FLEXIBILITY ASSESSMENT TO MITIGATE COMPLEXTITY: TRUCKS PRODUCTION ANALYSIS

Jorge Muniz Jr.
Universidade Estadual Paulista – UNESP
Brazil
jorge86056@gmail.com[1]

Luis Oliveira Nascimento
Universidade Estadual Paulista – UNESP
Brazil
luisdeoliveiranascimento@gmail.com

Henrique Rocha Martins
Universidade Estadual do Rio de Janeiro – UERJ
Brazil
prof.henrique_rocha@yahoo.com.br

Luis Alberto Duncan Rangel
Universidade Federal Fluminense - Campus de Volta Redonda
Brazil
duncan@metal.eeimvr.uff.br

ABSTRACT

New products are continuously developed in order to support customized demands. Flexibility supports customized demands, low costs, and agility, but it remains a challenge with regards to high-volume and high-diversity complexity as observed in trucks production. This research aims to discuss an assessment approach based on AHP application to rank flexibility projects. It is a multi-criteria decision method based on the Analytic Hierarchy Process (AHP). Decision-makers (88 managers) from different truck plant areas (production, logistics, quality, sales and finance) were interviewed and asked to consider lean thinking, mass customization, and agility to rank flexibility improvement projects that aim to reduce time-to-market and increase company competitiveness increase. *https://doi.org/10.13033/ijahp.v9i1.404*

[1] The authors are grateful to Professor Valerio Antonio Pamplona Salomon (UNESP) for AHP assistance during this research, and to the comments in the review process. In addition, we would like to thank the Brazilian National Research Council (CNPq) which supported this research (Proc. 309028/2015-9).

Keywords: Flexibility; lean, agility; complexity; trucks

1. Introduction

This research discusses an assessment approach based on an AHP application to rank flexibility projects in a bus and truck manufacturing plant. The selection and prioritization of such projects was based on manager's judgment, taking into consideration the company's need to support flexibility improvement and to mitigate complexity. Usually this decision process uses questionnaires with Likert scales and/or interviews. The assessment approach and flexibility factors discussed in the present research could interest operations management scholars and practitioners.

The Incomplete Pairwise Comparison algorithm – IPC was applied to assess factors that influence flexibility and to mitigate industrial operation complexity (Harker, 1987). IPC allows for far fewer judgments from experts in order to consolidate and validate findings.

This research was performed in a truck and bus chassis plant, which operates with the concept of modular consortium, where eight different partner companies work simultaneously at the same facility to handle a high-volume/large-variety portfolio, sharing investments, infrastructure, risks, responsibilities, values, and decision processes. The findings are the result of manager's (experts) judgments from the areas of production, quality, finance and information technology about flexibility, agility, mass customization and lean thinking and their influence on operation complexity.

Automotive industry models encompass a variety of different platforms, bodies and models produced in assembly lines, and result in component management complexity (Naga & Kodali, 2016). Modrak, Marton and Bednar (2015) correlated performance decrease with complexity growth. They showed evidence that product variety increases efforts to deliver faster-cheaper-better products as observed at the studied automotive plant. Slack (2005) suggests that flexibility in managing an uncertain environment enables high-performance manufacturing with reliability, speed, and low cost. Flexibility is an organizational requirement needed to handle consumer's needs, changes and an uncertain environment (Baykasoglu & Ozbakir, 2008; Boyle, 2006; Chang et al., 2007; Wahab, Wu & Lee, 2008).

The mantra of lean thinking has contributed to the improvement of industrial competitiveness grounded in waste reduction and continuous improvement (Holweg, 2006). Lean thinking and flexibility have antagonistic approaches influenced by standardization, operation complexity, supply chain, logistics risks, market dynamics, and consumer behavior changes. Based on such a dichotomous situation, the following questions arise: Which factors would enable flexibility in a high-volume / high-variety scenario? How can we prioritize or rank flexibility improvement projects based on the conflicts that exist in different areas? These questions can be addressed with a multi-criteria technique. AHP-IPC is suitable to rank improvement projects to support a company's managerial decisions, and consider trade-offs between lean thinking, agility, and mass customization.

In this context, the research findings would support the decision-making process to improve flexibility and mitigate complexity, and are aligned with the following research themes: (a) organizational agility strategies (Hallgren & Olhager, 2009), (b) lean thinking maintenance (Jeyaraman, Kee & Teo, 2010); (c) employee engagement in continuous improvement (Emiliani & Stec, 2004).

The article is organized into five sections including the introduction. Section 2 examines the basic theoretical underpinnings while discussing lean thinking, agility, flexibility, mass customization and complexity in the industrial context of high-volume and high-variety. The Analytical Hierarchy Process (AHP) with Aggregation of Individual Priorities (AIP) is also discussed. The third section addresses the methodological aspects, followed by Section 4, which presents and discusses the results; and Section 5 sets out the main conclusions and some suggestions for future research.

2. Theoretical background

Baykasoglu and Ozbakir (2008), Boyle (2006), Chang et al. (2007), MacCormack, Verganti, and Iansiti (2001), Slack (2005), and Wahab, Wu, and Lee (2008) indicate flexibility as the solution for several scenarios such as demand for quick responses and product variety in a fiercely competitive environment, tight schedules, rapidly changing consumer preferences, and high uncertainty. They suggest this allows for better design and high-performance manufacturing with reliability, speed and low costs.

Holweg (2006) states that lean thinking changed the relationship between productivity and quality in the automobile industry by connecting waste avoidance with continuous improvement. However, most Western manufacturers have not realized that Toyota's production system is an extension of their product development philosophy and not the reverse (Baines et al., 2006).

Hu et al. (2011) highlight the cause-effect relationships between variety, flexibility and complexity. Product variety influences production flexibility, which, in turn, results in complexity in the operation. Hayes and Wheelwright (1979) in their original paper do not indicate options for production systems with high volumes and large variety in traditional assembly line configurations (Figure 1).

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i1.404

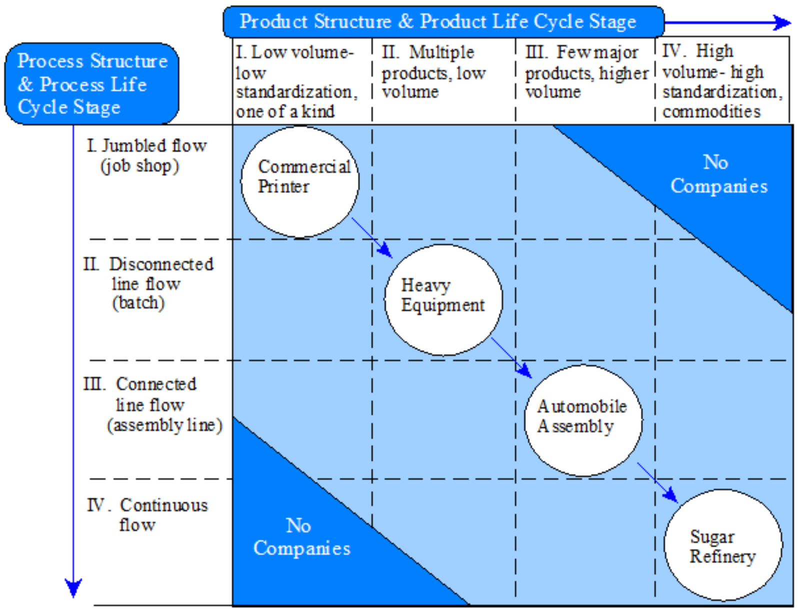

Figure 1. Traditional Process–Product matrix (Hayes and Wheelwright, 1979)

Lean thinking, flexibility, agility, and mass customization influence operations complexity in an uncertain environment as observed in their definitions:

- Flexibility is the capacity to respond to changes (Gupta & Buzacott, 1989). Kara and Kayis (2004) related flexibility to market (demand, product/technology life cycle, variety, customization, and delivery time) and/or operations (machines, materials, and manpower);
- Agility is the ability to deal with the market uncertainties and deliver goods and services with a high level of service. It is a concept related to flexibility and speed (Agarwal; Shankar & Tiwari, 2006);
- Mass customization (MC) means the production of higher product variety with cost and volume tradeoffs (Boyton, Victor & Pine II, 1993). The goal of mass customization is to create customized products, with mass production volumes, costs and competitive efficiencies (Smith et al., 2013).

With the emergence of production systems with high volumes and large variety (such as Dell Computers), the traditional Process–Product matrix was updated to include mass customization (where the truck production fits) and cellular manufacturing concepts (Hayes & Wheelwright, 1979) See Figure 2.

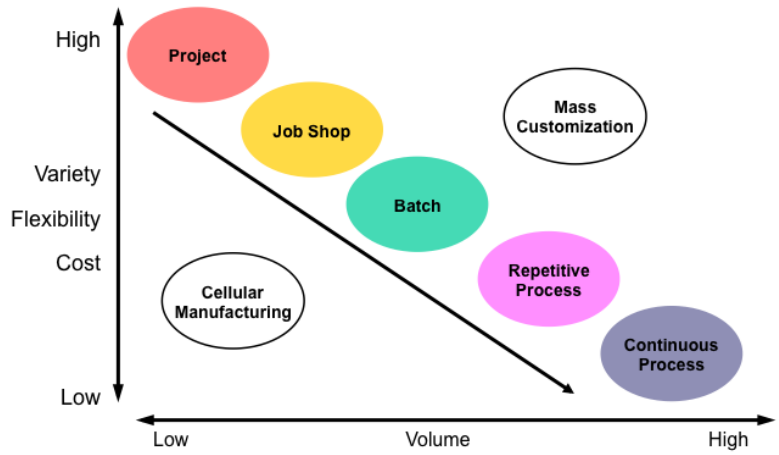

Figure 2. Updated Process–Product matrix (Swink et al., 2013)

The flexibility to provide complexity mitigation may be influenced by purchase ordering and manufacturing processes through the following factors, as described in Table 1:

- Materials ordering flexibility: Order stream and product profitability.
- Manufacturing flexibility: Supplier flexibility cost; frozen time sensivity; and supplier continuous improvement.

Table 1
Flexibility factors to commercial vehicles

Factors	Description	Authors
Purchase order stream	Waste on the order input process, aiming to reduce vehicles delivery lead time.	Leeuw, Holweg and Williams (2010) Cachon and Olivares, (2009)
Product profitability	Process regarding the lead time that affects high profitability products.	Wittel, Gustafsson and Johnson (2013) Riesenback*et al.* (2005)
Supplier flexibility cost	Costs resulting from changes in frozen (re)planning period and volume	Wang, Zhang and Ying (2007) Chen, Paulraj and Lado(2007)
Frozen time sensivity	Effects produced in supply chain by adoption of different planning materials frozen periods	Powell (2012) Wee and Wu, 2009
Suppliers continuous improvement	Lean thinking implementation program in the suppliers' line up, in order to improve the entire chain capability and reduce costs.	Kerbacheand Van Delft (2013) Guo and Xu (2007)

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i1.404

3. Methods

Bertrand and Fransoo (2002) indicated the need to validate the usability and performance of a model used in quantitative theoretical research to solve real-life operational problems. Quantitative model-based empirical research grounded this study. In the present study, the proposed construct is the Analytic Hierarchy Structure– AHS (see Figure 4). The quantitative empirical research made it feasible to test the validity of the findings and AHS with respect to real-life operational processes.

Operations management literature indicated different research methods to approach an operational flexibility decision problem. AHS conceptualization encompasses literature about lean thinking (manufacturing, administration/ office), flexibility, agility, and mass customization, Multi-Criteria Decision Methods and Analytic Hierarchy Process (AHP). Therefore, AHP was chosen to rank the factors based on expert's judgment.

Managers and staff involved in operations management (production & logistics, quality, finance, information technology, and sales, marketing & after-sales) were given an electronic questionnaire. We received 88 responses (55.7% of the population) from 1 Industrial Vice President, 6 senior managers, 10 managers, 20 supervisors, 2 coordinators, and 49 technical staff/engineers. The group that was interviewed represents a significant sample of a broad spectrum of experience in the automotive production processes.

The questionnaire (see Appendix) was based on an AHP variation called Incomplete Pairwise Comparison, which decreases the number of questions (Harker, 1987). It uses Saaty's (1991) 5-point scale, i.e.: (1) same importance; (3) low importance; (5) middle importance; (7) high importance; and (9) extreme importance.

Theoretical research results used to rank improvement projects were based on the assumption that the underlying process models are valid and the theoretical solutions are useable and will perform well (Bertrand & Fransoo, 2002). However, this belief is seldom tested because it increases research time and cost.

In the present research, AHS was used in the flexibility projects to assess the better fit between the model and reality. Focus groups validated the findings and the research instrument. Data were analyzed to rank factors using manager's judgments (experts). After that, the AHS was used to guide the actions of the flexibility projects and the managers recognized it as a robust decision-making tool. These theoretical and empirical procedures based on focus groups validated the research.

The Analytic Hierarchy Process (AHP) is a structured technique of multi-criteria decision analysis for organizing and analyzing complex decisions. Developed in the 1970s by Thomas L. Saaty, the method decomposes decision problems into a hierarchy of sub-problems and, after that, compares qualitative or quantitative data to each other, with respect to their impact on an element above them in the hierarchy tree (Saaty, 1980).

Salgado et al. (2012) indicated judgments inserted in the comparisons matrices are often based on the fundamental scale of absolute numbers (Saaty, 1980). That is, a linear scale from 1 to 9. Value 1, from that scale, is used when it was judged that both objects have the same priority. One implication of the use of the fundamental scale is that the comparison matrix will be a positive reciprocal matrix. That is $a_{ij}=1/a_{ji}$ and $a_{ij}>0$, $\forall i, j=1, 2, \ldots, n$. Therefore, x , the number of comparisons required to fulfill a comparison matrix can be obtained by Equation 1.

$$x = n(n-1)/2 \qquad (1)$$

A limitation in applying the AHP is the time required to complete all possible pairwise comparisons. A large number of comparisons is a concern when using a questionnaire based on AHP. Incomplete pairwise comparisons (IPC) is an algorithm developed to reduce the number of comparisons allowing the group to focus on the debate and decrease time used to fill in a comparison matrix (Harker, 1987). Harker (1987) explains that the two advantages that the AHP has over other multi-criteria methods are the ease of use and the ability to handle inconsistencies in judgments. Nevertheless, the author states the capability to handle such inconsistencies, based on the redundancy within the method, is also a drawback because of the amount of work required to make all of the necessary pairwise comparisons.

This research restricted pairwise comparisons to the diagonal above the main diagonal of the comparison matrix. Figure 3 shows an example of the comparisons needed when ten factors are evaluated. Using IPC, the number of comparisons in a ten-factor evaluation is reduced from 45 to 9.

a)

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	**1**	C1	C10	C18	C25	C31	C36	C40	C43	**C45**
F2		**1**	C2	C11	C19	C26	C32	C37	C41	C44
F3			**1**	C3	C12	C20	C27	C33	C38	C42
F4				**1**	C4	C13	C21	C28	C34	C39
F5					**1**	C5	C14	C22	C29	C35
F6						**1**	C6	C15	C23	C30
F7							**1**	C7	C16	C24
F8								**1**	C8	C17
F9									**1**	C9
F10										**1**

b)

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	**1**	C1								
F2		**1**	C2							
F3			**1**	C3						
F4				**1**	C4					
F5					**1**	C5				
F6						**1**	C6			
F7							**1**	C7		
F8								**1**	C8	
F9									**1**	**C9**
F10										**1**

Figure 3. AHP matrices for complete and incomplete comparisons (F are factors and C are comparisons)

Now C10 can be obtained by multiplying C1 by C2 and so on. The advantage of this approach is that inconsistency is not possible which is quite useful when dealing with survey studies.

The judgments were collected anonymously from executives of automotive companies. The data were aggregated with Aggregation of Individual Priorities – AIP, and the findings were discussed with a sample of these executives to assess the adherence with their industrial experience (Forman and Peniwati, 1998). By reducing the number of comparisons, from x to $n-1$, a greater involvement of the respondents was expected. As a matter of fact, the response was 55.7% of the population.

4. Data analysis

The Analytic Hierarchy Structure (Table 2 and Figure 4) presents the results calculated from the expert's/executive's judgments to increase flexibility based on the criteria of agility, mass customization and lean thinking. The results were aggregated based on Forman and Peniwati (1998), the aggregation of individual priorities (AIP). That is, priorities from each executive were aggregated by arithmetic mean, according to executive area (production, logistics, quality, sales, and finance).

AIP was the appropriate approach to treat the data collected because of the broad research characteristics including number of areas researched, and size of the population. More importantly, because of the use of direct judgments (first diagonal) in aggregating the priorities (AIP), and not the aggregation of estimated values of judgments based on geometric mean (AIJ), there is a greater significance to the results.

The lean office had a lower priority when compared with lean manufacturing, agility, and mass customization, but this is because the major plant focus has, so far, been given to increase the production value-added.

Table 2
Flexibility Analytic Hierarchy Structure

Objective		Flexibility Increase			
Criteria		Lean Manufacturing 32.6%	Lean Office 14,8%	Agility 27,2%	Mass Customization 25,3%
Sub-criteria	Product profitability	21.0%	22.2%	18.5%	19.9%
	Ordering stream	15.2%	22.8%	14.9%	16.0%
	Supplier continuous improvement	16.6%	13.8%	16.9%	16.5%
	Frozen time sensivity	17.1%	15.6%	12.4%	17.5%
	Suppliers flexibility cost	30.0%	25.7%	37.4%	30.1%

The lean office had a lower priority when compared with lean manufacturing, agility, and mass customization, but this is because the major plant focus has, so far, been given to increase the production value-added.

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i1.404

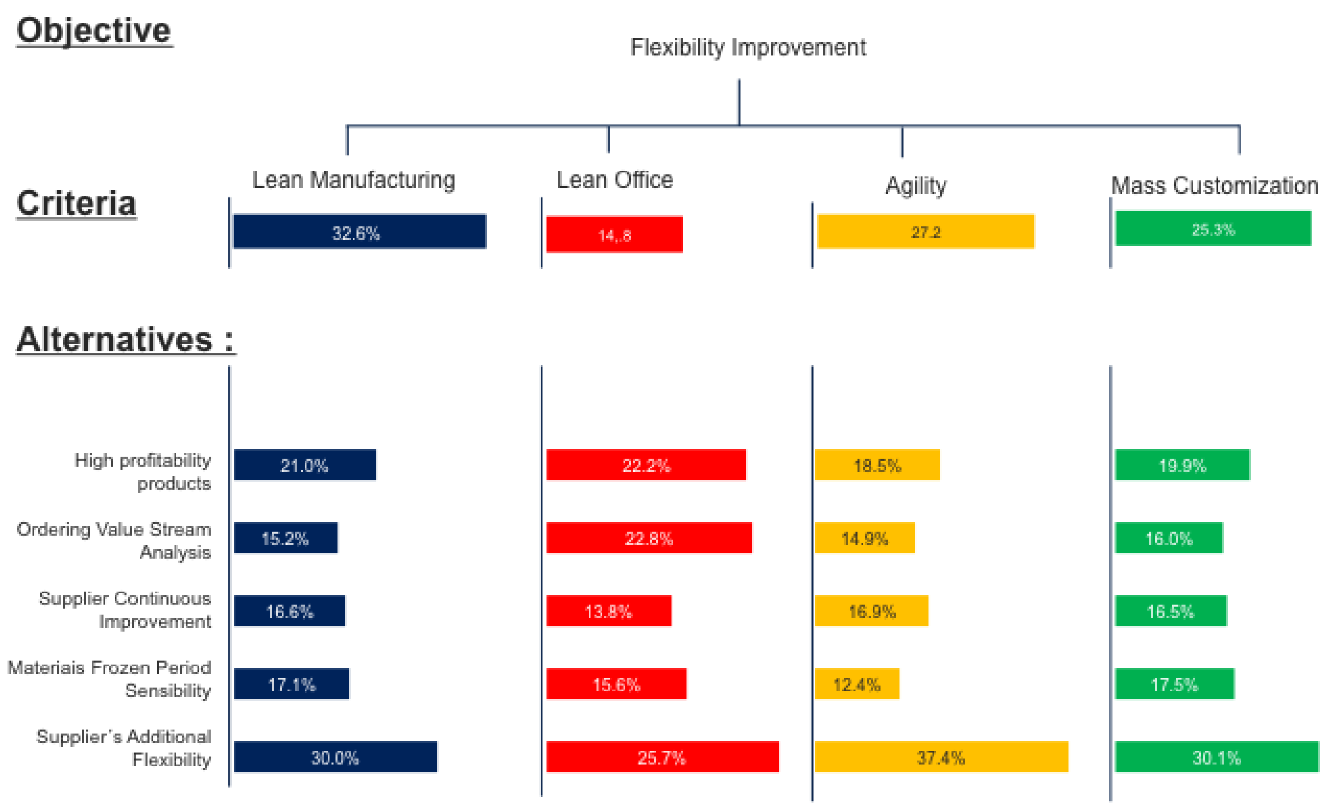

Figure 4. Analytic Hierarchy Structure to improve flexibility

The overall results of the alternatives indicate that the supplier's additional flexibility presented the greatest importance (31.4%), followed by the focus with profitability products, the analysis of ordering stream (16.5%), suppliers continuous improvement (16.2%) and frozen time sensivity (15.7%). Table 3 presents the results consolidated by industrial area.

Table 3
Areas results

Criteria	Area				
	Production	Logistics	Quality	Sales	Finance
Lean Manufacturing	37.96%	18.59%	39.59%	28.98%	34.84%
Lean Office	11.71%	10.33%	14.57%	11.95%	12.20%
Agility	26.30%	37.70%	19.35%	30.63%	27.82%
Mass Customization	24.03%	33.38%	26.48%	28.44%	25.14%
Respondents	25	19	8	18	18

The alternatives weights support project ranking to improve flexibility. The following lean thinking projects were proposed and submitted for appraisal:

(1) Make product development faster;
(2) Reduce ordering lead time; and
(3) Increase administrative service level

Such analysis reinforces Harker's statement about IPC, i.e. the time saved enables the group to focus on the debate by simplifying the work involved in making pairwise comparisons. Therefore, it gives the individual or group of decision makers more time to debate certain judgments and create different hierarchical structures for the problem, which can then be compared and synthesized (Harker, 1987).

The decision in regards to the project to be implemented was the lean office, focused on the ordering value stream. The rationale for this choice was as follows:

(1) Several lean production projects have been developed in the studied company since 2008; therefore, it is a known subject and the results have proved effective. Besides that, the principles of agility are also present in the organization by focusing on service tailored to customer needs, the pursuit of satisfaction in specific niches, which results in time-reduction activities, mainly in its supply chain.

The mass customization was recently implemented in product development; and

(2) the studied company had never tried to analyze/implement lean office techniques.

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v9i1.404

Implementation was supported by Shingijutsu Global Consulting (SGC), a global company specializing in performance increase efficiency in manufacturing, logistics and processes. SGC consultants attended to three kaizen events focused on logistics, production, and administrative processes, in which previous performance jeopardized the company's competitiveness.

4.1 Managerial implications

The results obtained led to improved implementation, discussion with the team and moderation by SGC consultants which created the conditions to reduce 30% of the frozen order placement time, reducing the time-to-market and leading customers to have a higher product value-added perception, which increased the company's service level and competitiveness.

Even though the company started lean implementation in 2008, it has, since then focused on manufacturing activities. The initiation of a lean office approach has proven the ability to unveil hidden waste-avoidance opportunities, uplift performance in time-to-market, reduce overall manufacturing throughout time and the planning horizon, all of which increased production flexibility. Positive results were recognized by senior management and evidenced in the focus group meetings.

5. Conclusions

There is a contradiction when the concepts of lean thinking and flexibility are associated. Lean thinking is based on waste elimination, standardization, and production levering resulting in cost reduction and capacity optimization; and flexibility requires the adaptation of the entire system based on a new constraint or opportunities which unbalances the lean system. However, lean thinking implementation associated with an agility program enables the enterprise to deal with uncertain scenarios and improves their flexibility.

The data analysis showed different perceptions depending on the department, even though they share the same company´s objectives regarding product conformity, parts and production flow, products delivery to customers and profit. In this case, the balance in the research participant's mix is an important part to unveiling the company global vision.

The research results highlighted the importance of lean manufacturing factors, speed, mass customization, and lean office to improve the flexibility. It also established an AHP-IPC-based model for productivity enablement projects rating and prioritization, based on the perceptions of managers and technical staff. Future research could monitor results from now on and, upon adhering to an actual trend, and be applied to other products and plants.

REFERENCES

Agarwal, A., Shankar, R., &Tiwari, M.K. (2006). Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach. *European Journal of Operational Research, 173*, 211-225. Doi: http://dx.doi.org/10.1016/j.ejor.2004.12.005

Baines, T., Lightfoot, H., Williams, G.M., & Greenough, R. (2006). State-of-the-art in lean design engineering: A literature review on white collar lean. *Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture, 220(9*), 1539-1547.

Baykasoglu, A., & Ozbakir, L. (2008). Analysing the effect of flexibility on manufacturing systems performance. *Journal of Manufacturing Technology Management. 19(2),* 172-193. Doi: http://dx.doi.org/10.1108/17410380810847909

Bertrand, J. W. M. and Fransoo, J. C. (2002). Operations management research methodologies using quantitative modeling, *International Journal of Operations & Production Management, 22(2),* 241-264 Doi: http://dx.doi.org/10.1108/01443570210414338

Boyle, T. A. (2006) Towards best management practices for implementing manufacturing flexibility. *Journal of Manufacturing Technology Management. 17(1)*, 6-21. Doi: http://dx.doi.org/10.1108/17410380610639470

Boyton, A.C., Victor, B., & Pine II, B. J. (1993). New competitive strategies: Challenges to organizations and information technology. *IBM Systems Journal, 32(1),* 40-64. Doi: 10.1147/sj.321.0040

Bozókia, S., Fülöpa, J., &Rónyaib, L. (2007). On optimal completion of incomplete pairwise comparison matrices. *Mathematical and Computer Modelling, 52(1-2)*, 318-333. Doi: http://dx.doi.org/10.1016/j.mcm.2010.02.047

Cachon, G. Olivares, M. (2010). Drivers of finished goods inventory in the U.S. automobile industry. *Management Science, 56(1),* 202-216. Doi: http://dx.doi.org/10.1287/mnsc.1090.1095

Chang, S., Lin, R., Chang, F., Chen, R. (2007). Achieving manufacturing flexibility through entrepreneurial orientation. *Industrial Management & Data Systems, 107(7),* 997-1017.Doi: http://dx.doi.org/10.1108/02635570710816711

Chen, I.J., Paulraj, A., Lado, A.A. (2004). Strategic purchasing, supply management and firm performance. *Journal of Operations Management, 22*, 505-523. Doi: http://dx.doi.org/10.1016/j.jom.2004.06.002

Emiliani, M.L, Stec, D.J. (2004). Using value stream mapping to improve leadership. *Leadership & Organization Development Journal, 25*, 622-645. Doi: http://dx.doi.org/10.1108/01437730410564979

Fedrizzia, M. &Gioveb, S. (2007). Incomplete pairwise comparison and consistency optimization. *European Journal of Operational Research, 183(1),* 303-313. Doi: http://dx.doi.org/10.1016/j.ejor.2006.09.065

Forman, E. & Peniwati, K. (1998). Aggregating individual judgments and priorities with the analytic hierarchy process. *European Journal of Operational Research, 108(1),* 165-169. Doi: 10.1016/S0377-2217(97)00244-0

Guo, Y.; Xu, Z. A. (2007). Model of lean supplier management based on the lean production. *International Federation for Information Processing, 254(1),* 717-726. Doi: 10.1007/978-0-387-75902-9_81

Gupta, D. and Buzacott, J. A. (1989). A framework for understanding flexibility of manufacturing systems. *Journal of Manufacturing Systems, 8(2),* 89-96. Doi: https://doi.org/10.1016/0278-6125(89)90028-9

Hallgren, M., Olhager, J. (2009). Lean and agile manufacturing: External and internal drivers and performance outcomes. *International Journal of Operations & Production Management, 29(10),* 976-999. Doi: http://dx.doi.org/10.1108/01443570910993456

Harker, I.J. (1987). Incomplete pairwise comparison in the Analytic Hierarchy Process. *Mathematical Modelling, 9(11),* 837-848. Doi: https://doi.org/10.1016/0270-0255(87)90503-3

Hayes, R. H., Wheelwright, S. C. (1979). Link manufacturing process and product life cycles. *Harvard Business Review*, 133-140. Doi: 10.1002/9780470618813.app3

Holweg, M. (2006). The genealogy of lean production. *Journal of Operation Management, 25(2)*, 420-437. Doi: http://dx.doi.org/10.1016/j.jom.2006.04.001

Hu, S. J., Ko, J., Weyand, L. Elmaraghy, H. A. Lien, T. K. Koren, Y., Bley, H., Chryssolouris, G., Nasr, N., Shpitalni, M. (2011). Assembly system design and operations for product variety. *CIRP Annals - Manufacturing Technology, 60(2),* 715–733. Doi: http://dx.doi.org/10.1016/j.cirp.2011.05.004

Jeyaraman, K., Kee Leo, L. (2010). A conceptual framework for critical success factors of lean six sigma. *International Journal of Lean Six Sigma. 1*, 191-215. Doi: http://dx.doi.org/10.1108/20401461011075008

Kara, S., & Kayis, B. (2004). Manufacturing flexibility and variability: An overview. *Journal of Manufacturing Technology Management, 15(6),* 466-478. Doi: http://dx.doi.org/10.1108/17410380410547870

Kerbache, L., Van Delft, C. (2014). Efficient purchaser incentive when dealing with suppliers implementing continuous improvements plans. *International Transactions in Operations Research, 21*, 673-701. Doi: 10.1111/itor.12059

Kwiesielewicz, M., van Uden, E. (2003). Ranking decision variants by subjective paired comparisons in cases with incomplete data. In: V. Kumar (Ed.), et al., Computational

Science and Its Applications–ICCSA 2003, Lecture Notes in Computer Science, 2669, Springer-Verlag, Berlin/Heidelberg, 208–215. Doi: 10.1007/3-540-44842-X_22

Leeuw, S., Holweg, M., Williams, G. (2011). The impact of descentralized control on firm-level inventory. *International Journal of Physical Distribution & Logistics Management, 41(5),* 435-456. Doi: http://dx.doi.org/10.1108/09600031111138817

MacCormack, A., Verganti, R., &Iansiti, M. (2001). Developing products on "Internet time": The anatomy of a flexible development process. *Management Science, 47(1),* 133-152. Doi: http://dx.doi.org/10.1287/mnsc.47.1.133.10663

Modrak, V., Marton, D., &Bednar, S. (2015). The influence of mass customization strategy on configuration complexity of assembly systems. *Conference of Intelligent Computation on Manufacturing Engineering (CIRP), 33,* 538-543. Doi: https://doi.org/10.1016/j.procir.2015.06.071

Naga, V. & Kodali, J.M. (2016). An empirical study for implementation of lean principles in Indian manufacturing industry. Benchmarking: *An International Journal, 23(1),*183-207.Doi: http://dx.doi.org/10.1108/BIJ-11-2013-0101

Powell, D. (2013). ERP Systems in lean production: New Insights from a review of lean and ERP literature. *International Journal of Operations & Production Management, 33(11/13),* 1490-1510. Doi: http://dx.doi.org/10.1108/IJOPM-07-2010-0195

Riesenbeck, H., Herrmann, A., Heitmann, M., Algesheimer, R. (2006). An approach to profit-maximizing product design on the basis of the platform concept. *International Journal of Quality & Reliability Management, 23(7),* 788-806. Doi: http://dx.doi.org/10.1108/02656710610679815

Saaty, T.L. (1980). The Analytic Hierarchy Process. New York, NY: McGraw-Hill. Doi: http://dx.doi.org/10.1080/00137918308956077

Salgado, E. G., Salomon, V. A. P., Carlos H. P. Mello, C. H. P. (2012). Analytic Hierarchy prioritization of new product development activities for electronics manufacturing. *International Journal of Production Research, 50(17),* 4860-4866. Doi: http://dx.doi.org/10.1080/00207543.2012.657972

Slack, N. (2005). The flexibility of manufacturing systems. *International Journal of Operations & Production Management, 25(12),* 1190-1200.

Smith, S., Smith, G.C., Jiao, R., & Chu, C. (2013). Mass customization in the product life cycle. *Journal of Intelligent Manufacturing, 24(5),* 877-885. Doi:10.1007/s10845-012-0691-0

Swink, M., Melnyk, S. A., Cooper, M. B., & Hartley, J. L (2013). Managing operations across the supply chain 2nd. ed., McGraw Hill.

Wahab, M.I. M., Wu, D. & Lee, C. (2008). A generic approach to measuring the machine flexibility of manufacturing systems. *European Journal of Operational Research, 186,* 137–149. Doi: http://dx.doi.org/10.1016/j.ejor.2007.01.052

Wang, R., Zhang, T., Ying, S. (2007). Analysis of supply chain contract on supplier flexibility. *International Conference on Management Science & Engineering*. Doi: 10.1109/ICMSE.2007.4421915 Doi: 10.1109/ICMSE.2007.4421915

Wedley. W.C. (1993). Consistency prediction for incomplete AHP matrices. *Mathematical and Computer Modelling, 17(4–5),* 151-161. Doi: https://doi.org/10.1016/0895-7177(93)90183-Y

Wee, H.M., We, S. (2009). Lean supply chain and its effect on product cost and quality: a case study on Ford Motor Company. *Supply Chain Management: an International Journal,14/15,* 335-341. Doi: http://dx.doi.org/10.1108/13598540910980242

Witell, L., Gustafsson, A., Johnson, M. (2014). The effect of customer information during new product development on profits from goods and services. *European Journal of Marketing, 48(9),* 1709-1730. Doi: http://dx.doi.org/10.1108/EJM-03-2011-0119

APPENDIX

Welcome

We are conducting a survey in the Truck Plant. You have been invited to answer this questionnaire because of your work experience and leadership. The research objective is to evaluate the factors to improve flexibility, that in your opinion, contribute to and mitigate complexity. We need your cooperation to fill it up this questionnaire. Certainly, you will respond it within minutes and this effort will be very useful to better know the shop floor and guide improvement opportunities. You can feel free to answer what you think, because the questions not involve confidential aspects of your work. You do not need to identify yourself.

Scale:

Importance Intensity	**Definition** (...from na alternative to other)
1	Equal importance
3	Little more importance
5	Somewhat Importance
7	Great Importance
9	Absolute Importance

To increase Production Flexibility, indicate the relative importance of the following strategies:

	9	7	5	3	1	3	5	7	9	
Lean Manufacturing	○	○	○	○	○	○	○	○	○	Lean Office
Lean Office	○	○	○	○	○	○	○	○	○	Agilidade
Agilidade	○	○	○	○	○	○	○	○	○	Customização em Massa

<u>The alternatives follow the same structure of questions.</u>

Interviewees' profile:

How long have you worked in this company (years)?
How long have you taken up managerial or supervisory assignment (years)?
What is your job title?

Additional Comments:

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i1.404