FLEXIBILITY ASSESSMENT TO MITIGATE COMPLEXITY: TRUCKS PRODUCTION ANALYSIS

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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. 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).
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.
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 sensitivity; and supplier continuous improvement.

Table 1
Flexibility factors to commercial vehicles

<table>
<thead>
<tr>
<th>Factors</th>
<th>Description</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product profitability</td>
<td>Process regarding the lead time that affects high profitability products.</td>
<td>Wittel, Gustafsson and Johnson (2013) Riesenbacket et al. (2005)</td>
</tr>
<tr>
<td>Supplier flexibility cost</td>
<td>Costs resulting from changes in frozen (re)planning period and volume</td>
<td>Wang, Zhang and Ying (2007) Cheral, Paulraj and Lado (2007)</td>
</tr>
<tr>
<td>Frozen time sensivity</td>
<td>Effects produced in supply chain by adoption of different planning materials frozen periods</td>
<td>Powell (2012) Wee and Wu, 2009</td>
</tr>
<tr>
<td>Suppliers continuous improvement</td>
<td>Lean thinking implementation program in the suppliers’ line up, in order to improve the entire chain capability and reduce costs.</td>
<td>Kerbach and Van Delft (2013) Guo and Xu (2007)</td>
</tr>
</tbody>
</table>
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 usable 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 subproblems 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 $a_{ij} \geq 0$, $\forall i,j=1, 2, \ldots, n$. Therefore, $x$, the number of comparisons required to fulfill a comparison matrix can be obtained by Equation 1.

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

(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.

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

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Objective</th>
<th>Flexibility Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lean Manufacturing</td>
<td>Lean Office</td>
</tr>
<tr>
<td>Product profitability</td>
<td>21.0%</td>
<td>22.2%</td>
</tr>
<tr>
<td>Ordering stream</td>
<td>15.2%</td>
<td>22.8%</td>
</tr>
<tr>
<td>Supplier continuous improvement</td>
<td>16.6%</td>
<td>13.8%</td>
</tr>
<tr>
<td>Frozen time sensitivity</td>
<td>17.1%</td>
<td>15.6%</td>
</tr>
<tr>
<td>Suppliers flexibility cost</td>
<td>30.0%</td>
<td>25.7%</td>
</tr>
</tbody>
</table>

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.
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 sensitivity (15.7%). Table 3 presents the results consolidated by industrial area.

Table 3

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Area</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Production</td>
</tr>
<tr>
<td>Lean Manufacturing</td>
<td>37.96%</td>
</tr>
<tr>
<td>Lean Office</td>
<td>11.71%</td>
</tr>
<tr>
<td>Agility</td>
<td>26.30%</td>
</tr>
<tr>
<td>Mass Customization</td>
<td>24.03%</td>
</tr>
<tr>
<td>Respondents</td>
<td>25</td>
</tr>
</tbody>
</table>

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.
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 leveraging 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


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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:

<table>
<thead>
<tr>
<th>Importance Intensity</th>
<th>Definition</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>(…from na alternative to other)</td>
</tr>
<tr>
<td>3</td>
<td>Little more importance</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Somewhat Importance</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Great Importance</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Absolute Importance</td>
<td></td>
</tr>
</tbody>
</table>

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

The alternatives follow the same structure of questions.

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: