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Assessment of lean manufacturing effect on business performance using Bayesian Belief Networks

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ABSTRACT

The challenge of agility for adopting new business norms creates the need for measuring performance under changing conditions. This study aims to demonstrate the financial and non-financial consequences of implementing different combinations of lean techniques on the business performance. Bayesian Belief Network is used in studying the effects of factors under changing conditions. There are seven lean factors and four achievements studied to analyze the impact on three performance indicators. Bayesian Belief Network is constructed on the lean aspects that stimuli flexibility, reliability, quality and time of operations, which will have positive impacts on the financial, non-financial and sustainability performances of suppliers. A case study is carried out for suppliers in the automotive industry and scenarios with different combinations of lean factors are studied. This study gives a new vision in applying Bayesian network for business performance measures considering both the tangible and intangible results under changing business conditions.

1. Introduction

With the publication of *The Machine that Changed the World: The Story of Lean Production* (Womack, Jones, & Roos 1990), the benefits of lean principles have been widely recognized. The term 'lean' implies a series of activities or solutions to eliminate waste, reduce non-value added operations, improve value added processes and maximize performance (Womack & Jones, 1996). Lean principles emphasize system-level optimization, where the emphasis is on integration and how the parts work together as a whole, rather than on individual performance and excellence of any one feature or element (Oliver, Schab, & Holweg, 2007). Originally derived from manufacturing operations, these principles have subsequently also been applied to service operations (Cuatrecasas, 2004; Vlachos & Bogdanovic, 2013; Womack, 2004). Although lean management is widely regarded as a business strategy and implementation of lean techniques improves business competitiveness and organizational performance, few researchers have concentrated on the validation of its positive link with business performance (Detty & Yingling, 2000; Li, Sawhne, & Wilck, 2013; Macedo & Camarinha-Matos, 2013; Singh, Kumar, Choudhury, & Tiwari, 2006; Vinodh & Joy, 2012).

Scenario analysis provides valuable insight with a systematic approach to anticipate alternative future outcomes. This approach facilitates business decisions by taking a number of possible upcoming events in business environments into account and how the performance changes accordingly. As Wong and Wong (2007) states, scenario analysis has high benefits for the decision makers who can estimate the best cut-off points under the previously defined objectives and constraints. Majority of scenario analyses on business performance are focused on the preparation of simulation models for current status continuing without any change, facing the best options to the benefit of the firm or facing the worst conditions (Antón, McCracken, & Potts, 1994; Suryani, Chou, Hartono, & Chen, 2010; Tan & Takakuwa, 2007). Sensitivity analysis can also be performed by changing the input values and multivariable hypothesis testing (Allwood, Laursen, Russell, Malvido de Rodríguez, & Bocken, 2008; Brinckmann, Grichnik, & Kapsa, 2010; Rubio & Corominas, 2008). As a future studies technique, scenario analysis using naïve Bayes is mainly used in success, failure or risk analyses (Groth & Muntermann, 2011; Sun & Shenoy, 2007).

Landuyt et al. (2013) gives a review of Bayesian Belief Networks and states that it has an important role in scenario analysis. This tool has recently taken over an important role of linking quantitative methods with qualitative methods in managerial decision

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making (Fabian, Cristhian, Ricardo, Diego, et al., 2010; Hänninen, Valdez Banda, & Kujala, 2014; Lee, Song, & Cho, 2010; Li et al., 2013; Shen, 2008; Ulengin, Kabak, Onsel, et al., 2010; Ulengin, Onsel, Topcu, Aktas, & Kabak, 2007). This tool has been widely accepted in constructing future plans by changing the decision parameters, since it performs well in combining the observations and the expert opinions under uncertainties (Cinar & Kayakutlu, 2010; Cinicioglu, Sahin, & Ülengin, 2012; Marcot, 2012; Santos, Santos, Wilkinson, et al., 2011; Dias, 2013; Medina, Jankovic, Okudan Kremer, & Yannou, 2013; Perkusich, Soares, Almeida, & Perkusich, 2015; Zhang, Wu, Ding, Skibniewski, & Yan, 2013).

Lean production has mainly focused on financial savings and reductions in processing time and effort, which are hardcore optimization objectives. Information and knowledge dimensions are the only qualitative and human judgment based variables that are given more attention. Dependency among variables and ambiguity can be resolved by using scenarios for changing the environmental state. There is yet only limited number of studies using Bayesian Network analysis on lean manufacturing implementations by Li, Rajpal, Sawhney, and Li (2009), Li et al. (2013) and Hristea and Colhon (2012). Li et al. (2009) use Bayesian network to improve sustainability using lean techniques. Hristea and Colhon (2012) use Bayes Network to cluster the knowledge for achieving lean business. Li et al. (2013) analyze the risks and supportive processes for the success of Lean 6 Sigma application. These papers emphasize the benefits of Bayes networks in uncertain environments with limited knowledge.

This study aims to determine the effects of lean manufacturing techniques on quantitative and qualitative business performance for manufacturing companies, where several applications are combined. The case study is performed for the Turkish automotive suppliers. There are three objectives of this study; the first is to evaluate the combined performance of qualitative and quantitative lean factors, the second is to resolve the dependence problem faced in linguistic evaluation and the last one is to validate the effect of combined Lean Techniques on financial performance, non-financial performance and sustainability under changing conditions by using Bayesian Belief Network.

The study follows the main steps below:

- *Selecting the Lean factors to be analyzed;*
- *Combining and eliminating independent criteria;*
- *Construction of the cause and effect diagrams among the criteria;*
- *Formation of the Bayesian Map;*
- *Preparing the dependency matrices;*
- *Constructing the Scenarios and perform scenario analysis;*
- *Discussion of the Lean Factor effects on the business performance in different scenarios.*

Following the above workflow, the next section of the article is reserved for the literature review about the impact of lean approach on business performance and scenario analysis studies. The Bayesian Belief Networks are detailed in the third section and the implementation is explained in the fourth section, including scenarios and discussions. Conclusions and suggestions for future studies will be briefed in the fifth and last part. This paper gives a new approach for measuring business performances with a focus in the automotive industry.

2. Literature survey

2.1. Lean effect on business performance

Lean management principles serve the purpose of delivering the highest quality at the lowest total cost, in the shortest time to the customers as well as continuously improving them to achieve perfection for long term benefits (Ramesh & Kodali, 2012). Although the lean concept is a popular manufacturing and managerial philosophy utilized across the globe, successful implementation of lean management can be considered as a complex task, depending on the fact that investments are required to implement this approach. Lean practices can be evaluated as noteworthy, based on the significant returns they generate via operational effectiveness and cost savings (Mackelprang & Nair, 2010). Previous empirical research exposed significant evidences related to lean practices and business performance. In this section, the role of contingency factors is investigated based on the past research findings.

Organizations carry responsibilities to their shareholders with a profit maximization objective. Business performance can be described as a performance criterion, commonly used for capturing the long term behavior of the firm (Olhager & Prajago, 2012). Business performance elements are basically conceptualized as operational-competitive performance (Camacho-Miñano, Moyano-Fuentes, & Sacristán-Díaz, 2012; Mackelprang & Nair, 2010), market performance and financial performance (Olhager & Prajago, 2012; Yang, Hong, & Modi, 2011). Typically; cost, inventory, cycle-time, delivery, flexibility, quality (for operational performance); sales growth and market share (for market performance); return on investments-assets-sales (ROI-ROA-ROS), profits and market value (for financial performance) and other similar measures are used to define business performance.

On the other hand, the lean approach basically tries to eliminate all activities that do not provide added value. Thus, lean practices can reduce costs and improve productivity. Particularly, internal lean implementations might provide higher company profitability due to the performance effect on total cycle-time reductions, better customer service levels and higher profit margins (Camacho-Miñano et al., 2012).

Implementation of lean manufacturing & management techniques improves business competitiveness and organizational performance, owing to the fact that it reduces both the number of defects and the cost of production. Vinodh and Joy (2012) argue that the lean approach streamlines the production process and reduces waste, contributing to the financial performance of the firm. Thus, financial performance should be seen as the ultimate measure of business performance and firm's strategic success (Camacho-Miñano et al., 2012).

Internal lean practices enhance manufacturing and management productivity by reducing setup times and work in process inventory, through which firms can improve their market performance. External lean practices are useful for providing support to solve some innovative problems in the business process, such as new product development, order fulfilment and customer services. Consequently, customer satisfaction can be achieved through increased customer responsiveness and reduced customer lead-time (Yang et al., 2011).

Lower inventory levels, higher quality and operational performance with less waste can be listed among the benefits of lean production (Hofer, Eroglu, & Hofer, 2012). Lean manufacturing & management practices (Amin & Karim 2013; Saurin, Marodin, & Ribeiro, 2011; Arnas et al., 2013) such as, Just-in-Time (JIT), Total Quality Management (TQM), Total Preventative Maintenance (TPM), Pull-Kanban System, Setup Time, Cellular Manufacturing (Layout), Small Lot Size, Housekeeping (5S), Standardized Work, Production Scheduling, Work Groups and Value Stream Mapping are positively correlated with competitive operational performance criteria (Ramesh & Kodali, 2012) like efficiency, responsiveness, productivity and quality. However, all these improvements on competitive priorities also allow the firm to achieve lower cost performance (Arnas et al., 2013).