Not lean by default

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Chapter 5

Conclusion and Discussion

5.1 Introduction

In this dissertation, the focus is on the relationship between lean manufacturing and performance. As argued in chapter 1, lean manufacturing can be characterized as a philosophy implemented by a set of interrelated manufacturing practices which are, in turn, supported by a large number of associated tools and techniques. Based on the classification, we identified two general research objectives in chapter 1 which stipulate the need to understand how lean manufacturing practices jointly affect performance and how the design of these practices affects performance. In the following sections, we provide a summary and discuss the main findings presented in each of these chapters and relate them to the stated research objectives. In addition, we provide suggestions to further each research objective.

5.2 Summary and main findings

In the following sections, we briefly discuss the premise, methods used, main findings, and major contributions of each chapter.

5.2.1 Infrastructural and core quality management practices

The study, presented in chapter 2, addresses the relationship between core and infrastructural quality management practices and performance. The study aims to reconcile three competing perspectives by synthesizing previous studies on the relationship between quality management practices and performance. In this study, we aim to determine whether or not core and infrastructural quality management practices are distinct and, if so, whether a direct or indirect perspective provides a better explanation.

To address our aims, we use a combination of meta-analysis and structural equation modeling. Meta-analysis allows us to synthesize previous studies. Confirmatory factor analysis allows us to assess whether core and infrastructural quality management practices are distinct and structural equation modeling allows us to assess to what degree quality management practices affect performance.

There are four main findings. First, the meta-analytical results suggest that core and infrastructural quality management practices are positively associated with quality, operational, and business performance. Second, the meta-analytical results also suggest that the relationships between quality management practices and between quality management practices and performance are subjected to considerable heterogeneity. The amount of heterogeneity implies that the strength of the relationship is subject to moderating factors. Third, the confirmatory factor analysis suggests that core and infrastructural quality management practices are not distinct. Finally, the structural model suggests that quality management practices positively affect quality, operational, and business performance. Overall, the results do not favor the direct or indirect perspective, but rather the third perspective which considers core and infrastructural quality management practices to be indistinct.

The study makes a number of contributions. First, the study shows core and infrastructural quality management practices to be indistinct and thereby furthers the debate on the roles these subsets of practices play. Second, the study shows the importance of addressing the relation between manufacturing practices themselves in addition to addressing the relation between manufacturing practices and performance. Previous meta-analyses only consider the relationship between practices and performance and disregard the relation between the manufacturing practices themselves (Mackelprang & Nair, 2010; Nair, 2006). Finally, the study highlights the importance of considering contextual factors when studying how lean manufacturing practice, or quality management practices in particular, affect performance. In conclusion, the study contributes to our understanding of the role core and infrastructural quality management play in the realization of improved performance.

5.2.2 Work-in-progress restrictions and workload balancing

The study, presented in chapter 3, addresses the effective workload balancing capability of unit-based pull production systems. More specifically, the study explores how the placement of route-specific work-in-progress restrictions affects the effective workload balancing capability of unit-based pull production systems. Previous studies showed that unit-based pull production systems were able to effectively balance the workload if they were able to pass information related to the availability of capacity within a route upstream to be used to prioritize the release or dispatching of work. The placement of work-in-progress restrictions determines how route-specific information is passed upstream. In this study, we showed how the placement of route-specific work-in-progress restrictions affects the effective workload balancing capability of a unit-based pull production system.

To address our aim, we used discrete-event simulation. Two shop floor models were used, namely a three- and a four-stage divergent shop floor model. Divergent shop floor models allowed us to evaluate the effective workload balancing capability of unit-based pull production systems at multiple stages. POLCA was used to control work on the shop floor because it used multiple work-in-progress restrictions which allowed us to evaluate the placement within a routing of each of these restrictions.

There are four main findings. First, work-in-progress restrictions should be placed to facilitate workload balancing near the end of the route in case of shorter routes. Balancing the workload before the second to last workstation in a routing was most effective. Second, additional work-in-progress restrictions should be placed at the beginning of the route in case of longer routes. Balancing the workload at the second to last workstations was most effective. The placement of an additional work-in-progress restriction at the first workstation to balance the workload at release also improves the effective workload balancing capability in longer routings. Third, the effective workload balancing capability of a unit-based pull production system improves when utilization and batch size increase. However, these effects were less pronounced if the release of orders to the shop floor is not restricted. Finally, processing time variability erodes the effective workload balancing capability of the unit-based pull production system. Regardless of where the work-in-progress restrictions were placed, the unit-based pull production system was not able to balance the workload in case of processing time variability. In conclusion, the findings suggest that the placement of work-in-progress restrictions influences the effective workload balancing capability of the unit-based pull production system.

The study makes a number of contributions. First, the study demonstrates that unit-based pull production systems are able to balance the workload effectively. Only a few studies demonstrated that unit-based pull production systems were able to effectively balance the workload. Second, the study shows that not all work-in-progress restrictions contribute to the effective workload balancing capability and that the placement of work-in-progress restrictions should be carefully evaluated. The study showed that by carefully considering the placement of each work-in-progress restriction it is possible to outperform the traditional placement of work-in-progress restrictions. In conclusion, the study contributes to our understanding of how the placement of work-in-progress restrictions contributes to the effective workload balancing capability of unit-based pull production systems.

5.2.3 Work-in-progress restrictions and worker behavior

The study, presented in chapter 4, addresses the coordination losses and motivation losses and gains of individuals working in work-in-progress restricted production lines. Previous studies showed that individuals in work-in-progress restricted production systems were motivated to avoid idle time. Social comparison and social indispensability theories offer an explanation for the observed behavior. In this study, we aim to identify to what degree these two mechanisms – social comparison or social indispensability – drive the behavior of individuals in work-in-progress restricted production lines.

To address our aim, we conducted an experiment. In the experiment, participants worked on the assembly of printed circuit boards. The experiment allowed us to evaluate the relative importance of the social comparison and social indispensability mechanisms.

There are four main findings. First, social comparison results in motivation gains facilitated by the development of productivity norms or standards. Second, the structure of the serial production line and the associated task and outcome interdependencies result in motivation losses. The design of the serial production line emphasizes the contribution of the last individual within the line and obscures the contribution of others within the line which may explain the observed motivation losses. Third, in case the use of a serial production line cannot be avoided, a more severe work-in-progress restriction is able to mitigate the motivation losses or even facilitate motivation gains to a certain extent. However, the reduction of the motivation losses comes at the expense of increase coordination losses. Finally, the findings suggest that individual differences play an important role in work-in-progress restricted production systems. The more severe the work-in-progress restriction, the more severe the variation in motivated behavior. In conclusion, the findings show that the design of the pull production system not only influences performance through coordination losses but also through motivation gains and losses.

The study shows that restricting work-in-progress does not result in motivation gain, instead, it minimizes motivation losses. These motivation losses cannot be overcome by relying on social comparison alone. Social comparison should be supported in case sequential interdependencies are absent to facilitate motivation gains, whereas social indispensability should also be supported in case sequential dependencies are present to minimize motivation losses associated with the sequential nature of work in a production line. Subsequently, the study, similar to other studies within the domain of behavioral operations management (Bendoly, Donohue, & Schultz, 2006; Gino & Pisano, 2008), show that it is worthwhile to integrate ideas from reference disciplines, such as organizational behavior, industrial psychology, social psychology, or cognitive psychology to explore how the design of lean manufacturing practices, such as pull production, determines performance. Finally, the study highlights the importance of considering individual differences. In conclusion, our study contributes to both theory on pull production system design and theory on social comparison and indispensability.

5.3 Theoretical implications

As stated, this dissertation addresses two research objectives. The first objective, how lean manufacturing practices jointly affect performance, is explored in chapter 2. The second objective, how the design of lean manufacturing practices affects performance, is explored in chapters 3 and 4. In each chapter, we provide specific recommendations for future research. Here, we provide more general suggestions for future research related to the objectives outlined previously.

5.3.1 Lean manufacturing practices

In our study, presented in chapter 2, we address how lean manufacturing practices jointly affect performance. The findings, presented in the chapter, have several important implications for theory development and future research in the field of lean manufacturing.

First, our study furthered a longstanding debate using a novel approach. The study not only advanced theory on quality management but also provides a way to use secondary data to study the entire set of lean manufacturing practices. In the study, we showed how core and infrastructural quality management practices jointly affect quality, operational, and business performance. That is, we focused on a subset of lean manufacturing practices. In addition to quality management practices, lean manufacturing also includes practices related to just-in-time, productive maintenance, supply chain management, and human resource management (e.g. Furlan, Dal Pont, & Vinelli, 2011). As such, a first recommendation would be to use the methods employed in chapter 2 to study the remaining subsets of lean manufacturing practices or include the entire set of lean manufacturing practices in a single study. As we have shown in chapter 2, these studies should include the relation between practices and performance as well as the relation between the practices themselves. Previous meta-analyses on lean manufacturing practices only considered the aforementioned whilst ignoring the latter (e.g. Nair, 2006; Mackelprang and Nair, 2010). Including both types of relationships makes it possible to construct a complete correlation matrix and use structural equation modeling techniques to evaluate alternative models. The comparison of alternative models allows us to assess what role practices play in realizing improved performance whether direct or indirect, supportive or otherwise. However, such an approach is not without difficulty. Extending the approach outlined above is made difficult by inconsistent used of constructs, lack of studies, and inconsistent reporting.

Second, our study also highlights the need for a longitudinal perspective. The study, presented in the second chapter, makes use of secondary data derived from cross-sectional studies. As a consequence, our study shares the same limitations. As of yet, few studies have been published that use a longitudinal design and comparable measures to track the development of lean implementations over time. Netland (2016) takes a long-term perspective and argues that path dependencies will result in a unique implementation of lean practices and their associated tools and techniques. That is, selection of practices over time and differences in their design and implementation can result in similar outcomes, but under different circumstances. For instance, the practice of pull production can be implemented to reduce throughput times in a repetitive manufacturing environment using KANBAN or in a non-repetitive manufacturing environment using POLCA. Not only do these practices develop along their unique trajectories, combinations of practices implemented and refined together develop along a combined unique trajectory as well. These differences in implementation might, at least partially, explain the amount of heterogeneity found in our study. As such, the heterogeneity observed in our study provides a starting point for other researchers to investigate the circumstances surrounding successful quality management or lean manufacturing implementations. A promising direction for future research is to conduct longitudinal studies which document the development of lean manufacturing practices or sets of lean manufacturing practices over an extended period of time. Not only will these longitudinal studies shed new light on the causes of heterogeneity observed in our own study, they also will shed new light on the design of these practices and move the debate towards the mechanism underlying the effectiveness of lean manufacturing practices which is more informative for practice.

Longitudinal studies, using similar survey instruments as the cross-sectional studies, are a good first start (see Birdi et al., 2008 for an example). However, to document and understand the underlying mechanisms more longitudinal case studies are necessary (see Netland, 2016 for an example). These two examples suggest the approach to be viable, but underused.

5.3.2 Lean manufacturing practices, their design, and underlying mechanisms driving performance

In our studies, presented in chapter 3 and 4, we address the design of lean manufacturing practices. Both studies demonstrate the need to move away from studying lean manufacturing as a set of interrelated practices and towards studying the design of these practices and the underlying mechanisms that drive performance. The heterogeneity observed in the first study indicates that similar manufacturing practices are implemented in different ways and under different circumstances. The mechanisms exposed in the second and third study show that these circumstances should dictate the design of these practices. The findings, presented in these chapters, have a number of important implications for future research and theory development.

First, in the study presented in chapter 3, we show that improved performance can be realized by making adjustments to the design as originally intended. In the study, we demonstrated that the design of a pull system determines its workload balancing capability which, in turn, determines throughput time performance. Reconsidering the placement of work-in-progress restrictions results in improved throughput time performance by creating a more balanced distribution of work on the shop floor despite moving away from the implementation of the pull system as originally intended. The study shows that not the practices themselves, but rather the design of these practices determines performance. Moreover, in the study we establish that the effective workload balancing capability also depends on characteristics of the manufacturing environment such as variability in arrivals, variability in routings, and variability in processing times. The study shows how quickly the benefits erode under increased variability in processing times. Future research should consider how to tailor pull production systems to the specific characteristics of the manufacturing environments (see also González-R & Framinan, 2009 for a similar argument). A lot of promising work is already being done in this area (see also Thürer, Stevenson, & Protzman, 2016b for a review of literature) such as load-based alternatives to traditional pull production systems (e.g. Fernandes, Thürer, Stevenson, & Carmo Silva, 2017) or the incorporation of specific prioritization rules (e.g. Thürer, Fernandes, Stevenson, & Qu, 2017). Furthermore, the robustness of these alterations to traditional pull systems in various manufacturing environments should be evaluated. Actual manufacturing environments are characterized by considerable complexity often not captured in simulation models. As a consequence, it is necessary to explore the effectiveness of certain design choices in more complex environments characterized by the interaction of multiple environmental factors.

Second, in the study presented in chapter 4, we show that the underlying mechanisms that drive performance are best understood by considering different perspectives. In most studies, pull production system designs are evaluated using mathematical approaches or discrete-event simulation. In our study, we evaluate the design of various pull systems using an experiment. Simulation studies are suitable to analyze the design of pull systems in complex manufacturing environments as outlined previously. However, these simulation studies, by necessity, rely on simplified assumptions. In particular, worker behavior is often modeled in a simplistic manner with little to no regard for the mechanisms that drive worker behavior. The experiment allows us to observe how the behavior of workers is affected by the design of the pull system. In addition, the use of experiments allows us to evaluate how the design of practices can be refined by integrating literature from reference disciplines such as organizational behavior, industrial psychology, cognitive psychology, social psychology, and cognitive ergonomics (see also Bendoly et al., 2006; see also Croson et al., 2013; Gino & Pisano, 2008 for overviews of behavioural operations management literature). Future work can use a similar approach to evaluate the extent to which the design of pull systems affects the degree to which these mechanisms materialize. For instance, by relaxing work-in-progress restrictions to evaluate the sensitivity of these underlying mechanisms as suggested in earlier studies (Schultz et al., 1998, 1999). Moreover, future work can use experimentally derived insights to inform researchers to relax or validate certain assumptions when it comes human behavior that underlie most simulation models by integrating state-dependent behavior (see also Bertrand & Van Ooijen, 2002; Heimbach et al., 2012; Öner-Közen et al., 2017; Powell & Schultz, 2004 for examples of studies which integrated state-dependent behaviour in simulation models).

Third, taken together these studies demonstrate the use and necessity of different research approaches in order to further our understanding of lean manufacturing practices and their design. Each study makes use of a different research approach. The study in chapter 2 relies on a combination of meta-analytical and structural equation modeling techniques, the study in chapter 3 utilizes discrete-event simulation, and the study in chapter 4 makes use of an experiment. Although the choice of research approach in each chapter was dictated by the specific question asked in each study, there is considerable merit in using different approaches to study the performance implications of lean manufacturing. The approach taken in this dissertation did not combine multiple methods to answer a single question. A next step would be to combine multiple methods to answer a single question. For instance, survey research to quantify the performance implications of lean manufacturing practices can be supplemented with qualitative research to expose underlying mechanisms that drive performance. Similarly, as stated before, experiments can be used to validate or relax assumptions commonly used in simulation research. The push towards these types of multi-method studies is shared by others (Boyer and Swink, 2008; Choi, Cheng, & Zhao, 2016).

5.4 Practical implications

In each chapter, we provide specific suggestions for practitioners. Here, we provide more general suggestions linked to the two objectives stated above.

5.4.1 Lean manufacturing practices

In the first study presented in chapter 2, we address the first research objective and address how lean manufacturing practices jointly affect performance. Manufacturers are advised to consider the joint implementation of core and infrastructural quality management practices. Three different perspectives were evaluated in the study: a direct perspective, an indirect perspective, and an indistinct perspective. Each perspective has different implications for practitioners with respect to what practices to implement and the sequence in which to implement them. The direct perspective suggests manufacturers to implement those practices that predict performance best. The indirect perspective suggests that core quality management practices require infrastructural quality management practices in order to be beneficial. The indistinct perspective suggests that certain practices to be implemented together. The results favor the third perspective and, as such, managers are advised to consider the joint implementation of these practices. Therefore, when implementing a quality management practice, or lean manufacturing practice for that matter, the implementation of other practices should be considered as well. Product design and management practices, for example, cannot be separated from process management practices, nor can process management practices be separated from quality data and analysis practices or quality training practices. These insights are likely to extend towards other lean bundles, such as the just-in-time bundle, as well. The notion of joint implementation is not new. However, our study allows us to provide a conclusive recommendation. Manufacturers are therefore advised to consider the entire set of manufacturing practices when formulating an improvement strategy. The study provides support for the mutually reinforcing nature of lean manufacturing practices. A holistic approach to lean is required rather than considering lean manufacturing practices in isolation.

5.4.2 Lean manufacturing practices, their design and underlying mechanisms driving performance

Although in the studies, presented in chapter 3 and 4, we only consider the design of a specific lean manufacturing practice, namely pull production, a number of general recommendations can be made. First, customizing pull production systems results in improved performance. The results of chapter three demonstrate that moving away from the implementation of POLCA, as intended by its originators, by carefully considering the placement of work-in-progress restrictions results in improved performance. Similarly, it stands to reason that manufacturers should consider a more customized approach to the design of pull production systems. The implementation of lean manufacturing practices or the tools and techniques used to support them are highly specific. As such, the design of lean manufacturing practices should be matched with the current and future demands of the manufacturer. Managers are advised to move away from a standard approach towards a more tailored approach. A finding which is also supported by the degree of heterogeneity observed in chapter 2.

Second, both operational and behavioral aspects should be considered when designing pull production systems. The results presented in chapter 4 show that the design of the production planning and control system affects worker behavior. Ignoring worker behavior results in incorrect recommendations for the design of the production planning and control systems where workers are the primary determinant of processing times. More specifically, in the fourth chapter, we show that social comparison and social indispensability can be facilitated by an appropriate production planning and control system design. Manufacturers are advised to consider not only operational but also behavioral concerns in their approach to lean manufacturing practice design by, for instance, aligning incentive policies to match the design of the production planning and control system used.

5.5 Concluding remark

Taken together, these studies demonstrate the need to study how lean manufacturing practices jointly affect performance and the need to study how the design of those practices affects performance. This dissertation shows that lean manufacturing practices should be jointly implemented as these practices are mutually reinforcing. However, the degree to which lean manufacturing practices are mutually reinforcing depends on contextual factors. The design of these practices should, therefore, be tailored to the specific circumstances manufacturers find themselves in. These circumstances determine whether or not the underlying mechanisms that drive performance are able to actually do so. A default approach to lean, where practices are implemented with little regard for these underlying mechanisms, might not be enough to realize improved performance. Successful lean implementations require a holistic yet custom approach in which these mechanisms take center stage. In conclusion, the studies in this dissertation shows that such a 'lean by design' approach is more likely to pave the way for improved performance.