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Trattner, Alexandria Lee; Hvam, Lars; Herbert-Hansen, Zaza Nadja Lee; Raben, Christian

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Product variety, product complexity and manufacturing operational performance: A systematic literature review

Alexandria Moseley (alemo@dtu.dk)
Technical University of Denmark

Lars Hvam
Technical University of Denmark

Zaza Nadja Lee Herbert-Hansen
Technical University of Denmark

Christian Raben
Technical University of Denmark

Abstract

Manufacturing in the twenty-first century has been wrought with the struggle to satisfy the rising demand for greater product variety and more complex products while still maintaining efficient manufacturing operations. However, the literature lacks an overview of which operational performance measures are most affected by increased variety and complexity. This study presents a systematic literature review of the recent scholarly literature on variety, complexity and manufacturing operational performance (MOP). Results show that product variety has a consistently negative relationship with MOP across different time, cost, quality and flexibility measures while product complexity lacks evidence of strong relationships with MOP measures.

Keywords: Product variety, Complexity, Performance

Introduction

Manufacturing in the twenty-first century has been wrought with the struggle to satisfy the rising demand for greater product variety and more complex products while still maintaining efficient operations. Scholars have discussed how to optimize production in the face of rising customer demands for custom product over the past 20 years from different perspectives (Berry & Cooper 1999; da Silveira 1998; MacDuffie et al. 1996). Concepts such as flexible manufacturing systems, Lean, setup time reduction, and production scheduling have all been discussed as solutions to help manufacturers cope with the rising demands on their facilities (Balakrishnan & Geunes 2003; da Silveira 1998; MacDuffie et al. 1996).

Among all the descriptions of techniques, there has yet to be presented a comprehensive overview of the literature assessing the relationships between product variety and product complexity and different measures of manufacturing operational performance. Such an overview would reveal where manufacturers can expect to see the impact of increased variety and complexity in their products on their internal performance measures such as labor hours per unit and external performance measures, such as delivery service level and flexibility towards customers. Further, the data would reveal that factors that allow manufacturers to produce as efficiently as possible while still maintaining a high product mix in different industries. In this study, we undertake to meet this need using a systematic literature review.

The research question guiding this study is: what is the impact of product variety and product complexity on manufacturing performance? As the two terms have been used interchangeably in the literature, both “product variety” and “product complexity” are considered in this study along with related terms, such as “mass customization” and “product diversity.” For the purposes of this study they will be distinguished. Product variety (PV) will refer to number of products produced or components used in production (Berry & Cooper 1999). Product complexity (PC) will refer to the level of complexity of the products produced at the firm (Bortolotti et al. 2013; Caniato & Größler 2015).

Operational performance has been defined in previous work as unit manufacturing cost, quality, speed of new product introduction, flexibility, and delivery dependability (Ferdows & De Meyer 1990). Within this study, the performance of manufacturing processes is assessed and termed manufacturing operational performance (MOP) will be defined as measures of cost, time, quality, flexibility (or responsiveness) within the production environment at manufacturing companies, including productivity, which relates to time.

The objective of this research is synthesizing the relationships between PV, PC, and specific measures of MOP in recent scholarly literature and reveal directions for future research. This paper is structured as follows: first, the methodology behind the systematic literature review is presented, second, the analysis and coding of the articles is described and discussed, and last conclusions are drawn and future research is suggested.

Methodology

The systematic literature review approach proposed by Tranfield, et al. (2003) was used to conduct this study to obtain and unbiased and thorough search of the existing knowledge of the relationships between PV, PC, and MOP. Systematic literature review is an acknowledged method for ascertaining the key concepts within scholarly literature in the fields of medicine and management which typically consists of three phases: planning, conducting and reporting a review (Tranfield et al. 2003). In this study, a search string was developed to explore the body of literature regarding the three constructs of product variety, product complexity and manufacturing performance. Two literature databases SCOPUS and Web of Science were selected as they contain relevant management and engineering journals of high academic quality and cover different sets of journals.

To ensure a comprehensive and unbiased search, the search string has been developed through multiple iterations. The initial search string was constructed in collaboration with four researchers to ensure a broad perspective and reduce the risk of omitting key words and synonyms. Keywords were added to the search string through an initial literature search until the additional terms did not give any new results. An overview of the search strings used for each database is shown in Table 1. Search results were limited to journal articles written in English and published within the past 25 years.

To narrow the body of literature further and bring forward the most relevant works in the field, journal quality criteria were applied next. The journals must have scored in the first of second quartile of the SCImago Index in 2015 in operations management or related field (e.g. strategy and management) in order to pass through the quality screening. Next, abstract criteria were applied to the literature sample to identify articles which utilized the constructs of product variety, product complexity and manufacturing performance or similar. Only articles which utilized the terms for

PV, PC and MOP from the search strings as their key constructs were assessed for full text reading. The final selected articles were analyzed through a full text reading, concept mapping and synthesis as detailed by Rowley and Slack (2004). The result of this process is summarized in Figure 1 where an initial search result of 955 articles from both databases was reduced to 30 articles for full text reading and coding.

Table 1 - Article search strings by database

Database	**Search String**
Scopus (Elsevier)	(TITLE-ABS-KEY ("product customisation" OR "mass customisation" OR "product diversity" OR "product vari*" OR "complexity management" OR "product divers*" OR "product proliferation" OR "product complexity" OR "product architecture" OR "product portfolio complexity") AND TITLE-ABS-KEY ("production performance" OR "manufacturing performance" OR "operational performance" OR "production impact" OR "manufacturing impact" OR "operational impact" OR "manufacturing flexibility" OR "productivity" OR "throughput" OR "order initiated production" OR "continuous production" OR "flow production"))
Web of Science (Thomson Reuters)	(("product customization" OR "product customisation" OR "mass customization" OR "mass customisation" OR "product diversity" OR "product variability" OR "product variation" OR "complexity management" OR "product diversification" OR "product proliferation" OR "product variety" OR "product complexity" OR "product architecture" OR "product portfolio complexity") AND ("production performance" OR "manufacturing performance" OR "operational performance" OR "production impact" OR "manufacturing impact" OR "operational impact" OR "manufacturing flexibility" OR "productivity" OR "throughput" OR "customized production" OR "customised production" OR "order initiated production" OR "continuous production" OR "flow production")

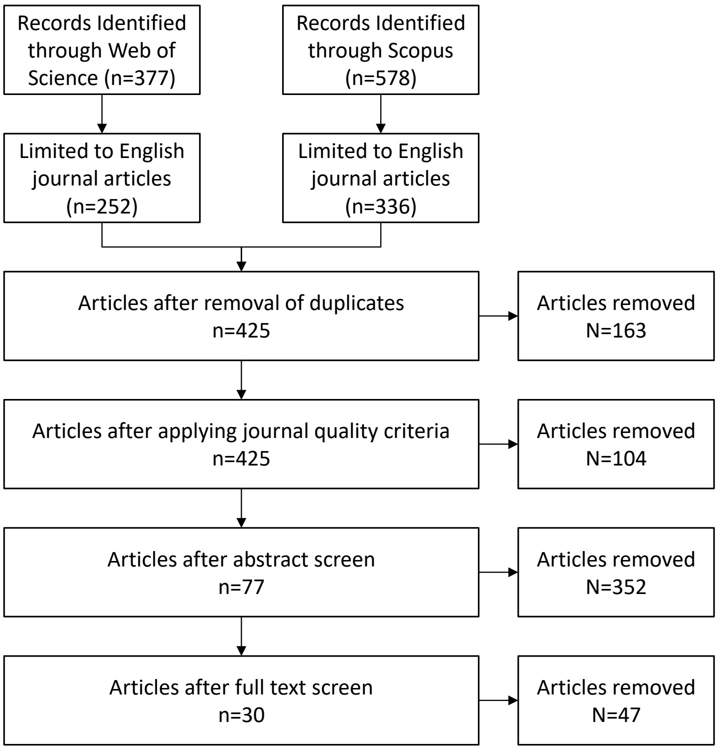

Figure 1 – Article selection process

Analysis

The thirty articles selected for full text review were analyzed by publication date, industry, and coded based on the nature of the relationships shown between PV, PC, and MOP. As can be seen in Figures 2, there has been an interest in the impact of PV and PC on MOP since the late 1990s but with a relatively low interest level, seen as only 1-4 articles published per year on the topic. Interest appears to have risen in the last decade with at least one journal publishing an article on the topic every year since 2009. Results are limited to the last 25 years of research due to database restrictions. It is expected that further research would result in another peak in article publication in the 1980s around the time of World Class Manufacturing and the proliferation of Lean manufacturing practices.

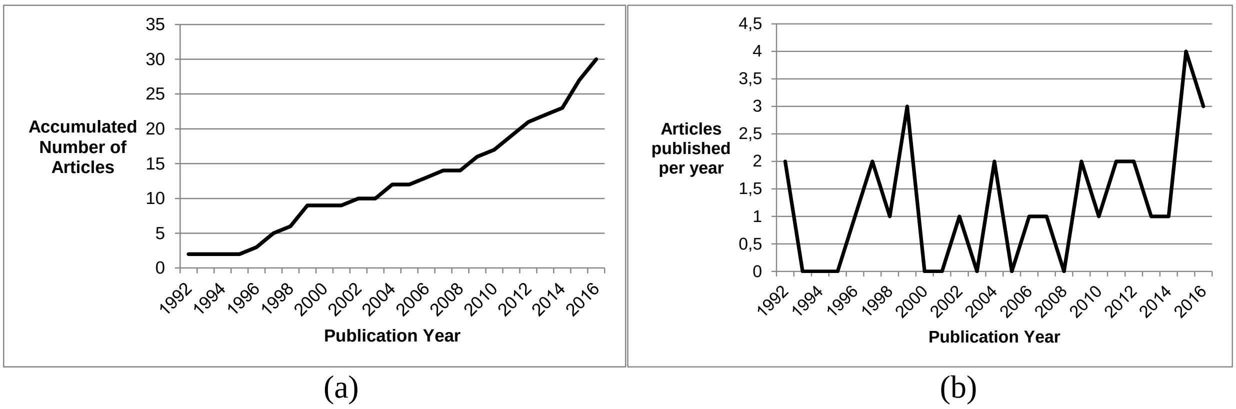

Figure 2 – Articles published which discuss the relationships between PV/PC and MOP showing (a) accumulated articles per year and (b) absolute articles per year

The research detailing the relationship between PV, PC and MOP span a range of industries, as can be seen in Table 2. To classify the industry of the cases and examples used in the articles, the Thomsons Reuters Business Classification scheme was applied (Anon 2017). The articles which used single cases or examples to illustrate their purpose are counted within one of the industry codes. Articles with multiple cases are counted in the code "Mixed" and articles without a case or with cases which had no distinct industry group are counted in the group "N/A".

Table 2 – Articles grouped by the industry code of their case examples

Thomsons Reuters Industry Code	**Number of Articles**
51101010 Commodity Chemicals	1
52102010 Industrial Machinery & Equipment	1
52102020 Heavy Machinery & Vehicles	1
53101010 Auto & Truck Manufacturers	2
53101020 Auto, Truck & Motorcycle Parts	2
53202030 Footwear	2
53203010 Homebuilding	1
54102020 Food Processing	1
57106020 Phones & Handheld Devices	1
Mixed (e.g. survey research)	11
N/A (e.g. generic mixed model assembly lines)	7
Grand Total	**30**

The results of the industry analysis show a good representation of the automotive, footwear and machinery industries, accounting for 8 of the 12 articles which were able to be classified by industry code. As these were some of the first industries to experience mass customization, it is logical that they should be represented in the list. Under represented in the list are cases of companies operating within the process industries, with only two articles represented from the chemicals and food industries.

Literature Coding

In the full text literature review, relationships between PV and MOP and PC and MOP were identified and mapped into an overview in Table 3. A relationship qualified for inclusion if it was observed and discussed within the article. For case study research articles, the relationships emerged from the empirical data gathered from the case company. For the quantitative research articles, the positive and negative relationships included in Table 3 were the statistically significant relationships found in the analysis. The relationships discussed in conceptual and methodological papers were included only if a numerical example was provided or previous work was cited to support the claim.

The relationships were coded first according to the four MOP measures of time, cost, quality, and delivery and second according to the direction of the relationship: positive, no relationship, or negative. Positive relationships between PV and MOP (or PC and MOP) were defined as increasing time-based performance (e.g. increased throughput or efficiency, decreased cycle time, decreased lead time), decreasing cost of production or inventory, increasing quality, and increasing flexibility, delivery or responsiveness. Negative relationships imply the opposite relationships as the positive relationships. The category “no relationship” was included to categorize the articles which tested relationships but found them not to be significant nor present in the data.

The overview in Table 3 shows that PV and its impact on MOP has been studied more in the past 25 years than PC, with roughly three times more relationships identified for PV than PC. At a high level, it appears that PV has a consistently negative impact on MOP across the selected measures of performance while the impact of PC on MOP is slightly positive or not existing. This distinct difference between PV and PC suggests that these constructs be clearly distinguished when utilized in the literature as they have different effects on MOP. Examples supporting the relationships between PV/PC and MOP are discussed below.

Table 3 – Relationships identified in full text reading between PV and MOP and PC and MOP

PV / PC	**MOP Measure**	**Positive relationship**	**No relationship**	**Negative relationship**	**Total**
PV	Time	3	3	11	17
	Cost	2		3	5
	Quality		3	4	7
	Flexibility	1		1	2
	General MOP			1	1
	Subtotal	5	6	20	32
PC	Time	1	2		3
	Cost		1		1
	Quality		1		1
	Flexibility	1	3		4
	Subtotal	2	7		9

Impact of PV → MOP

The overview in Table 3 clearly shows that the impact of increasing the number of units in production leads to reduced time-based MOP. This was directly observed or quantified in 11 instances within from the sample of 30 which were assessed with full text reading and is the most relationship with the highest frequency of discussion in the recent literature.

The impact of PV on time based performance came largely from the case study literature which shows that increased PV leads to reduced batch size, increased of setup time, and reduced line speed, leading to decreasing efficiency and productivity. This was discussed in the automotive industry, footwear industry, chemicals industry, and general batch manufacturers (Barnett et al. 2004; Berry & Cooper 1999; Nandkeolyar & Christy 1992; MacDuffie et al. 1996; Gollop 1997; Nagarur & Azeem 1999; da Silveira 2006).

One interesting case showing a positive relationship between PV and time-based MOP was the case of a gearbox producer in the automotive industry which decreased lead time while increasing PV via use of smaller batches (ElMaraghy et al. 2009). A correlation analysis of survey results from UK manufacturers showed similar findings (Mapes et al. 1997). This comparison suggests that increasing PV could lead to decreased productivity or throughput in production, but shorter, more competitive lead times due to smaller batches and greater agility.

A few of the studies shows no relationship when quantifying the impact of PV on MOP, but this was due to the type of variety being assessed and nature of the company (MacDuffie et al. 1996; Fisher & Ittner 1999). MacDuffie et al (1996) showed that base model variety did not affect performance of an automotive manufacturer for all 70 automotive manufacturing plants assessed while the variety at the intermediate level of the product architecture (e.g. wire harness, engine type) did not affect productivity in companies which had Lean capabilities. his suggests that variety type and organizational capabilities moderate the effect of PV on MOP.

There is disagreement in the literature regarding the impact of PV on inventory costs, with some studies finding that increased PV leads to decreasing finished goods inventory (ElMaraghy et al. 2009; Macchion et al. 2016) and another study showing increased inventory costs due to variability in the production plant (Fisher & Ittner 1999). Besides the topic of inventory costs, there is consensus in the literature that increasing PV leads to higher costs in production (Mapes et al. 1997; Jacobs & Swink 2011; da Silveira 1998).

Regarding quality, the results in Table 3 show a slight negative relationship. PV led to decreasing quality in three studies of various manufacturer plants in the automotive, footwear, and mechanical products industries (Jacobs & Swink 2011; Macchion et al. 2016; da Silveira 1998). However, no relationship was found in a further three articles covering a similar span of industries (MacDuffie et al. 1996; Mapes et al. 1997; Fisher & Ittner 1999). The balance in the discussion between a negative relationship and no relationship suggests that there are moderating factors which affect the way PV impacts product quality, though these moderating effects were not investigated.

The relationship between PV and flexibility was found to be underrepresented in the recent literature with mixed findings, thus making it difficult to conclude on (Mapes et al. 1997; Salvador et al. 2007). A further study assessed MOP as a general construct comprised of weighted values of individual performance measures and found an overall negative impact of PV on MOP using panel data analysis of 3857 publicly traded firms (Kovach et al. 2015).

Impact of PC → MOP

The literature addressing PC shows that there is no strong relationship between the complexity of the products produced and any measure of manufacturing operational performance. No relationship was found between PV and efficiency, cost, quality, flexibility, nor responsiveness (Bortolotti et al. 2013; Caniato & Größler 2015) while two studies showed a positive impact of PC on costs and responsiveness (Fan et al. 2016; Wang et al. 2012). MacDuffie et al.(1996) offers an interesting perspective on why there could be a lack of relationship between PC and MOP in their study of *model mix complexity*, or the complexity arising from the number of base models produced on a product line (MacDuffie et al. 1996). MacDuffie et al. states that production lines are typically built to handle the certain number of base models on the line, and thus they are able to cope with stress of product variations at the base model level without compromising operational performance (MacDuffie et al. 1996). Thus, it is not necessarily true the production lines which make more complex products should perform worse than production lines making simpler products because each line is designed to handle the required level of product complexity.

A conceptual paper revealed another potential reason for the lack of relationship between PC and MOP. When assessing the complexity of a set of products, Jacobs and Swink (2011) suggest that it is not the *multiplicity* (presence of many options for the same basic component) within a set of products that causes decreasing operational performance, but rather the *diversity* that causes the negative impact to performance. Returning to the comparison of a line making complex products to a line making simple products, this implies that it is the variability in PC or PV of a products coming down a line would cause the deviation in MOP, not the level PC or PV. This finding on the variability of PV was discussed in other papers in the analysis (Fisher & Ittner 1999).

In the many of the studies which proposed relationships, PC was operationalized as a combined measure of various answers from survey results (Bortolotti et al. 2013; Caniato & Größler 2015). While such operationalization is required for high level analysis with regression and structural equation modelling of vague topics such as complexity, these combined measures do not create a clear picture of how complexity within a products structure can impact production performance.

Secondary relationships

The articles selected for full text reading were further screened for secondary relationships and other factors with influence the relationship between PV and MOP and PC and MOP. Secondary relationships which were found within the 30 article sample include:

- Machinery flexibility (Berry & Cooper 1999; Comstock et al. 2004)
- Product modularity (Salvador et al. 2002; Kamrani et al. 2012; Vickery et al. 2015; da Silveira 2006)
- Sequencing and scheduling (Barnett et al. 2004; Liu et al. 2012; Nandkeolyar & Christy 1992)
- Organizational capabilities (e.g. organizational learning) (Jacobs & Swink 2011)
- Mass customization capability (Liu et al. 2012)
- Lean, quality programs and continuous improvement (MacDuffie et al. 1996; da Silveira 2006)
- Work station complexity (Wang & Hu 2010; Wong et al. 2015; Zhao et al. 2015)

These relationships should assessed further to understand the how much and in which contexts they influence the relationships between PV and MOP and PC and MOP.

Conclusion

The systematic literature review of the recent scholarly literature on variety, complexity and performance shows a distinct difference between the relationship between product variety and manufacturing operational performance and product complexity and manufacturing operational performance. In the final literature sample of 30 articles from the past 25 years of research, product variety showed a consistently negative relationship with MOP across the different time, cost, quality and flexibility measures while product complexity showed a lack of strong relationships with the MOP measures.

The discussion of the relationships show that PV and PC should be clearly distinguished when used in scholarly work as their effects are distinctly in manufacturing environments, across industries. Regarding the negative impact of PV on MOP, it was generally found that increased PV lead to decreased productivity but increased responsiveness (i.e. shorter lead time) due to the use of smaller batches. This tradeoff can be used by manufacturers when assessing production strategy for their manufacturing plants. Furthermore, a set of moderating variables which influence the relationships between PV and MOP and PC and MOP were identified, including machine flexibility, product modularization, production scheduling practices, organizational capabilities, mass customization capability, Lean, and work station complexity.

Future research topics include investigation of the effects of PC on MOP as this relationship was found to be under researched compared PV, investigation of the how moderating factors impact the relationships between PC and MOP and PV and MOP, and investigation into the relationships of PV and PC on MOP in the process industry.

References

Anon, 2017. Thomsons Reuters Business Classification. *TRBC Sector Classification*. Available at: http://financial.thomsonreuters.com/ [Accessed May 4, 2017].

Balakrishnan, A. & Geunes, J., 2003. Production Planning with Flexible Product Specifications: An Application to Specialty Steel Manufacturing. *Operations Research*, 51(1), pp.94–112.

Barnett, L., Rahimifard, S. & Newman, S., 2004. Distributed scheduling to support mass customization in the shoe industry. *International Journal of Computer Integrated Manufacturing*, 17(7), pp.623–632.

Berry, W.L. & Cooper, M.C., 1999. Manufacturing flexibility: methods for measuring the impact of product variety on performance in process industries. *Journal of Operations Management*, 17(2), pp.163–178. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0272696398000333 [Accessed December 23, 2016].

Bortolotti, T., Danese, P. & Romano, P., 2013. Assessing the impact of just-in-time on operational performance at varying degrees of repetitiveness. *International Journal of Production Research*, 51(4), pp.1117–1130.

Caniato, F. & Größler, A., 2015. The moderating effect of product complexity on new product development and supply chain management integration. *Production Planning & Control*, 7287(March), pp.1–12. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84928038818&partnerID=tZOtx3y1.

Comstock, M., Johansen, K. & Winroth, M., 2004. From mass production to mass customization: enabling perspectives from the Swedish mobile telephone industry. *Production Planning & Control*, 15(4), pp.362–372.

ElMaraghy, H. et al., 2009. Managing variations in products, processes and manufacturing systems. *CIRP Annals - Manufacturing Technology*, 58(1), pp.441–446.

Fan, H. et al., 2016. The Effectiveness of Supply Chain Risk Information Processing Capability: An Information Processing Perspective. *IEEE Transactions on Engineering Management*, 63(4), pp.414–425. Available at: http://ieeexplore.ieee.org/document/7558193/ [Accessed December 23, 2016].

Ferdows, K. & De Meyer, A., 1990. Lasting improvements in manufacturing performance: in search of a new theory. *Journal of Operations Management*, 9(2), pp.168–184.

Fisher, M.L. & Ittner, C.D., 1999. The Impact of Product Variety on Automobile Assembly Operations: Empirical Evidence and Simulation Analysis. *Management Science*, 45(6), pp.771–786. Available at: http://dx.doi.org/10.1287/mnsc.45.6.771.

Gollop, F.M., 1997. The pin factory revisited: Product diversification and productivity growth. *Review of Industrial Organization*, 12(3), pp.317–334.

Jacobs, M.A. & Swink, M., 2011. Product portfolio architectural complexity and operational performance: Incorporating the roles of learning and fixed assets. *Journal of Operations Management*, 29(7–8), pp.677–691. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0272696311000702 [Accessed December 23, 2016].

Kamrani, A., Smadi, H. & Salhieh, S.M., 2012. Two-phase methodology for customized product design and manufacturing. *Journal of Manufacturing Technology Management*, 23(3), pp.370–401.

Kovach, J.J. et al., 2015. Firm performance in dynamic environments: The role of operational slack and operational scope. *Journal of Operations Management*, 37, pp.1–12. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0272696315000352 [Accessed December 23, 2016].

Liu, G. (Jason), Shah, R. & Schroeder, R.G., 2012. The relationships among functional integration, mass customisation, and firm performance. *International Journal of Production Research*, 50(3), pp.677–690.

Macchion, L., Fornasiero, R. & Vinelli, A., 2016. Supply chain configurations: a model to evaluate performance in customised productions. *International Journal of Production Research*, 7543(January), pp.1–14. Available at:

https://www.tandfonline.com/doi/full/10.1080/00207543.2016.1221161.
MacDuffie, J.P., Sethuraman, K. & Fisher, M.L., 1996. Product Variety and Manufacturing Performance: Evidence from the International Automotive Assemnbly Plant Study. *Management Science*, Vol. 42(No. 3), pp.350–369.
Mapes, J., New, C. & Szwejczewksi, M., 1997. Performance trade-offs in manufacturing plants. *International Journal of Operations & Production Management*, 17(10), pp.1020–1033.
Nagarur, N. & Azeem, A., 1999. Impact of commonality and flexibility on manufacturing performance: A simulation study. *International Journal of Production Economics*, 60–61, pp.125–134. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0925527398001984 [Accessed December 23, 2016].
Nandkeolyar, U. & Christy, D.P., 1992. An investigation of the effect of machine flexibility and number of part families on system performance. *International Journal of Production Research*, 30(3), pp.513–526.
Rowley, J. & Slack, F., 2004. Conducting a Literature Review. *Management Research News*, 27(6), pp.31–39. Available at: http://www.emeraldinsight.com/doi/pdfplus/10.1108/01409170410784185.
Salvador, F. et al., 2007. Mix flexibility and volume flexibility in a build-to-order environment: Synergies and trade-offs. *International Journal of Operations & Production Management*, 27(11), pp.1173–1191.
Salvador, F., Forza, C. & Rungtusanatham, M., 2002. Modularity, product variety, production volume, and component sourcing: theorizing beyond generic prescriptions. *Journal of Operations Management*, 20(5), pp.549–575. Available at: http://linkinghub.elsevier.com/retrieve/pii/S027269630200027X [Accessed December 23, 2016].
da Silveira, G., 1998. A framework for the management of product variety. *International Journal of Operations & Production Management*, 18(3), pp.271–285. Available at: http://dx.doi.org/10.1108/01443579810196471.
da Silveira, G.J.C., 2006. Effects of simplicity and discipline on operational flexibility: An empirical reexamination of the rigid flexibility model. *Journal of Operations Management*, 24(6), pp.932–947.
Tranfield, D., Denyer, D. & Smart, P., 2003. Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*, 14, pp.207–222.
Vickery, S.K. et al., 2015. The effects of product modularity on launch speed. *International Journal of Production Research*, 53(17), pp.5369–5381. Available at: http://www.emeraldinsight.com/doi/full/10.1108/01443570710820620.
Wang, H. & Hu, S.J., 2010. Manufacturing complexity in assembly systems with hybrid configurations and its impact on throughput. *CIRP Annals - Manufacturing Technology*, 59(1), pp.53–56. Available at: http://dx.doi.org/10.1016/j.cirp.2010.03.007.
Wang, K., Rao, Y. & Wang, M., 2012. Modeling impact of choice complexity on production rate in mixed-Model assembly system. *International Journal of Advanced Manufacturing Technology*, 59(9–12), pp.1181–1189.
Wong, C.W.Y., Lai, K. & Bernroider, E.W.N., 2015. The performance of contingencies of supply chain information integration: The roles of product and market complexity. *International Journal of Production Economics*, 165, pp.1–11. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0925527315000730 [Accessed December 23, 2016].
Zhao, X. et al., 2015. A genetic algorithm for the multi-objective optimization of mixed-model assembly line based on the mental workload. *Engineering Applications of Artificial Intelligence*, 47(2008), pp.1–7. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0952197615000573.