requests are integrated in the sales-side dashboard shown in Figure 3.17. The pick-up ready section displays the orders which are ready to be picked up by customer-dispatched carriers – additional columns were added to save time when sales have customers on the phone. It is now also possible to see which inside sales representative is assigned to each order, as well as to know what is the customer-side PO number associated with the company order number.

One of the first features to be added was drill-down – its importance has been outlined in the literature review. This was implemented with the help of Pivot Tables, where dates and machines can be selected via slicers to analyze the distribution of orders processing time (see Figure 3.14). It was included in an additional sheet inside the production workbook. The tool helps to quickly identify which order contributes most to an abnormal capacity utilization. This is useful for what-if analysis when contingencies such as outside processing are considered.

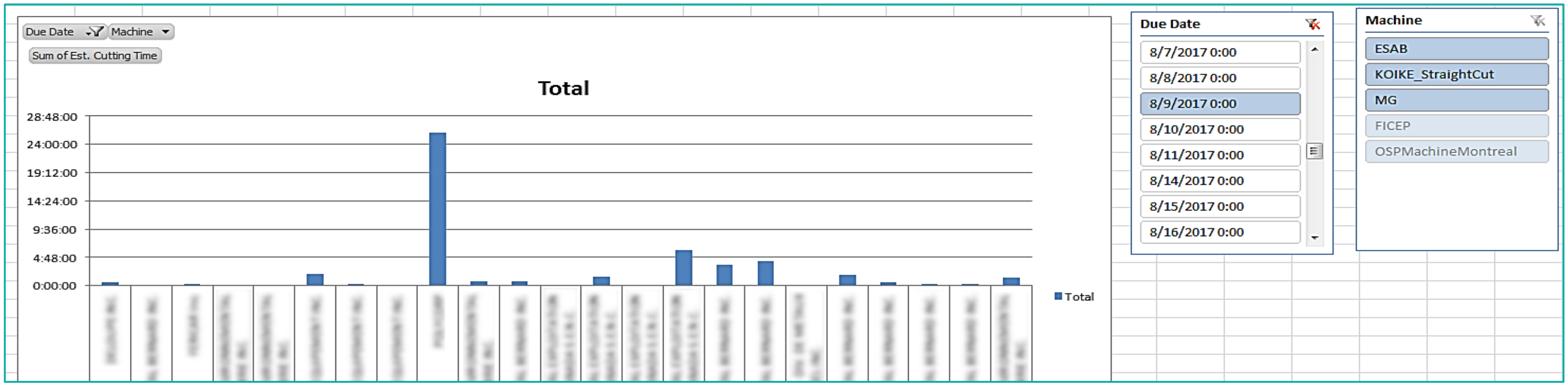


Figure 3.14 Daily view per machine drill-down feature

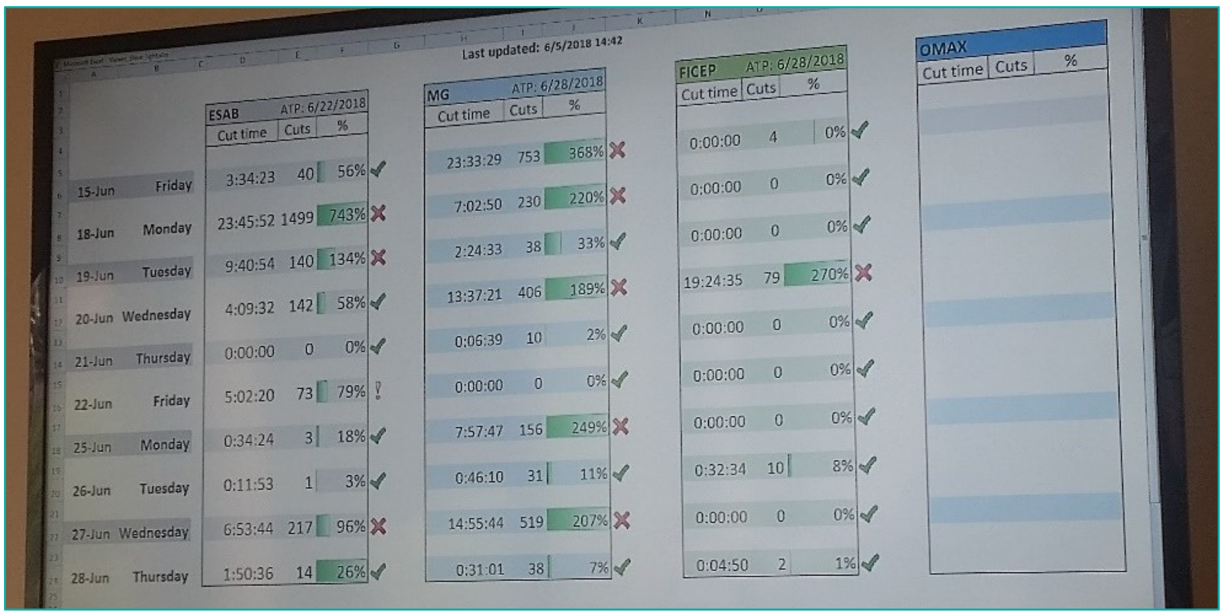


Figure 3.15 Dashboard physical deployment machines slide

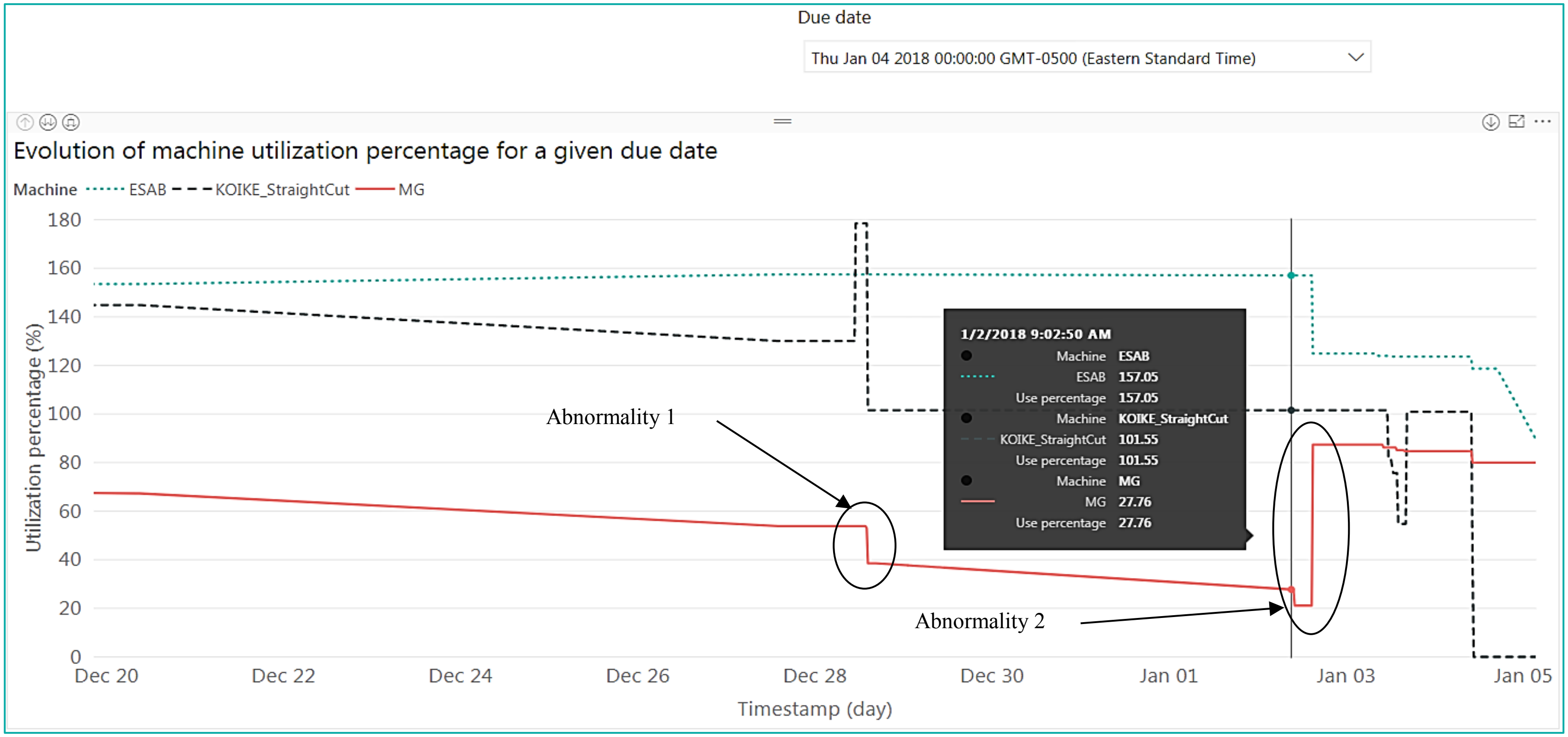


Figure 3.16 Capacity utilization history analyzed in Power BI

Subsequent improvements include adding a data-logging feature to the dashboard to track capacity utilization for specific dates over time. This was integrated in the production-side add-in with the purpose of tracking occurrence of capacity utilization abnormalities. To accomplish this, an Access database with the fields used in the main dashboard was created. Through VBA, a routine was established to add a timestamp to each instance of this data being logged into the database through execution of an Access Database Engine statement. The offline version of Power BI was then used to build a dashboard to analyze this data, as shown in Figure 3.16; this offline version was used to avoid using data gateways at this time. The dashboard shows how orders are being gradually entered for a date, and then processed as the due date nears. This data is however subject to interference from other factors such as delays in manual releasing of orders, as well as delays in marking those as complete after they have been processed. Calculation for this Power BI analysis tool are performed following the logic shown in equation (3.1), with an added timestamp dimension.

As can be seen on the red curve corresponding to a plasma cutting machine at Figure 3.16, daily capacity usage was 70% three weeks before the date selected. This utilization declined at a steady rate as orders were cut and marked as complete in the MES.

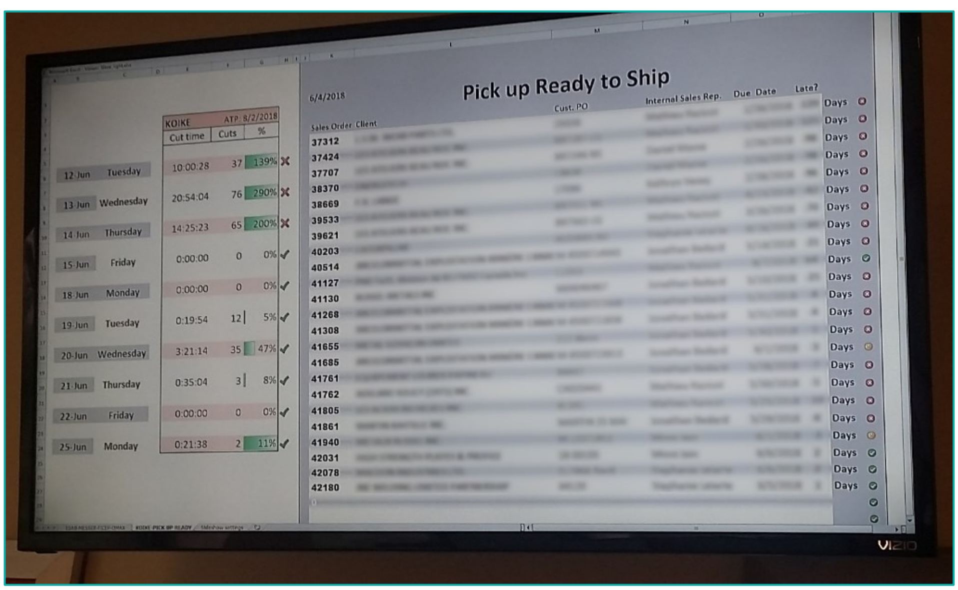


Figure 3.17 Dashboard physical deployment ready to ship slide

However, there was then a sudden decrease in capacity utilization (see abnormality 1). This was caused by nests being cut in more accessible plates to limit manutention, as those nests then had to be modified to reflect actual changes in physical inventory. As such nests are processed as a batch and marked as complete, artificial discontinuities in capacity utilization were generated. Then, the opposite happened, as orders entered in the ERP needed to be released manually in order to appear in the MES and contribute to capacity utilization as represented by the red curve (see abnormality 2). Since those were not released often, a large spike in utilization occurred a week before the due date. Capacity utilization did not decrease to zero exactly because there were late orders, as well as orders which were cut in more accessible plates and marked as complete later on.

Queries have also been refined to account for particular cases, such as times when part of an order is outsourced. The capacity utilization for due dates and the lead times are lowered since outsourced orders do not use in house line production capacity, helping sales win more orders. The queries used here have also been copied over and adapted in application-specific workbooks, for instance a production checklist to help shipping employees quickly find out how an order was split between multiple production lines. Data connections were transferred without issue upon transition from Excel 2010 to the 2016 version, but some add-in VBA code had to be reworked for the tool to keep running unattended.

3.6 Evaluation of the artifact developed

The evaluation survey has been sent to three internal sales representatives, and two employees involved in production planning. Results are displayed at Figure 3.18. The average for all criterions for both departments is 4.26 out of 5, which is above the threshold set on this Likert scale given sample and population size. Implementation is considered satisfactory to stakeholders, which is key to empirical validation.

Survey results also reveal that completeness and expressiveness are two criterions for which satisfaction was lower. Satisfaction is generally higher for the production department than for the sales department with 4.43 versus 4.14 on average for the criterions. This is also observed for the global satisfaction factor. From an effectiveness standpoint, sales however appreciate the tool better – time savings are noticed.

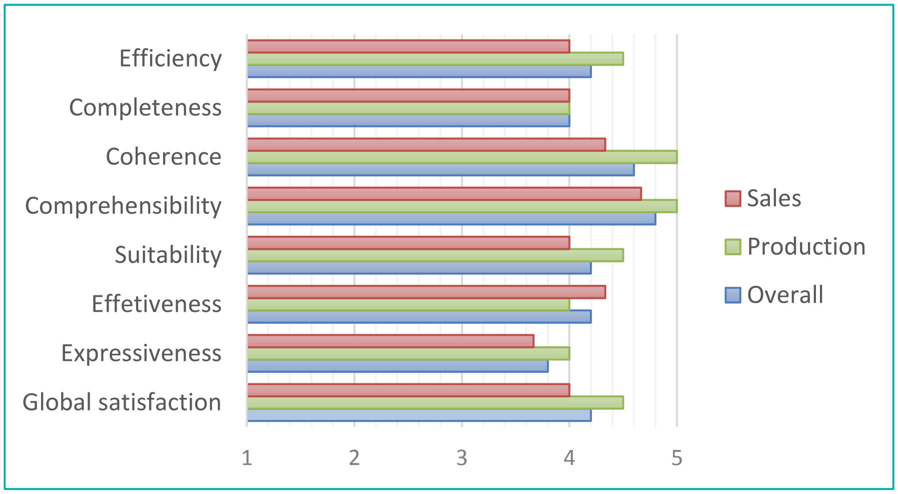


Figure 3.18 Evaluation survey results

From a qualitative standpoint, lead times are an important feature of the tool. Upon initial deployment of the SSBA, those were similar to what they were with the original whiteboard at Figure 3.2. With continued sales growth and production difficulties, lead times however increased over the course of a few months, to a point where those neared a month. As the cost of lost sales due to excessive lead times is high, measures such as outside processing for order cutting were utilized to lower lead times. This contingency can be used only when problems are identified in advance, as subcontractors also need turnaround time. This eventually led to a third shift being added on a line. Towards the end of the research project, lead times were back at about two weeks. Field observations thus point in the direction that the tool helped to increase the awareness of manufacturing capacity.

3.7 Lessons learned

Executive sponsorship was obtained through communication of the expected benefits of the project, as well as the low upfront software investments required. Direct communication proved to be an effective approach given the paternalistic management culture of this manufacturing company.

Some difficulties were however encountered later on which could not be overcome given the weak matrix project management structure. This occurred, for instance, when Robotic Process Automation (RPA) was considered to simplify the order releasing process (Blue Prism, 2018). This is a shortcoming in the initial workflow, as a contingency plan could have been put in place had this pitfall been identified sooner. While IS assessment had been ad-hoc – a Gemba walk –, a more structured assessment including data flow analysis may have revealed earlier that the manually triggered transactions would induce lag in capacity utilization calculations. An interdepartmental communications management plan could then have been developed to guide timely resolution.

Standardized mapping of the processes created a blueprint to help communicate the project's vision to all stakeholders; it was therefore validated as an essential part of the framework. The stakeholder's approach has also demonstrated its effectiveness later on, as several continuous improvements to the tool have been possible thanks to feature requests, refining it into something more useful for all parties involved. There were however unforeseen risks, and those may have been identified had an approach such as a risk criticality matrix been integrated. Strategies to mitigate those risks could then have been planned, along with contingencies. A good example of such a risk was that an add-in stopped functioning properly after the Excel version update, and had to be reworked – tests could have been run before updating to the newer version.

The factors identified as important given our industrial partner's situation – accessibility, flexibility, and scalability – have led to selection of Power Query. The software has demonstrated compatibility with existing IS, and its flexibility made it possible to quickly implement several documented feature requests. Even though a quantitative decision-making method (e.g. AHP) was not used to select the SSBA software, this is a case where a qualitative approach proved satisfactory. Of course, there will be companies where the management culture is against to such an approach, but this case shows that a simple decision-making process leveraging analyst reports and corporate requirement fit can work for SSBA given the low initial investments – changing the selected software at early stages is a possibility.

Initial deployment of the tool was carried out with an agile (Wördenweber & Weissflog, 2005) approach, with stand-up meetings with stakeholders to introduce the SSBA. While meetings with key stakeholders proved to be an effective way of improving the tool, subsequent ad-hoc stand-up meetings made it possible to sprint and roll out hotfixes for glitches before significant negative impacts could be observed. Direct communication and time on site are therefore identified as important success factors for SSBA deployment. Lessons learned from the implementation are summarized at Table 3.3.

Table 3.3 Clarification of learning achieved

Proposed workflow step	Issues for SSBA implementation	Lessons learned & integrated in framework
1 – Assess available information systems	Too short notice to the IT department for the enabling data quality project	Develop an inter-departmental communication management plan at early stages
2 – Map current versus desired processes	No visibility on the interaction of delayed data with the system	Make a data flow diagram to highlight data interactions
3 – Select SSBA software	Software update necessitating unforeseen code rework on the live SSBA tool	Set up a test environment to test the update before going live with the SSBA tool
4 – Develop a change management plan	Much improvisation was required as a result of unforeseen risks	Risks should be assessed, with identification of mitigation and contingency strategies
5 – Deploy SSBA and continuously improve	Expressiveness is the evaluation criterion with the lowest score	Reduce lag in SSBA data to a minimum

3.8 Artifact generalization

From the designed methodological artifact, its development, and the lessons learned from the implementation case, generalizations can be made for a class of problems. The resulting framework is presented at Figure 3.10.

The class of the SSBA implementation problem is at the intersection of the “problem analysis and decision-making support” and “project management” classes outlined by Dresch et al. (2015). The goal is to provide guidelines to managers for leveraging SSBA within the 3 to 6 months timeframe of a lean six sigma project. This framework differs greatly from pure agile project management, as it is geared towards managers driving lean manufacturing improvement projects with limited resources. One significant difference is the absence of daily scrum meetings, as those fit better in a strong matrix project management context.

The scope of the framework is also limited by the specificities of corporate cultures. As such, the generalization is limited to companies where top management sponsorship is available – this was identified as the top success factor for such changes initiatives, with employee involvement as the second most important factor (Selvaraju & Peterson, 2017). Involvement is key to the stakeholder’s approach integrated in the framework. The framework is also geared towards organizations with a weak matrix project management support structure, as different approaches may be required given strong or balanced matrix. Indeed, in a strong matrix context, there may be a full-time project manager available for the implementation, with access to much more resources to develop a satisfactory tool in less time. In such a situation, embedded analytics (Zaby & Wilde, 2017) may be a better option than SSBA, as the information could be made available to stakeholders in an even more seamless way – right from the applications they already use. Although the framework was originally developed for use in the manufacturing industry, further research would have the potential to extend its generalizability to other fields such as service.

3.9 Conclusion and future work

3.9.1 Main research contributions

Managers striving to achieve improvements in the dynamic data-driven processes of industries within 3 to 6 months are faced with several challenges. While there can be much data available, the information systems landscape is often fragmented, which means the data from different sources will have to be combined in a single tool before it can contribute to problem-solving. While tools fulfilling this purpose can be developed by experts given enough time, SSBA add flexibility by making it possible to readjust the tool nearly "on the fly".

A systematic review of recent SSBA implementation literature shows that there are no guidelines readily available as to implementation of SSBA tools. To our best knowledge, the framework presented is the first attempt at manager-oriented guidelines for implementation of SSBA. It integrates not only recommendations as to project management, but also development of the tool itself, and how to continuously improve it. While several elements from existing methodologies such as Agile and Lean Six Sigma are integrated in the developed framework, lessons learned from the case provide empirical evidence as to the systemic considerations for successful SSBA implementation. The DSR methodology used made it possible to empirically validate successful implementation with results meeting the threshold defined for stakeholder satisfaction.

3.9.2 Limitations and directions for future work

The research in this paper has some limitations. First of all, generalizability is limited by the nature of the case studied. The implementation case was in the manufacturing industry, at a company with a weak matrix project management structure. There was also limited time to organize meetings at the case company to avoid disrupting operations, which limits the extent of the empirical validation of the tool. The empirical evidence gathered is largely qualitative in nature. Still, qualitative analysis is essential in management, and valuable lessons can be learned from the case study.

While a data-logging feature was included in the SSBA to study its impact on the manufacturing ecosystem quantitatively, noise arising from manually triggered transactions made this impact difficult to isolate without enabling robotic process automation projects – excessive scope creep. Not all of the features highlighted in the literature review could be integrated given the limited timeframe in this case. A different set or a higher number of features may have had an impact on the empirical evaluation results.

Taking in account these limitations, further research should improve artifact generalizability by applying it to organizations of different sectors such as service or mining. Confirmatory work should be held in a longer timeframe to increase generalizability of the framework with long-term performance evaluation. The impact of SSBA implementation should be documented quantitatively in a setting where an enabling data quality project will not be required. In this case, removing the abnormalities in the data at Figure 3.16 would have required two RPA projects – one for automatically releasing orders, and another to account for shop floor improvisation. More features should be experimented in SSBA systems, for instance the use of neural networks to assist detection of upcoming sales and operations planning problems.

3.9.3 Managerial implications

Manufacturing companies are looking out for new and better ways to adapt to fluctuating demand in order to stay competitive. Investments in ERP systems are an important starting point, but the combination of those with manufacturing execution systems can have a fragmenting effect on the information required to support timely control decision. SSBA are often directly accessible to managers, entail low upfront cost, and can be leveraged through the fast-changing landscape in lean manufacturing projects.

The framework presented in this paper highlights best practices for managers to implement SSBA within a 3 to 6 months timeframe. The mind map representation provides insight on the interactions between the different steps of the implementation methodology. Holistic perspective is key, as efficiently piloting such implementations requires planning and iterating the project as it is carried out. The implementation case reveals a dynamic process, where the initial implementation workflow had been sequential.

Top recommendations to managers looking to implement SSBA would be to walk the process, and draw a clear map of information systems and their interactions. Meetings with key stakeholders to gather feedback and feature requests are helpful in securing the buy-in critical to implementation success.

CHAPTER 4

DISCUSSION AND CONCLUSIONS

4.1 Discussion

As mentioned in section 3.8, the DSR study results in an implementation framework for SSBA. This study has additionally provided empirical evidence towards the effectiveness of state-of-the-art techniques for continuous improvement, as well as the ToC with the DBR model, KPI-supported S&OP, and stakeholder-oriented change management.

The continuous improvement toolkit used for the case study was LSS. Gemba walks enabled capturing subtleties of the process, leading to more representative process mappings. Those process mappings have led to better visibility throughout the implementation; lessons learned were delineated regarding the IS and communication dimensions in section 3.7. Enabling data quality projects would improve the ability to quantitatively assess the impact of the SSBA tool on the manufacturing ecosystem as shown in Figure 3.16. Well suited for systemic thinking, mind mapping was used to represent the implementation framework at Figure 3.10.

ToC and S&OP were both integrated in the SSBA tool of the case company; the tool was designed to communicate the right information and metrics to enact a DBR pull dynamic. While capacity utilization was communicated to help leveling production, dynamic lead times were updated every 3 minutes to regulate the flow of orders – maximize cash flow whilst avoiding late deliveries.

Empirical evidence of the positive impact of the tool was gathered through observations which were documented in section 3.6, as well as the evaluation survey results at APPENDIX II. It was observed that the lead times dynamically updated by the SSBA tool have had the regulatory effect of the rope in the DBR model, as those have increased from the original values at the lead times whiteboard at Figure 3.2 during peak periods, and lowered as production was ramped up to meet the increased demand. It is also mentioned in an anonymous commentary collected via the survey that this tool helps to identify capacity utilization peaks early on and solve some production problems before they occur, improving the ability to react to demand and helping to deliver on time.

Stakeholder-oriented change management fostered buy-in throughout the project, which led the feature requests shown in Table 3.2. The tool has evolved in a direction which was adapted to the requirements of the stakeholders, as shown in the average survey results of 4.26 out of 5, which exceeds the threshold of 4 initially set. This points in the direction that the tool is generally considered by key stakeholders as expressive, effective, suitable, comprehensible, coherent, complete, and efficient – globally satisfactory.

4.2 Conclusions

Leveraging existing IS in support of lean manufacturing is essential, as we cannot improve what we cannot measure, and IS are the richest repositories of data in modern enterprises. Yet, there are several challenges associated with navigating the fragmented structure of many modern IS, particularly when time and resources are constrained. The software class of SSBA enables non-experts to tackle these challenges.

A framework has been designed to address the research gap as to managerial guidelines for SSBA implementation supporting lean manufacturing. Through the DSR methodology, this framework was then applied at a case company, evaluated, and improved incrementally. Empirical evidence for the impact of the developed SSBA tool on the manufacturing ecosystem was gathered in the process. This qualitative analysis shows added value in exploiting current IS for improvement projects with SSBA – improved operational decision-making within a short timeframe.

Key opportunities for future research are implementation case studies in other sectors such as service or healthcare. Those would not only increase generalizability of the framework, but also enable incremental improvements to the methodology itself. Another research gap would be guidelines to guide the decision to opt either for SSBA, embedded analytics, or data science platforms.

As shown in the industrial case study, democratizing IS is one way to improve communication and bring a company closer to its goal of profitability. Improved communication is – to a much greater sense – what can help us become more effective, and bring us closer to our goal living fulfilling lives. It is a choice we all get time and again to either manage communications, or let communications manage us.

APPENDIX I

EVALUATION SURVEY

Sondage sur l'écran des leadtimes

Le projet d'écran (dashboard) pour afficher les leadtimes ainsi que l'utilisation de la capacité machine a été en cours depuis environ un an. Une évaluation de cet outil est maintenant réalisée pour mesurer l'atteinte du projet de ses objectifs et de vos attentes. Veuillez répondre le plus honnêtement possible; vos réponses sont anonymes.

*Obligatoire

Le génie pour l'industrie

Quel est votre département *

Sélectionner

Évaluation de l'outil

Veuillez attribuer une note de 1 à 5 pour chaque critère. 1 étant que le critère n'est pas du tout rempli (désaccord), et 5 étant qu'il est parfaitement rempli (accord). Une brève description ainsi que le critère original en anglais sont fournis pour fins de désambiguïsation.

Expressivité (l'outil représente bien les situations réelles) - expressiveness *

1	2	3	4	5
○	○	○	○	○

Efficacité (l'outil remplis bien les fonctions qui y sont intégrées) - effectiveness *

1	2	3	4	5
○	○	○	○	○

Convenabilité (l'outil est bien adapté à son application) - suitability *

1	2	3	4	5
○	○	○	○	○

Compréhensibilité (l'information véhiculée par l'outil est simple à comprendre) - comprehensibility *

1	2	3	4	5
○	○	○	○	○

Cohérence (l'outil forme un tout harmonieux) - coherence *

1	2	3	4	5
○	○	○	○	○

Complétude (l'outil remplis toutes les fonctions nécéssaires) - completeness *

1	2	3	4	5
○	○	○	○	○

Efficience (l'outil a un impact positif sur votre gestion du temps et de la capacité de production) - efficiency *

1	2	3	4	5
○	○	○	○	○

Satisfaction globale *

1	2	3	4	5
○	○	○	○	○

Commentaire anonyme (facultatif)

Votre réponse

APPENDIX II

EVALUATION SURVEY RESULTS

Table-A II-1 Evaluation survey results

Department	Expressiveness	Effectiveness	Suitability	Comprehensibility	Coherence	Completeness	Efficiency	Global satisfaction
Production	4	4	4	5	5	4	4	4
Sales	4	4	4	5	4	4	5	5
Sales	3	4	3	4	4	3	3	3
Sales	4	5	5	5	5	5	4	4
Production	4	4	5	5	5	4	5	5

Average for Sales: 4.14

Average for Production: 4.43

Commentaire anonyme (facultatif)

Une réponse

Ce tableau de bord nous est très utile pour savoir comment changer et réagir à nos demandes de production. Nous avons également considérablement augmenté nos livraisons à temps grâce à cet outil. Nous l'utilisons également pour identifier les situations problématiques avant qu'elles ne surviennent et nous aider à être plus dynamiques et polyvalentes.

APPENDIX III

CODE EXCERPTS

VBA code excerpt to write history data from Excel sheet to the Access database:

```
Dim Conn As ADODB.Connection
Dim strConn As String
Dim ssql As String
Dim dbWb As String
Set Conn = New ADODB.Connection
strConn = "Provider=Microsoft.ACE.OLEDB.12.0;Data Source= \\Line Schedule\Scheduler 1.2 history.accdb"
dbWb = Application.ActiveWorkbook.FullName

ssql = "INSERT INTO [Scheduler db v1] ([Timestamp], [Modified due date], [WO number], [Machine], [Qty], [Cutting time], [Est Cutting Time]) "
ssql = ssql & "SELECT * FROM [Excel 12.0;HDR=YES;DATABASE=" & dbWb & "]." & "[ExportAccess$]"

Conn.Open strConn
Conn.Execute ssql
Conn.Close
```

Full VBA code to alternate between the slides of the dashboard and refresh periodically:

```
Option Explicit

Public Slideshow_Stop As Boolean
Public SlideshowPause As Double
```

```
Public m As Long
Public SheetsToLoop() As Integer, size As Integer, i As Integer, j As Integer
Public WasLocked As Boolean
Private Declare Sub Sleep Lib "kernel32" (ByVal lngMilliSeconds As Long)
Function FileExists(ByVal FileToTest As String) As Boolean
  FileExists = (Dir(FileToTest) <> "")
End Function
Public Sub CreateLock()
   Dim fs, a
   Set fs = CreateObject("Scripting.FileSystemObject")
   Set a = fs.CreateTextFile("\\Line Schedule\Scheduler.lck", True)
   a.WriteLine ("Scheduler is locked")
   a.Close
   Set fs = Nothing
End Sub
Public Sub DeleteLock()
  Dim FileToDelete As String
  FileToDelete = "\\Line Schedule\Scheduler.lck"
  If FileExists(FileToDelete) Then
    SetAttr FileToDelete, vbNormal
    Kill FileToDelete
  End If
End Sub
Public Sub CommandButtonStart_Click()
On Error Resume Next
size = WorksheetFunction.Count(Worksheets("Slideshow settings").Columns(1))
ReDim SheetsToLoop(size)
Slideshow_Stop = False
SlideshowPause = Worksheets("Slideshow settings").Cells(2, 2).Value
```

```
If size > 0 And SlideshowPause > 1 Then

For j = 1 To size
   SheetsToLoop(j) = Worksheets("Slideshow settings").Cells(j + 1, 1).Value
Next j

For i = 1 To size
  With Worksheets(SheetsToLoop(i))
  .EnableSelection = xlNoSelection
  .Protect
  End With
Next i

Call LoopSheets

Else
MsgBox "Missing or invalid input in the Slideshow settings tab", vbExclamation
End If

End Sub
Public Sub LoopSheets()

Dim Maintenant As Double

   For m = 0 To (size - 1)

         Worksheets(SheetsToLoop(m + 1)).Select
         WaitSeconds (SlideshowPause)
         If Slideshow_Stop Then Exit Sub
```

```
    Next m

    Call RefreshData

End Sub
Public Sub RefreshData()

If Slideshow_Stop Then Exit Sub

WasLocked = True

Application.ScreenUpdating = False
        For i = 1 To size
            With Worksheets(SheetsToLoop(i))
                .Unprotect
            End With
        Next i

            If FileExists("\\Line Schedule\Scheduler.lck") = 0 Then
                Call CreateLock
                WasLocked = False
                ActiveWorkbook.RefreshAll
            End If

            Application.OnTime DateAdd("s", SlideshowPause, Now), "ContinueLooping"

End Sub
Public Sub ContinueLooping()

        If Not WasLocked Then
```

```
            Call DeleteLock
        End If

        For i = 1 To size
            With Worksheets(SheetsToLoop(i))
                .Protect
            End With
        Next i
        Application.ScreenUpdating = True
            'Worksheets(SheetsToLoop(1)).Select

        If Slideshow_Stop Then Exit Sub

        Application.OnTime DateAdd("s", SlideshowPause, Now), "LoopSheets"

End Sub
Public Sub CommandButtonStop_Click()
Slideshow_Stop = True
        For i = 1 To size
            With Worksheets(SheetsToLoop(i))
                .Unprotect
            End With
        Next i
End Sub
Public Sub WaitSeconds(intSeconds As Integer)
  ' Comments: Waits for a specified number of seconds
  ' Params  : intSeconds      Number of seconds to wait
  ' Source  : Total Visual SourceBook

  On Error GoTo PROC_ERR
```

```
  Dim datTime As Date

  datTime = DateAdd("s", intSeconds, Now)

  Do
   ' Yield to other programs (better than using DoEvents which eats up all the CPU cycles)
    Sleep 100
    DoEvents
  Loop Until Now >= datTime

PROC_EXIT:
  Exit Sub

PROC_ERR:
  MsgBox "Error: " & Err.Number & ". " & Err.Description, , "modDateTime.WaitSeconds"
  Resume PROC_EXIT
End Sub
```

APPENDIX IV

CONFERENCE PAPER PRESENTED AT INCOM 2018

Lizotte-Latendresse, S., & Beauregard, Y. (2018). *Implementing self-service business analytics supporting lean manufacturing: A state-of-the-art review* presented at 2018 IFAC Symposium on Information Control Problems in Manufacturing (INCOM 2018), Bergamo, Italy. doi: https://doi.org/10.1016/j.ifacol.2018.08.436. Retrieved at http://www.sciencedirect.com/science/article/pii/S2405896318315635

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Implementing self-service business analytics supporting lean manufacturing: A state-of-the-art review

Simon Lizotte-Latendresse * Yvan Beauregard *

* *École de technologie supérieure, Montréal, Canada, (e-mail: Simon.Lizotte-Latendresse.1@ens.etsmtl.ca), (e-mail: Yvan.Beauregard@etsmtl.ca).*

Abstract: Piloting lean manufacturing projects requires dynamically tailoring suitable sets of metrics. Quick turnaround in implementing such metrics is critical, as the typical duration of a Lean Six Sigma project is 3 to 6 months. Self-service Business Analytics (SSBA) can provide managers with the much-needed flexibility to efficiently design and redesign comprehensive metrics in fragmented information system contexts. A review of state-of-the-art practices for SSBA implementation is performed, which lays down the foundations for an upcoming framework geared towards lean manufacturing. Key SSBA planning and architecture findings are summarized. Practical evaluation of the framework in a complex information system landscape through Design Science Research (DSR) is projected with the Canadian division of an international steel parts manufacturing company

Keywords: Self-service analytics; Implementation; Lean manufacturing; BPMN; Constructive Research;

1. INTRODUCTION

In order to stay competitive, manufacturing companies need to improve their ability to quickly react to fluctuating demand. Execution of production routings through an increasingly global supply chain requires keen awareness of manufacturing capacity, as well as solid inter-departmental communication. Numerous information systems (IS) are available to assist production planners with these challenges. However, investing in powerful off-the-shelf software does not guarantee process improvement. While flagship ERP systems and modules are widely marketed as polyvalent, implementation in specialized manufacturing environments will often require compromise, even with subsequent investments. Managers navigating such environments to drive positive change – Lean initiatives – must adapt to the IS landscape with limited time and resources.

If effectively deployed, ERP neutral self-service tools can help managers bridge the gap between IS-native features and their lean manufacturing requirements. A literature review is conducted, which supports the outline of an upcoming implementation framework. Albeit broad-scoped, this study is geared towards application at a partner company in the steel parts manufacturing industry.

For our partner company, the core business is thermal cutting of parts out of sheet metal. SAP Business One (B1) enhanced by the BX Manufacturing module is adopted as corporate ERP, while the SigmaNEST software package enables programming CNC plate processing machines. From a supply chain perspective, it should be noted that this company also manufactures welded assemblies, and that a portion of orders require outside processing for operations such as bending or machining. Lean manufacturing projects impacted by the upcoming SSBA information system include improving lead time estimation with live update, increasing plasma/oxyfuel cutting torch time percentages by showing sales under-utilized machine capacity, and maximizing on-time delivery by detecting at risk orders.

Fig. 1 below shows current order management processes with the help of Business Process Model and Notation (BPMN) by the Object Management Group (2013). Lead times whiteboard & ad-hoc production impact assessments are central in the pre-SSBA workflow.

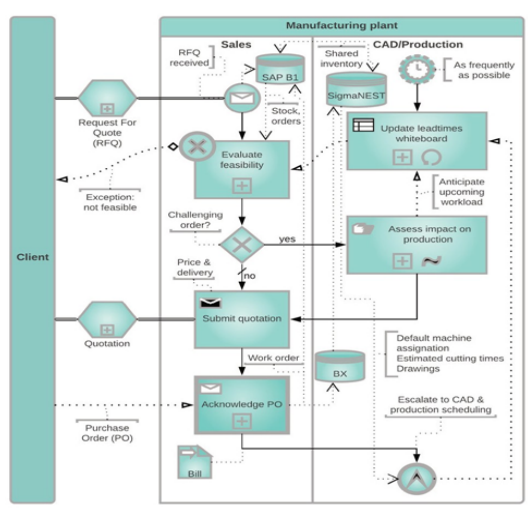

Fig. 1. Partner company current order management BPMN

Fig. 2 represents the projected SSBA integration with the whiteboard superseded. This paper begins with a presentation

Peer review under responsibility of International Federation of Automatic Control.
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of the background in related fields. Then, selected state-of-the-art literature is further detailed; findings are synthetized in a mental model, and we conclude on a validation roadmap for this projected integrative framework.

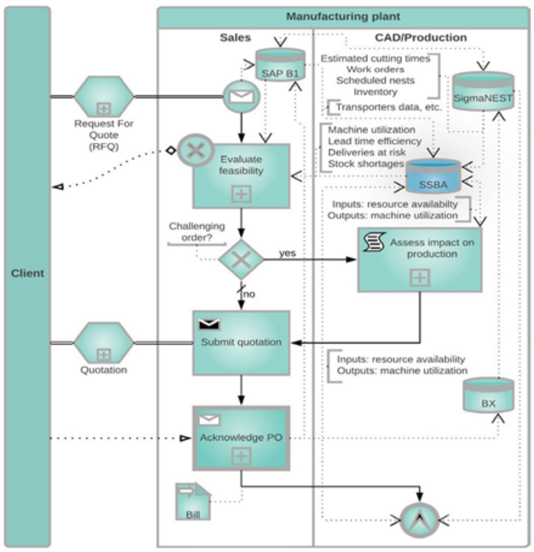

Fig. 2. Partner company projected order management BPMN

2. LITERATURE REVIEW

2.1 Background

A fundamental principle in Lean is that we need to measure if we are to improve. The more mature the lean organization, the harder the bottlenecks are to find and improve (Sims and Wan, 2017), and doing so will more often than not require gathering data. As in any science, data quality must be considered – cleansing big data is a major challenge today's organizations face (Sadiq, 2013). Still, data by itself is not enough to drive improvement, as it needs significance. Business Analytics (BA) address turning valid data into valuable insight for managers (Unver, 2012); this discipline adds the past and future dimensions (Calfa et al., 2015) to Business Intelligence (BI), which tracks real-time status (Unver, 2012).

The impact of Lean management initiatives (e.g. standard work) on key performance indicators (KPI) such as Overall Equipment Effectiveness (OEE) can then be tracked (Unver, 2012). With recent advances in the internet of things (IoT) yielding tools such as Worximity (2017), data acquisition (DAQ) can be performed from virtually any industrial equipment. Still, care must be taken to avoid pitfalls in defining KPIs, for instance setting the bar too low to make ourselves look good (Hammer et al., 2007).

On the other hand, analytic tools such as Bayesian networks can assist decision makers by effectively processing highly complex datasets to forecast Engineer-to-Order (ETO) project workloads (Eickemeyer et al., 2014), helping reduce bottom-line uncertainty (Kogan and Tell, 2009). Analytics can also interface with Enterprise Resources Planning (ERP) systems, modulating sales-production interactions, which in turn correlate with higher customer satisfaction (Parente et al., 2002, de Vries and Boonstra, 2012), all the while enabling dynamic pricing strategies (Özer and Uncu, 2015).

A new, disruptive trend in Business Analytics is self-service. Over the last decade, an increasing number of companies have opted for software such as Tableau, Microsoft Power BI, and IBM Watson Analytics (Dinsmore, 2016, Alpar and Schulz, 2016). Microsoft is positioned as the leader in this field for "ability to execute" and "completeness of vision" according to the Gartner (2018a) Magic Quadrant. Although less powerful than leading data science solutions like RapidMiner (Gartner, 2018b), these tools target end users instead of experts (Dinsmore, 2016).

As a result of the shorter design cycles these decision support tools facilitate, time-sensitive decision making can be improved (Mayer et al., 2015). Managers quickly get actionable intel – the edge to effectively adapt in fast-changing environments (Monostori et al., 2015, Balogun and Tetteh, 2014). Visual analytics can now be updated real-time (Selvaraju and Peterson, 2017), and multi-database query mashups modified in a few clicks – minimal "data-wrangling" (Lohr, 2014) is required. Another benefit of self-service BA is it requires managers to frame their requirements. Traditionally, resorting to Business Intelligence specialists without sufficient attention to requirements engineering (RE) could induce delays of weeks (Dinsmore, 2016), impacting long-term usability in notorious cases (Schlesinger and Rahman, 2016). Self-service attempts – even failed – can help mitigate such risks, as requirements are better framed should there be need for experts.

TABLE 1. Systematic literature review summary [b]

			OR			
AND			Framework	Model	Procedure	Process
			Implement*	Implant*	Deploy*	Operationaliz*
	OR	**AND**	Self-serv*	End-user		
			Business Intel* **OR** *BI*	Business Anal* **OR** *BA*	Manufact* Intel* **OR** *MI*	Decision Support **OR** *DS*
			SSBI	*SSBA*	*MIS*	*DSIS*
			Support*	For	Sustain*	Enabl*
			~~Lean~~ [c]			

[b] Strategy executed 31/07/17 in Scopus, Engineering Village, and Web of Science
[c] No hits if the "Lean" keyword is included

There is limited research on the relatively new topic of self-service analytics, particularly regarding the implementation dimension. In fact, the only two relevant hits in our systematic literature review at TABLE 1 (Olavson and Fry, 2008, Schuff et al., 2016) are not directly related to manufacturing. Since end-user software is involved, some improvisation is expected, which may explain in part why such implementations have been scarcely documented. This seems particularly true for the case of make-to-order (MTO) dominant manufacturing sites, where weak matrix project management support structures are frequent (Project Management Institute Inc, 2013). Nevertheless, a need is to be addressed for implementation guidelines to maximize results and minimize delays with respect to the project manager's triple constraint (see Fig. 3).

Fig. 3. Project management triangle (Project Management Institute Inc, 2013)

While project management best practices drive project team overall effectiveness to implement traditional ERP systems in manufacturing environments (Boykin, 2014), overemphasis on traditional project planning techniques may actually burden self-service BA implementations. This is analogous to the plan-centric and agile approach dichotomy in software development (van Waardenburg and van Vliet, 2013). Some implementations of self-service business analytics can also be seen as form of corporate entrepreneurship (intrapreneurship) initiative, for which autonomy and organizational ambiguity tolerance are key enablers – maturity factors (Elia et al., 2016). Furthermore, corporate culture factors such as workplace attitude and commitment should be taken into account in the implementation strategy, as they bear strong influence on long-term sustainability (Glover et al., 2011). Guidelines such as the MIT Lean Enterprise Self-Assessment Tool (LESAT) enable characterization of current versus desired states, as well as a Lean transformation roadmap (Lean Advancement Initiative, 2012).

Our aimed contribution to the body of knowledge (BOK) is through development of a structured methodology to implement SSBA in lean manufacturing environments with regard to current IS, sales and operations planning (SOP), and workplace culture. This state-of-the-art review constitutes the foundations for this upcoming framework, for which a first draft is discussed in form of a mental model in Fig. 6. This framework will be backed by lessons learned throughout SSBA implementation in the steel industry.

Related state-of-the-art literature addresses several problems associated with design and implementation of intelligent systems supporting lean improvement programs in multiple industries. Selvaraju and Peterson (2017) present critical socio-technical factors of success for analytics in a lean context. Unver (2012) introduces a manufacturing intelligence (MI) system assisting lean continuous improvement by contextualizing shop floor data. Saha et al. (2016) develop an expert system to help prioritize customer orders. Urabe et al. (2016) attempt to solve KPI conflicts between sales and production by means of better communication with the help of an inter-departmental cockpit – improved SOP. Dresch et al. (2015) produce a comprehensive guide to Design Science Research (DSR) in management and engineering, effectively synthetizing key advances such as those from Peffers et al. (2006) in information systems (IS) research.

2.2 Critical factors of success for analytics in a lean context

The first step in Selvaraju and Perterson's research is developing a framework to assess the organization's maturity for technology-supported Lean (Selvaraju and Peterson, 2017). A second goal of the authors is defining technology-supported business problem solving best practices. Thirdly, the authors wish to use analytics to monitor the lean transformation, as well as technology adoption rates. The framework aligns with Balanced Scorecard metrics: "Customer value, Financial excellence, Culture growth, and process excellence" (Selvaraju and Peterson, 2017).

The developed methodological artefact is based on existing state of the art models. First of all, an Organizational Culture Inventory (Human Synergistics International) is employed to characterize the organization's culture for key behavioral styles such as Constructive or Passive/Defensive. Secondly, this analysis is combined with a lean technology and process maturity assessment. The technology and process assessments are out of the article's scope. Then, BA are integrated in a decision-making methodology throughout the lean transformation. Here, BA enable managers to quickly identify improvement opportunities from dynamic performance measurements. The visual analytics process feedback loop enables continuous improvement of problem solving and decision-making processes.

Application of this methodology yields an "Information Delivery Management Tool". The resulting dashboard-based application is designed to gauge the effectiveness of organizational lean measures. The dashboard is deployed online with the help of IBM supply chain manufacturing. Selvaraju and Peterson (2017) conclude that the framework has been successfully validated for implementation in a complex manufacturing environment. Authors foresee application of the framework to other fields.

2.3 Contextualization of shop floor data with ERP systems

Unver (2012) aims to develop a framework for business analytics in the form of a manufacturing operations center (MOC) following guidelines of the International Society of Automation's ISA-95 standard. Another requirement for the framework is to support implementation of the Lean philosophy, namely measures such as total productive maintenance (TPM) (Unver, 2012). As a major improvement over current tools and techniques, the author wishes to address the disconnection problem between shop floor systems and corporate-level ERP.

The author's methodological approach is mainly one of software architecture. He is part of a team of developers at Oracle. The software architecture team starts by assessing the shortcomings of current ERP-integrated production support systems. Design requirements are outlined; for instance, the possibility for the system to bring relevant KPIs to both plant managers and cross-plant vice-presidents. An ERP-agnostic concept is then developed with numerous industry partners to support shop floor integration. The neutral design, bound by the ISA-95 standard, is meant to be sufficiently generic to harness components from various industries. Two use cases are presented, which are examples of lean transformations where the software helps.

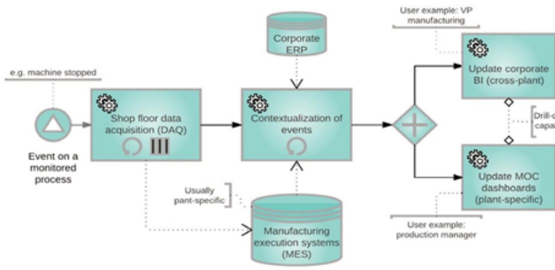

Fig. 4. BPMN for the MOC from Unver (2012)

Unver's research yields a MOC (see Fig. 4) which works by converting real-time data from shop floor equipment into business events, aggregating these events with context data acquired from ERP systems, and then generating relevant KPIs. A cornerstone of the system is hierarchical drill-down capability, which enables corporate-level managers to investigate otherwise superficial plant KPI components – disaggregate performance metrics down to problematic machine shifts to outline possible root causes. Use cases include TPM (i.e. OEE), as well as live production line status dashboards to improve incident response delays. The Oracle MOC offering is Oracle BI Enterprise Edition (OBIEE). Future work includes adding other important metrics such as work in progress (WIP) and manufacturing lead times.

2.4 An expert system to help prioritize work orders

Saha et al. (2016) endeavor developing an End-to-End (E2E) Customer Order Management System (COMS) constituted of three integrated tools and a real-time dashboard. The problem researchers mean to tackle is quantification of strategic and operational impacts of expert system assisted order prioritization decisions. Authors wish to assist the prioritization decisions, but also track order progression and late delivery risk.

The methodological approach employed by Saha et al. starts by a characterization of the system for which a COMS will be developed, and performing a diagnosis of areas where decision support is most needed. A set of assumptions is derived from the supply chain assessment, and the three-module decision support system is designed. The order prioritization tool relies on the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) as a multi-criteria decision-making model. Then, an order fulfillment progress projection tool (OFPPT) is developed. It utilizes a Mamdani Style Fuzzy Inference System (MSFIS) to simulate subject matter expert (SME) judgement. Finally, a risk mitigation tool (RMT) is developed to draw a risk criticality matrix by aggregation of order parameters and context into the Integrated Risk Likelihood (IRL) and Total Impact (TI) variables. Interactions between these systems and work in progress (WIP) are represented in Fig. 5.

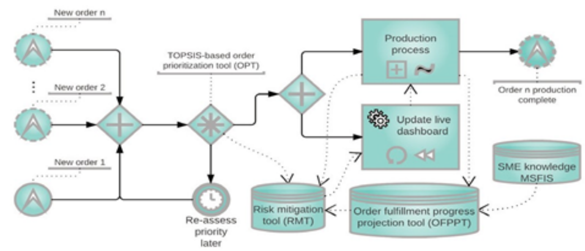

Fig. 5. BPMN for the expert system from Saha et al. (2016)

Evaluation of the system is possible with an application at a server manufacturer. An order management dashboard is implemented. The result is expressive, effective, suitable, comprehensible, coherent, complete, and efficient (Saha et al., 2016). The RMT could be improved by incorporating very low likelihood yet massive impact risks like terrorism.

2.5 Dashboards to help solving departmental KPI conflicts

Urabe et al. (2016) wish to address the problem where some departments will jeopardize other departments KPI to maximize their own. Low synergy and chronic finger-pointing are ultimately detrimental to the company's bottom line. The authors wish to develop a strategy to better manage this issue, and then implement it through an automated tool.

From a methodological standpoint, authors start by highlighting the issues with traditional methods for supply-demand planning. KPI conflict patterns are outlined. Then, a visualization system is developed in order to provide a communication-based solution.

In their diagnostic, authors emphasize a recurring KPI conflict pattern: if sales focus on fast-selling products to catch up on their KPI goals rather than to try selling overstocked items, not only will the overstock be detrimental to supply chain management (SCM), which is penalized by excess inventory, but the sales surge will also force the production department to utilize more resources than initially allocated to maintain on-time delivery rates. This is the production sales and inventory (PSI) problem. A communication-based strategy is then prescribed to help overcome the issue. It integrates the three departments affected by the diagnosed pattern: production, sales, and SCM. Where PSI problem-solving used to be done by individual departments – often neglecting the systemic perspective –, it should now be accomplished through inter-departmental cooperation. To implement a PSI-Cockpit supporting this strategy, two main features are selected: drill-down and alert. Drill-down enables involved departments to quickly identify item-level parameters which cause KPI conflicts, modify these in a tabular interface, all the while simulating the impact on KPIs real-time. The alert feature displays a notification when a departmental KPI reaches a critical threshold. Problem solving following an alert is performed through what-if analysis with the simulation feature. Future research will evaluate the impact of this tool on the manufacturing ecosystem.

2.6 Producing and presenting information systems research

Dresch et al. (2015) perceive a lack of systematization and consolidation of the concepts of DSR in current literature, particularly for application in management and engineering. To address this, authors wish to contextualize the foundations of Design Science, DSR, and synthetize a method for DSR.

The authors build upon pioneering work from Peffers et al. (2006) for DSR adapted to IS. Peffers et al. addressed a shortcoming in DSR (Dresch et al., 2015) methodological guidelines as to application to information systems research. Although DSR had existed for over a decade, very little research had been published following this method which effectively bridges the gap between rigorous research and prescriptive applications. Indeed, action research and case studies seldom focus on rigorous science fundamentals such as experimental repeatability and hypothesis falsifiability. Emphasis is put on designing artifacts which are consistent with current literature, and building upon those to expand the body of knowledge.

Design Science research in IS involves (Peffers et al., 2006):

- Identifying the problem and the research motivation, and defining objectives for a solution;
- Designing and developing an artefact;
- Demonstrating effectiveness of the artefact in problem-solving along with thorough evaluation, documenting lessons learned from the demonstration, and
- Communicating results.

As the development of DSR guidelines was done following the DSR methodology, the author's recommendations will be validated by upcoming Design Science Research papers which are successful with application of the methodology.

3. DISCUSSION

Key SSBA architecture findings can be summarized:

- Hierarchical drill-down capability can facilitate PSI problem investigations, SOP, and helps scalability;
- An alert feature can be integrated in order to notify stakeholders that a problem is to be addressed, especially in cases where timely action is needed;
- Simulation can improve the decision-making process. Predictive analytics leveraging statistics or machine learning can ultimately help modulate KPI outcomes;
- Tracked KPIs must be chosen carefully, as people will attempt to improve those if they are compensated to do so, even if the outcome is unproductive.

Implementation methodology has additionally been reviewed. Assuming sufficient stakeholder strategic involvement, best practices are split between the phases of planning and execution in the MIT LESAT. Best practice highlights as to planning are the following:

- Assess available information systems, data accessibility;
- Determine areas of possible improvement in current processes, preferably with a structured approach such as process mapping. Establish current versus desired;
- Evaluate data quality, for instance the standard times used to estimate production throughput;
- Adapt to corporate culture factors such as openness to change and inter-departmental power dynamics;

The mental model presented in Fig. 6 integrates these literature review findings into a high-level implementation workflow. A framework will be derived from the added lessons learned through application of the DSR methodology throughout SSBA implementation with our industrial partner. This resulting artefact will aim to fill the gap as to comprehensive SSBA implementation guidelines adapted to lean manufacturing. While current literature can most certainly provide guidance for each of the steps shown in Fig. 6, we wish to tackle the challenge of lean manufacturing SSBA deployment with a holistic perspective.

4. CONCLUSION AND FUTURE WORK

State of the art self-service business analytics architecture & implementation practices have been reviewed. A mental model was derived to define an implementation workflow adapted to lean manufacturing. This model is set to evolve into an integrative framework through application of the DSR methodology to the implementation case of our industrial partner scheduled 2017-2018.

Current and desired states were documented for this industrial partner. The initial SSBA software selected is the Microsoft Power Query Excel add-in, as it has a minimal learning curve for experienced Excel users, can scale into Power BI, and is already packaged by the company's IT department. A link with MES (SigmaNEST) and ERP (SAP B1) was successfully established, and a first draft of visual analytics have been deployed to stimulate interactions at the sales-production interface. Preliminary observations include faster identification of upcoming bottlenecks, enabling timely use of contingencies such as subcontracting.

ACKNOWLEDGMENTS

Many thanks go out to Christian Leblanc, Sylvain Thibault and Yanic Berube. Their leadership and commitment to process excellence was of great help to this research.

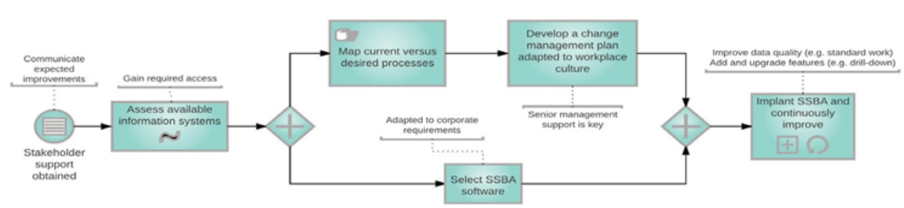

Fig. 6. Lean manufacturing SSBA implementation workflow

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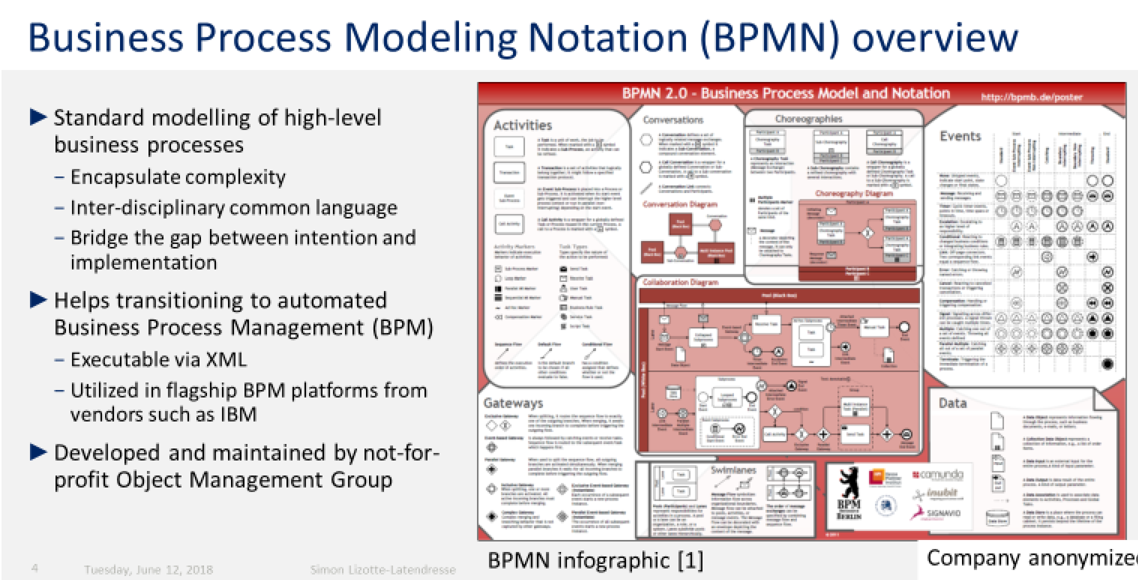
APPENDIX V

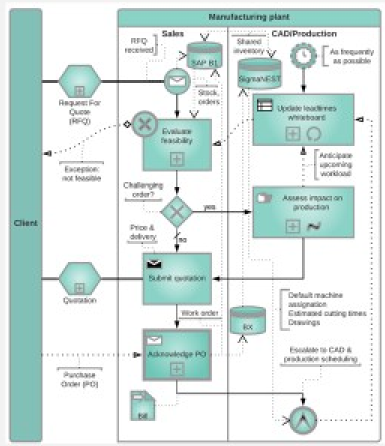
INCOM 2018 POWERPOINT PRESENTATION WITH COMPANY ANONYMIZED

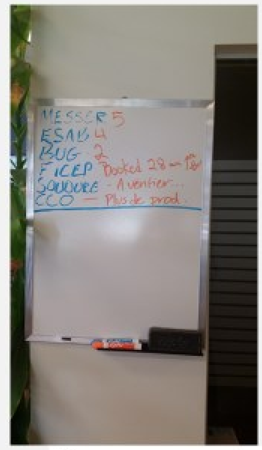

Current process mapping
Anonymized company order management
Company anonymized


Business Process Modeling Notation (BPMN) overview
▶ Standard modelling of high-level business processes
– Encapsulate complexity
– Inter-disciplinary common language
– Bridge the gap between intention and implementation
▶ Helps transitioning to automated Business Process Management (BPM)
– Executable via XML
– Utilized in flagship BPM platforms from vendors such as IBM
▶ Developed and maintained by not-for-profit Object Management Group
BPMN 2.0 - Business Process Model and Notation
http://bpmb.de/poster
Activities
Conversations
Choreographies
Events
Gateways
Collaboration Diagram
Swimlanes
Data
4
Tuesday, June 12, 2018
Simon Lizotte-Latendresse
BPMN infographic [1]
Company anonymized

Anonymized company order management process

- ▶ Two information systems
  - ERP: SAP Business One (B1) upgraded with the BX manufacturing module
  - MES: SigmaNEST nesting software package
- ▶ Heavy reliance on manual tools and techniques
  - Lead times whiteboard
  - Ad-hoc production impact assessments
- ▶ Both ERP and MES data is under-utilized
  - No context and aggregation
  - No dashboard





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Company anonymized

Self-service business analytics (SSBA)

Disruptive insights made accessible

Company anonymized

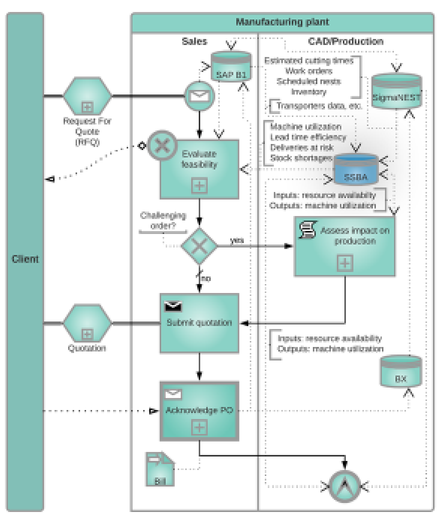
Business Case

- You can't change what you can't measure
  - Need to go above & beyond embedded corporate ERP metrics
- Quick turnaround in implementing metrics is critical
  - Lean Six Sigma project timeframe
  - Freedom to improve with iterative redesigns
- Need to adapt to fragmented information systems contexts
  - Corporate ERP
  - Manufacturing execution systems (MES)
  - Shop floor systems
  - Subject matter expert (SME) input
- Self-service Business Analytics provide the required flexibility

Company anonymized

Desired state

- Improve lead times management with live update
- Increase plasma/oxyfuel cutting torch time percentages by showing sales under-utilized machine capacity
- Maximize on-time delivery & minimize derogations by detecting at risk deliveries
- Remove need for a whiteboard



Company anonymized

Literature review

Leveraging precedents to guide current state improvements

Company anonymized

Background overview

- Business Analytics (BA) goes one step further than Business Intelligence (BI) by studying past and future dimensions
- Track impact of Lean management initiatives with metrics such as Overal Equipement Effectiveness (OEE)
- Harness recent advances in the internet of things (IoT) (i.e. industry 4.0)
- Self-service levels the playground for managers and analysts
  - Shorter design cycles
  - Minimal "data-wrangling"
  - Better requirements framing

Company anonymized

Systematic literature review

- Keyword search in specialized databases
- Related literature does not focus on SSBA implementation in a lean manufacturing context
- No guidelines to maximize results and minimize delays
  - Structured vs agile project management
  - Opportunity for constructive research

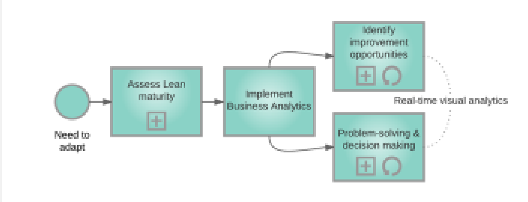
			OR			
AND			Framework	Model	Procedure	Process
			Implement*	Implant*	Deploy*	Operationaliz*
	OR	AND	Self-serv*	End-user		
			Business Intel* **OR** *BI*	Business Anal* **OR** *BA*	Manufact* Intel* **OR** *MI*	Decision Support **OR** *DS*
			SSBI	*SSBA*	*MIS*	*DSIS*
			Support*	For	Sustain*	Enabl*
			~~Lean~~ [c]			

[b] Strategy executed 31/07/17 in Scopus, Engineering Village, and Web of Science
[c] No hits if the "Lean" keyword is included

Company anonymized

Critical factors of success for analytics in a lean context

- Organizational maturity for technology-supported Lean
- Problem-solving best practices
- Analytics to monitor the transformation as per the Balanced Scorecard
  - Customer value
  - Financial excellence
  - Culture growth
  - Process excellence
- A dashboard-based application can help gauging the effectiveness of Lean measures

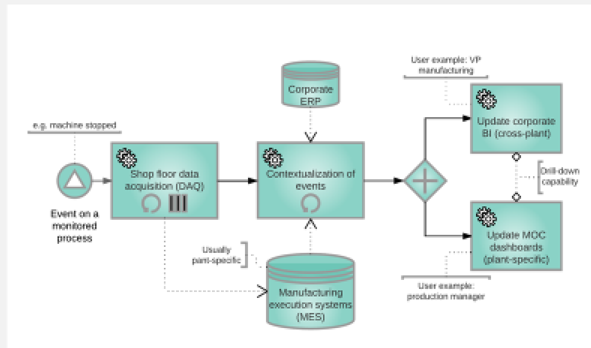


BPMN for the Selvaraju and Peterson [2] framework

Company anonymized

Continuous improvement by contextualization and analysis of shop floor data with respect to corporate-level ERP

- ▶ Address the disconnection in current information systems with a standardized approach (ISA-95 standard)
  - Shop floor
  - Manufacturing execution systems
  - Corporate ERP
- ▶ Cross-plan functionality
  - Production manager
  - VP of manufacturing
- ▶ Drill-down capability
- ▶ ERP agnostic solution Oracle BI Enterprise Edition (OBIEE)

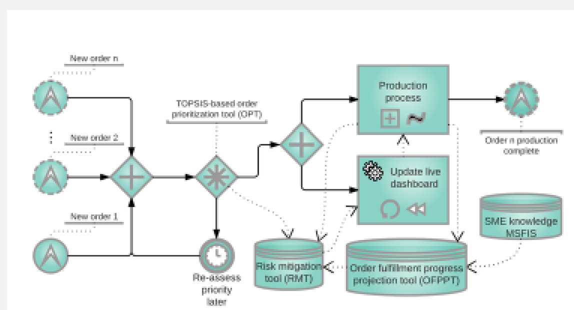


BPMN for the MOC from Unver [3]

Company anonymized

An expert system to help prioritize work orders

- ▶ End-to-End Customer Order Management System (E2E COMS)
- ▶ Three-module decision support system
  - Order prioritization tool (OPT)
  - Order fulfilment progress projection tool (OFPPT)
  - Risk mitigation tool (RMT)
    - Integrated Risk Likelihood (IRL)
    - Total Impact (TI)
- ▶ Expressive, effective, suitable, comprehensible, coherent, complete, and efficient

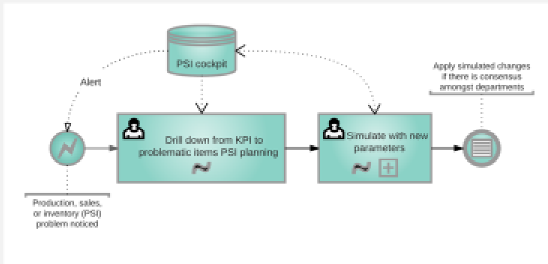


BPMN for the expert system from Saha, et al. [4]

Company anonymized

Dashboards to help solve departmental KPI conflicts

- In a silo environment, departments tend to jeopardize other departments KPIs if it maximizes their own
  - Low synergy
  - Production Sales and Inventory (PSI) problems
  - Negatively impacts the bottom line
- A dashboard-based system is developed to better manage the issue
  - Alert
  - Drill-down
  - Simulation of impact of changes on KPIs



BPMN for Urabe, et al. [5] PSI problem solving

Company anonymized

Design Science Research (DSR)

- Structured constructive research approach for Information Systems (IS) research [6]
  - Identifying the problem and the research motivation
  - Defining objectives for a solution
  - Designing and developing an artefact
  - Demonstrating effectiveness of the artefact in problem-solving
  - Rigorously evaluating artefact efficacy, documenting lessons learned from the demonstration
  - Communicating results
- Well suited for the current research project
  - A framework is synthetized
  - It will be validated through an application at the anonymized company

Company anonymized

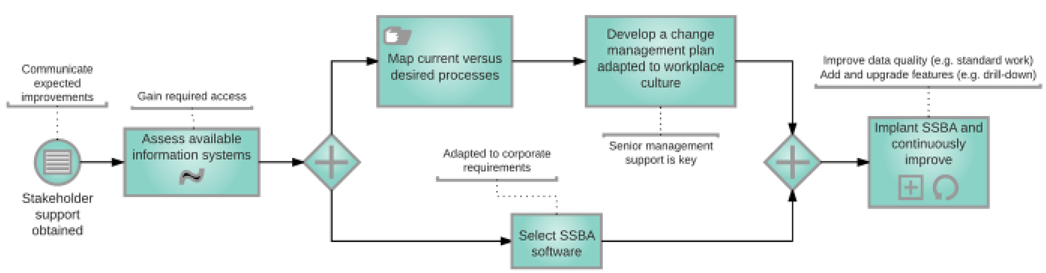
Implementation strategy

Research findings

Company anonymized

Lean manufacturing SSBA mental model

▶ Practical validation scheduled with industrial partner



Company anonymized

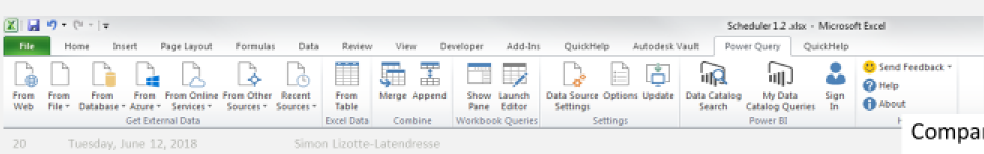
Implementation at the anonymized company

Microsoft Power Query

Company anonymized

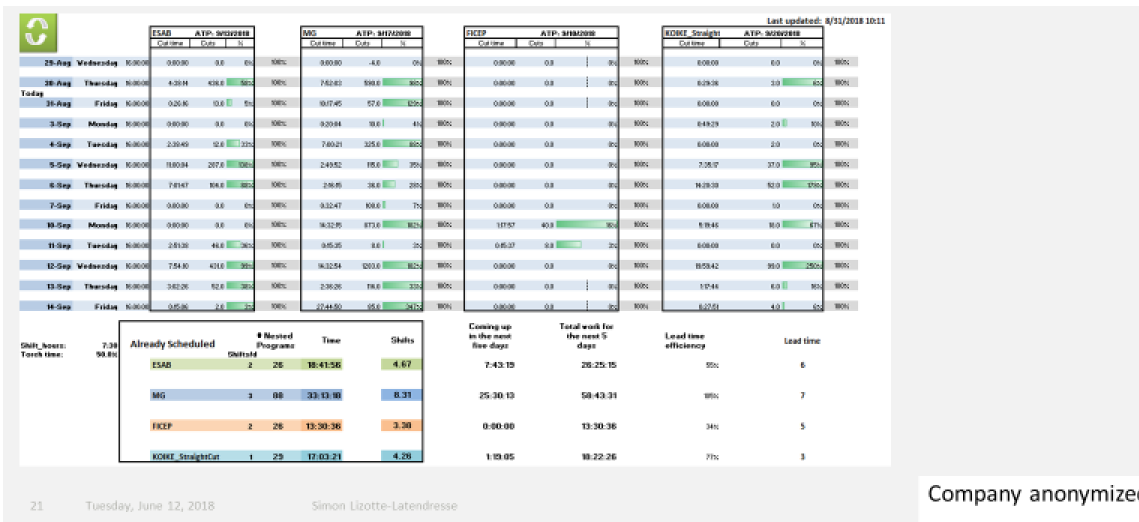
Why Power Query?

- ▶ Oriented towards managers and analysts rather than data scientists
- ▶ Performs well with fragmented data sets (Microsoft Mashup Evaluation Container)
- ▶ Minimal learning curve for experienced Excel users
- ▶ Can scale into the more advanced Power BI for cloud accessibility and drill-down functionality
- ▶ Readily available from IT



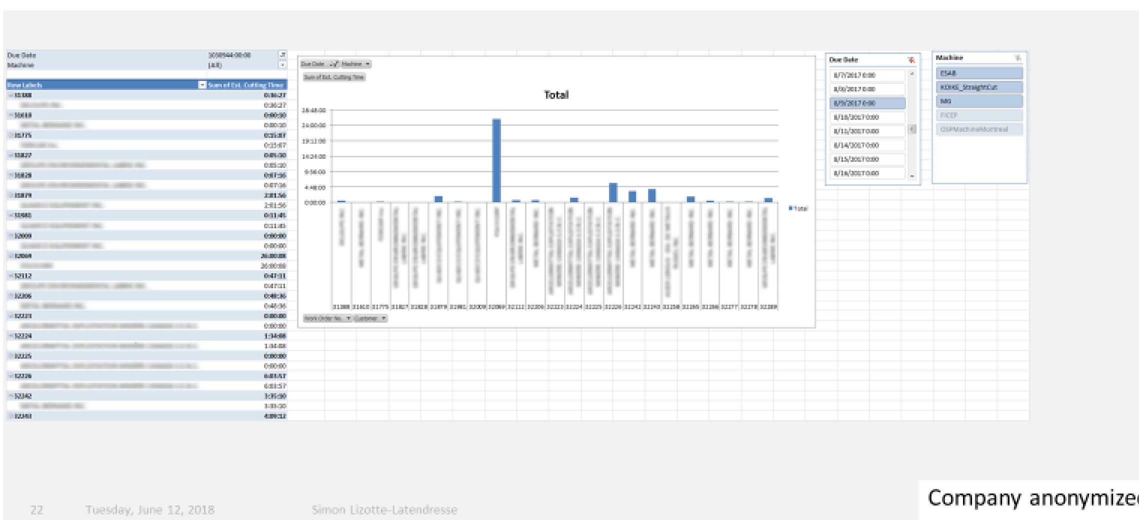
Company anonymized

Main capacity management dashboard



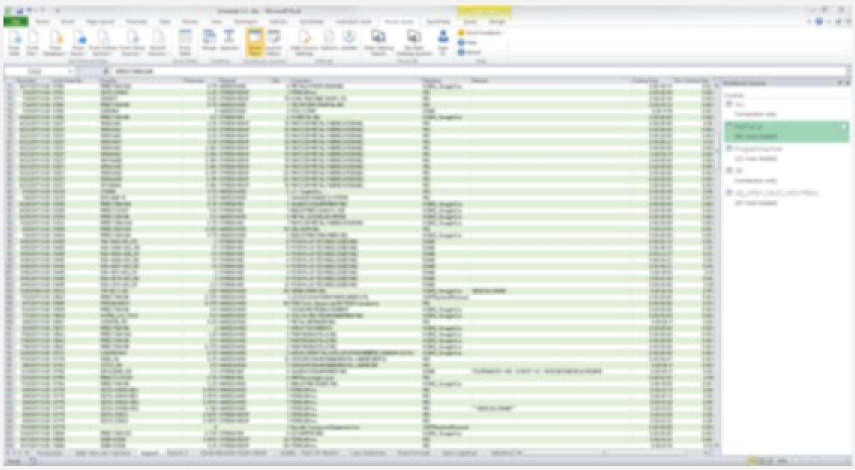
Company anonymized

Required production dates Pivot Table



Company anonymized

Data loading



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maintain
anonymity

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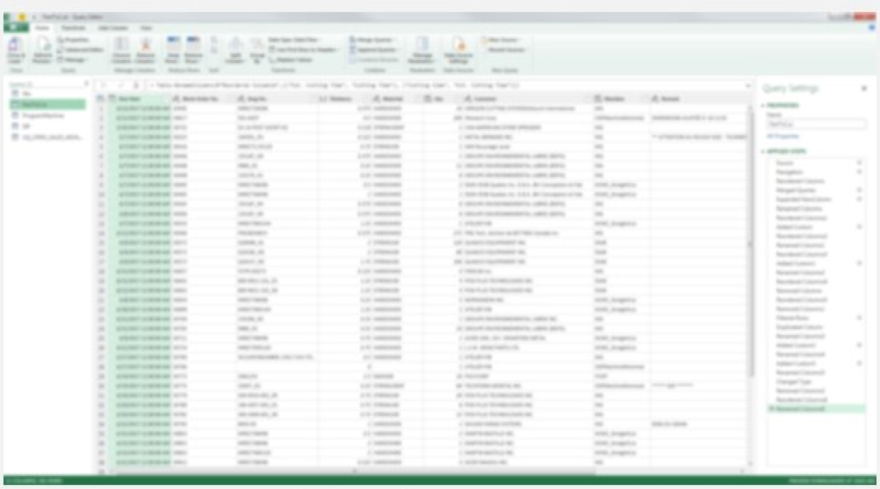
Query design



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Sales view part 1 – utilization by machine

Last updated: 6/7/2018 9:25

		ESAB ATP: 6/25/2018			MG ATP: 7/3/2018			FICEP ATP: 7/4/2018			OMAX		
		Cut time	Cuts	%	Cut time	Cuts	%	Cut time	Cuts	%	Cut time	Cuts	%
18-Jun	Monday	20:05:46	949	628% ✗	7:02:50	230	220% ✗	0:00:00	0	0% ✓			
19-Jun	Tuesday	9:40:54	140	134% ✗	2:22:40	37	33% ✓	0:00:00	0	0% ✓			
20-Jun	Wednesday	4:09:32	142	58% ✓	13:37:21	406	189% ✗	19:24:35	79	270% ✗			
21-Jun	Thursday	0:00:00	0	0% ✓	0:06:39	10	2% ✓	0:00:00	0	0% ✓			
22-Jun	Friday	5:02:20	73	79% !	0:00:00	0	0% ✓	0:00:00	0	0% ✓			
25-Jun	Monday	0:34:24	3	18% ✓	7:57:47	156	249% ✗	0:00:00	0	0% ✓			
26-Jun	Tuesday	0:11:53	1	3% ✓	0:46:10	31	11% ✓	0:32:34	10	8% ✓			
27-Jun	Wednesday	6:53:44	217	96% ✗	14:55:44	519	207% ✗	0:00:00	0	0% ✓			
28-Jun	Thursday	1:50:36	14	26% ✓	0:18:55	24	4% ✓	0:04:50	2	1% ✓			
29-Jun	Friday	1:43:54	25	27% ✓	0:00:00	0	0% ✓	21:30:52	56	336% ✗			

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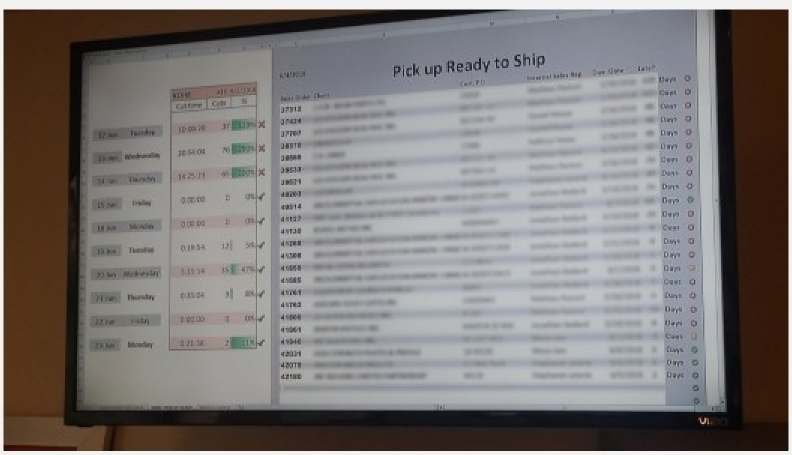
Sales view part 2 – utilization (continued), ready to ship



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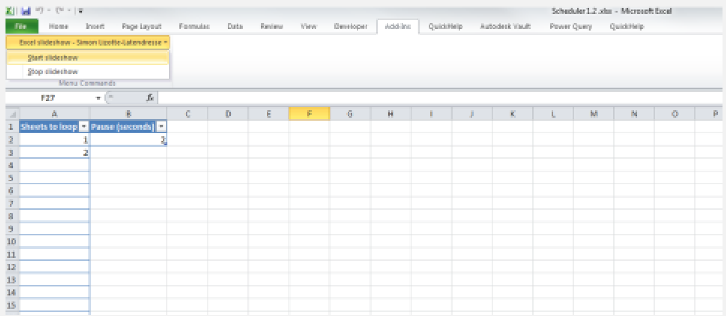
Company anonymized

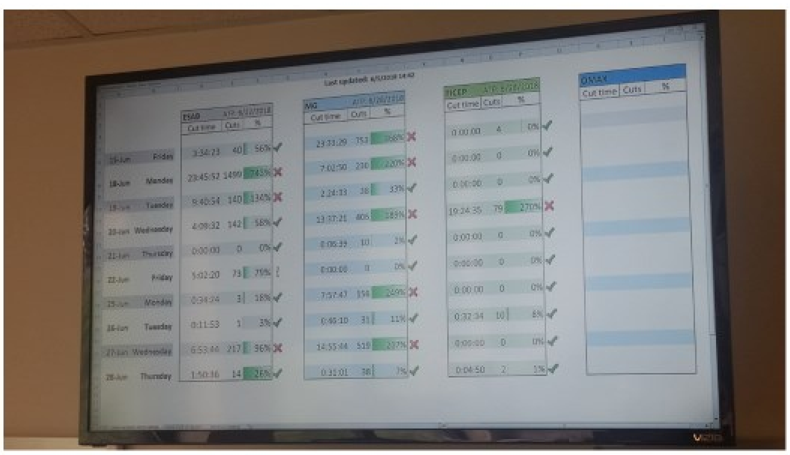
SSBA delivery

- Self-designed Excel add-in to loop through designated worksheets
- Wall-mounted television in the sales department running a slideshow (slave workbook for the airport view)
- Master workbook in the CAD/Production department
  - Subject matter expert (SME) input
  - Compensate for actual resource availability



Company anonymized

Airport view part 1



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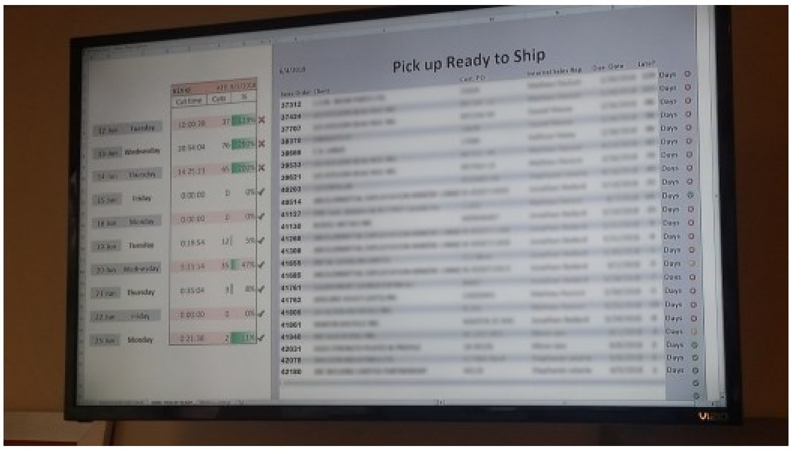
Airport view part 2



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Upcoming features

- ERP integration (SAP B1)
  - Automatically consider delays added by internal welding
  - Alert production of upcoming plate shipments for back-ordered items
- Standard times
  - Machining
  - Multi-torch cutting
  - Raw material manutention
- Transition to Power BI for scalability (e.g. drill-down)
  - Cloud platform possibility with a data gateway
- Cross-plant system? Vancouver, Chile, & beyond

Company anonymized

SSBA implementation takeaway

- Information System Architecture
  - Hierarchical drill-down capability is key to facilitate PSI problem investigations
  - An alert feature must be integrated in order to notify stakeholders that a problem is to be addressed
  - Simulation can improve the decision-making process
  - Tracked KPIs must be chosen carefully
- Implementation methodology
  - Assess available information systems, data accessibility
  - Determine areas of possible improvement in current processes
  - Adapt to corporate culture factors
  - Carefully select the SSBA software
    - Learning curve
    - Compatibility with existing IS
    - Scalability
    - Execution & vision

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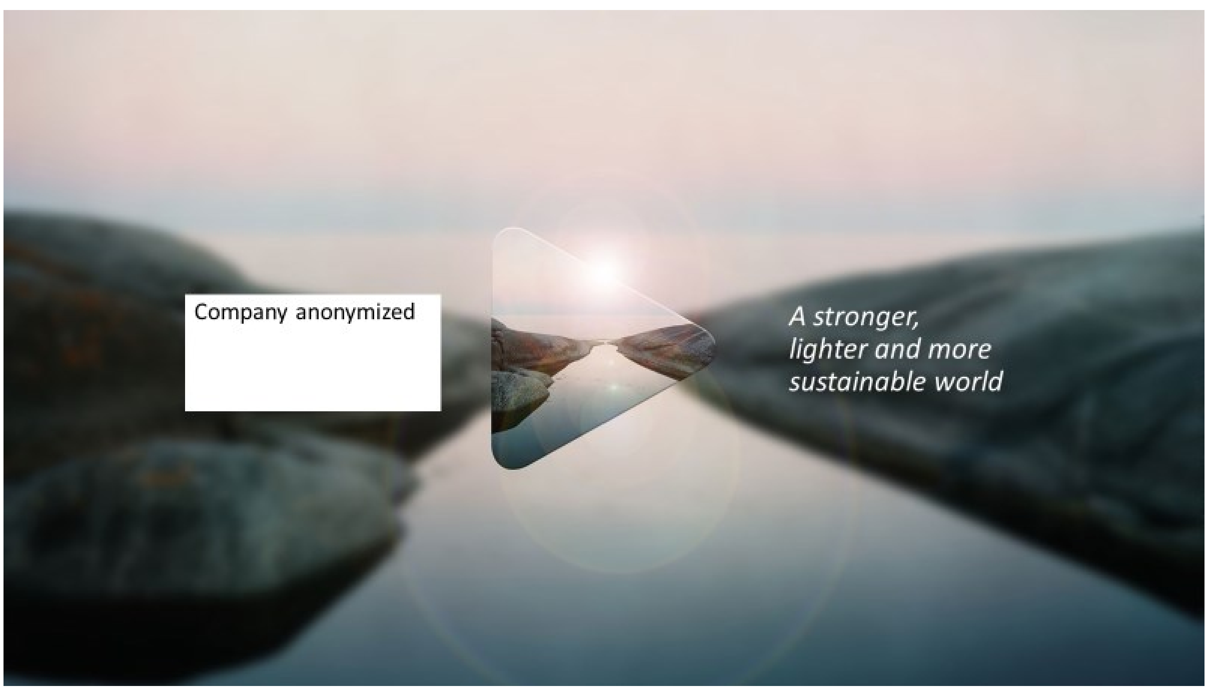

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►[1] BPM Offensive Berlin. (2009, retrieved 09/08/17). *BPMNPoster*. Available: http://www.bpmb.de/index.php/BPMNPoster

►[2] S. Selvaraju and C. Peterson, "A Framework to Utilize Business Analytics to Sustain a Lean Transformation," 2017.

►[3] H. O. Unver, "An ISA-95-based manufacturing intelligence system in support of lean initiatives," *The International Journal of Advanced Manufacturing Technology,* vol. 65, no. 5-8, pp. 853-866, 2012.

►[4] C. Saha, F. Aqlan, S. S. Lam, and W. Boldrin, "A decision support system for real-time order management in a heterogeneous production environment," *Expert Systems with Applications,* vol. 60, pp. 16-26, 2016.

►[5] S. Urabe, H. Shuangquan, and S. Munakata, "PSI-Cockpit: A Supply-Demand Planning System Focusing on Achieving Goals through Resolving KPI Conflicts," 2016.

Company anonymized

APPENDIX VI

APPROVAL FROM THE RESEARCH ETHICS COMMITEE

ÉTS
Le génie pour l'industrie

Comité d'éthique de la recherche
École de technologie supérieure

4 juin 2018

Titre du projet : A framework to implement self-service business analytics supporting lean manufacturing

Responsable : Yvan Beauregard

Numéro de référence : H20180505 **Type de demande :** *Nouvelle*

AUTORISATION DE PROCÉDER À LA RECHERCHE

Monsieur Beauregard,

Le projet de recherche mentionné en rubrique a été déposé le 26 mai 2018 pour évaluation par le Comité d'éthique de la recherche de l'ÉTS (CÉR). La présente lettre est pour vous informer que le CÉR a procédé à l'évaluation du dossier en comité délégué.

À la lecture du formulaire de présentation allégé, nous comprenons que l'objectif du projet n'est pas d'identifier des entreprises ou des participants, mais plutôt d'obtenir des avis d'experts. Conséquemment, votre projet ne requiert pas de certificat éthique au sens de l'*Énoncé de politique des trois Conseils* (ÉPTC-2014). Pour appuyer notre réflexion, voici un extrait de l'article 2.1 de l'ÉPTC-2014 :

> *« Dans certains cas, le projet de recherche peut comporter une interaction avec des personnes qui ne sont pas elles-mêmes visées par la recherche, en vue d'obtenir de l'information. Par exemple, un chercheur peut recueillir, auprès d'employés autorisés à communiquer des renseignements ou des données dans le cours normal de leur travail, de l'information au sujet d'organisations, de politiques, de méthodes, de pratiques professionnelles ou de rapports statistiques. Ces personnes ne sont pas considérées comme des participants aux termes de la Politique. »*

J'ai donc le plaisir de vous informer que votre projet peut aller de l'avant.

Le CÉR vous demande d'adopter une conduite responsable tout au long de vos travaux de recherche, notamment en adoptant les règles suivantes :

1. Soyez vigilant quant aux renseignements recueillis. Ceux-ci ne doivent pas porter atteinte aux personnes qui participent aux entrevues, et ne doivent en aucun cas permettre l'**identification par recoupement d'informations**.

2. Veuillez porter une attention particulière à la **protection de la confidentialité** des données qui seront recueillies durant le projet. À cet égard, le CÉR vous demande d'utiliser le réseau sécurisé de l'ÉTS plutôt qu'un service de stockage en ligne pour conserver vos données.

3. Si vous envisagez de publier les résultats de cette recherche dans un congrès scientifique (colloque, etc.), assurez-vous qu'aucune information permettant l'identification des participants ne soit dévoilée.

Veuillez agréer, Monsieur Beauregard, l'expression de mes sentiments les meilleurs.

Mathias Glaus, Ing., Ph.D.
Président,
Comité d'éthique de la recherche

cc : Claire Samson, Doyenne de la recherche
Mathias Glaus, Président du CÉR

p.2/2

APPENDIX VII

PROOF OF SUBMISSION OF THE INTEGRATED ARTICLE

Gmail Simon Lizotte-Latendresse <lizotte.simon@gmail.com>

International Journal of Lean Six Sigma - Manuscript ID IJLSS-10-2018-0111

1 message

International Journal of Lean Six Sigma <onbehalfof@manuscriptcentral.com> Thu, Oct 4, 2018 at 4:38 PM
Reply-To: J.Antony@hw.ac.uk
To: lizotte.simon@gmail.com, yvan.beauregard@etsmtl.ca

04-Oct-2018

Dear Mr. Lizotte-Latendresse:

Your manuscript entitled "An empirical framework for implementing self-service business analytics supporting lean manufacturing" has been successfully submitted online and is presently being given full consideration for publication in the International Journal of Lean Six Sigma.

Your manuscript ID is IJLSS-10-2018-0111.

Please mention the above manuscript ID in all future correspondence or when calling the office for questions. If there are any changes in your street address or e-mail address, please log in to Manuscript Central at https://mc.manuscriptcentral.com/ijlss and edit your user information as appropriate.

You can also view the status of your manuscript at any time by checking your Author Centre after logging in to https://mc.manuscriptcentral.com/ijlss.

Thank you for submitting your manuscript to the International Journal of Lean Six Sigma.

Sincerely,
International Journal of Lean Six Sigma Editorial Office

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