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A Hybrid Fuzzy Model for Lean Product Development Performance Measurement

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Abstract. In the effort for manufacturing companies to meet up with the emerging consumer demands for mass customized products, many are turning to the application of lean in their product development process, and this is gradually moving from being a competitive advantage to a necessity. However, due to lack of clear understanding of the lean performance measurements, many of these companies are unable to implement and fully integrated the lean principle into their product development process. Extensive literature shows that only few studies have focus systematically on the lean product development performance (LPDP) evaluation. In order to fill this gap, the study therefore proposed a novel hybrid model based on Fuzzy Reasoning Approach (FRA), and the extension of Fuzzy-AHP and Fuzzy-TOPSIS methods for the assessment of the LPDP. Unlike the existing methods, the model considers the importance weight of each of the decision makers (Experts) since the performance criteria/attributes are required to be rated, and these experts have different level of expertise. The rating is done using a new fuzzy Likert rating scale (membership-scale) which is designed such that it can address problems resulting from information lost/distortion due to closed-form scaling and the ordinal nature of the existing Likert scale.

1. Introduction

The instability in today's market and the ever increasing and emerging demands for mass customized products by customers, are driving companies to seek for cost effective and time efficient improvements in their product development process and this have led to real pressure for the adaptation of new developmental architecture and operational parameters to remain competitive in the market. Among such developmental architecture adopted, is the integration of lean thinking in the product development process. Lean which is a way of thinking and an improvement philosophy was first developed in the Toyota Motor Company, and its primary goal was to eliminate waste from the production system, however in recent years it have been extended into the product development (PD) environment. But, due to the lack of clear understanding of the lean performance and its measurements, many companies are unable to implement and fully integrate the lean principle into their product development process successfully [1], and without a proper performance measurement, the performance level of the organizational value stream will be unknown and the specific area of improvement as it relates to the LPD program cannot be tracked [2].

In order to meet this challenges, the study therefore proposed some key LPD components (enablers) which includes, Cross-functional teams, Set-based engineering, Poka-yoke (mistake-proofing), Knowledge-based environment, Supplier integration, Value-focused planning and development, Top management support and Continuous improvement (Kaizen) culture [3]–[11] for the integration and assessment of the LPDP. Although some techniques, approaches and models have been developed over the years for the assessment of the LPDP as demonstrated in the reviewed literature below, none have successfully been able to provide an effective means of measuring the performance and its improvement in a dynamic environment, also most of the existing models and techniques were designed such that they can only assess some few aspect of the LPDP there by neglecting other area. More so, most of the models were based on quantitate metrics, hence they can only measure the result obtained by the company and cannot measure the actual LPD process. In other to fill this gap, this paper therefore propose a novel hybrid fuzzy model based on the integration of Fuzzy Reasoning Approach (FRA), and the extension of the Fuzzy-AHP and Fuzzy-TOPSIS methods for the assessment of the LPDP using the ten Lean enablers mention in the previous section. Unlike the existing methods, the model assigns weights to the decision makers (Experts) according to the level of their experience and expertise, this is to control spurious influence; also a new fuzzy Likert rating scale is introduced for the collection of data.

2. Related Literature

The effective assessment of the LPDP is an essential task for monitoring the overall product development process, identification of weak areas, and increasing the PD efficiency. The LPDP which requires the measurement of the current and desired performance level helps in determining the maturity level of the business as it relates to the LPD implementation efforts (leanness). However, few attempts have been made over the years for the development of assessment model, tool and techniques for the LPDP, among such model, tools and techniques includes; Sopelana et al [12] who developed a maturity model and self-assessment tool called SMART (Start, Motivate, Apply, Review and improve, and Transform) for the assessment of the current and desired maturity levels of organizations and to assist lean practitioners in understanding the main lean practices (opportunity areas) that are most essential for achieving an effective LPD process. However since the model was an exploratory one, in their closing remark they suggested the need for a quantitative module for the performance assessment since all the available scorecards and assessment tools for the lean product development assessment none provides a Key Performance Indicators (KPIs) to actually measure the progress made after the implementation of lean product development [12].

Other research contribution that have been made to the assessment of LPDP includes, Graebsch et al [13] addresses the level of waste in a new PD process by bringing the lean concept through an assessment system, this was done by analysing the information transferred between team members in a PD process using a paper-based value stream map, frequencies of waste drivers in information transfer and the share of waste in information transfers to evaluate the level of information waste in the PD process. Al-ashaab et al [9] presented a LPD assessment tool to help define the actual status of organizations as it relates to the integration of the lean principles using a customized five-level scale to score the different readiness levels that define the transformation into the full lean implementation. The tool which is based on radar chart was used in assessing the current and desired lean situation of an aerospace company by considering five lean enablers including Value Focus; Knowledge-Based Environment; Continuous Improvement; Chief Engineer; and Set-Based Concurrent Engineering. [14] apply a fuzzy logic model for the evaluation of the variant solutions in the product development process by diminishing the subjectivity in the evaluation process (i.e. the uncertainty in the process, incomplete information that appear in the evaluation procedure and the weighting factors), such that the assessment values are chosen subjectively, and the fuzzy logic used in the decision making process for finding the optimal solution. Lolas et al [15], present a fuzzy based model for incorporating uncertainty into the various estimations necessary for the improvement of the product development process, by introducing a new concept for the design of a reliability improvement system, such that knowledge generated during and through the product development processes are not loss but effectively utilize. In the same vain, Badizadeh and Khanmohammadi [16], proposes a model for the evaluation and the prioritization of new products development ideas using a fuzzy multi-criteria decision making methodology, and in validating the proposed model the result from the evaluation were compared with the results from a traditional AHP model, and it was concluded that the application of the proposed model would lead to a more compatible and reliable results. Ahmed [17], developed a decision support tool that is implemented based on fuzzy logic approach for assessing the maturity level of a software product line process, the maturity assessment tool is to assist organizations in making crucial managerial decisions. The implemented fuzzy logic is to help in handling the imprecise and uncertain nature of the software process variables. Also, in trying to ensure the vast amount of knowledge and information (most of which are subjective or imprecise) generated during the early stages of product development process are not loss Yadav et al [18] proposed a formal structure for capturing the product development information and knowledge by extracting the information as an improvement indices from the various design tools, experiments, and design review records such that they are treated as fuzzy numbers or linguistic variables.

3. Proposed Methodology

The general framework of the LPDP assessment approach is depicted in Figure 1. Based on the prescriptive method adopted by researchers in the reviewed literature (radar chart), the proposed LPDP assessment model will focus on using Multi-criteria analysis method, this is to allow all aspect of the LPDP to be assessed from a common platform. The LPDP assessment which is a complex multi-criteria decision making problem, involves many alternatives and criteria [19], where these alternative will be based on the core lean enablers as mention above, while the criteria will be based on the actual performance of the lean practice (i.e. efficiency, effectiveness and capability). In this study, a three phase method with procedure has been proposed; the first phase uses the FRA to evaluate the performance of the LPD process, by using a weighted fuzzy reasoning algorithm for a rule-based system based on weighted fuzzy logic such that the fuzzy true value of the different conditions are automatically evaluated. In the second phase, the FAHP method is employed in determining the relative degree of importance for the criteria. Prior to this stage, the data are collected through a questionnaire survey from Experts in the field and these experts are assigned a weight according to the level of their expertise and experience, this is to control the spurious influence of response bias. The experts weighting scale is shown in Table 1.

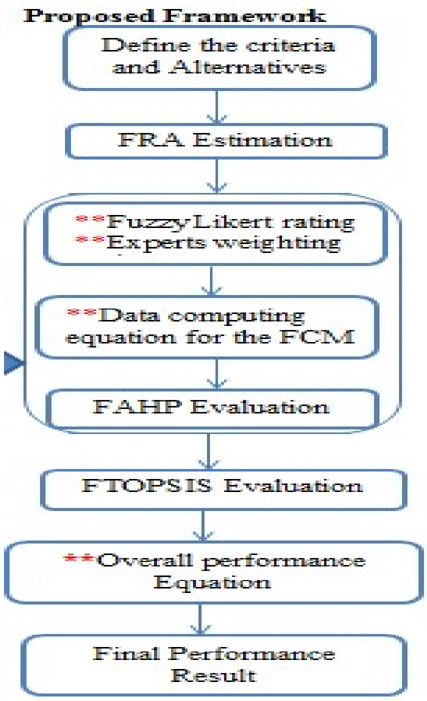

Figure 1. Framework of the LPDP assessment approach

Table 1. Experts weighting scale

Experts and their positions	Experts weight
Experts 1	0.1
Experts 2	0.2
Experts 3	0.3
Experts 4	0.4
Experts 5	0.5
Experts 6	0.6
Experts 7	0.7

The rating of the criteria is done using a modified [20] new Likert scale (see Table 2) and the resulted data are then used to compute the fuzzy comparison matrix (FCM) by bring the data through a new computing method (see equation 1), which is another contribution in this research. The FAHP method is then used to obtain the weight of lean enablers and criteria from the view point of each of the experts and with special consideration of each of their weight. While the third phase uses the FTOPSIS method for verifying and validating the rank of the alternatives and the overall performance equation is show in equation 2.

Table 2. Fuzzy Likert rating scale

Numerical rating	Description
0.1	Undecided
0.15 (or between 0.1 and 0.2)	Disagree Very Strongly
0.25 (or between 0.2 and 0.3)	Disagree Strongly
0.35 (or between 0.3 and 0.4)	Disagree Moderately
0.45 (or between 0.4 and 0.5)	Disagree Slightly
0.55 (or between 0.5 and 0.6)	Agree Slightly
0.65 (or between 0.6 and 0.7)	Agree Moderately
0.75 (or between 0.7 and 0.8)	Agree Strongly

$$Y = \begin{bmatrix} \frac{D_1W_1}{D_1W_1 + D_1W_1} & \frac{D_1W_1}{D_1W_1 + D_2W_2} & \cdots & \frac{D_1W_1}{D_1W_1 + D_nW_n} \\ \frac{D_2W_2}{D_2W_2 + D_1W_1} & \frac{D_2W_2}{D_2W_2 + D_2W_2} & \vdots & \frac{D_2W_2}{D_2W_2 + D_nW_n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{D_nW_n}{D_nW_n + D_1W_1} & \frac{D_nW_n}{D_nW_n + D_2W_2} & \cdots & \frac{D_nW_n}{D_nW_n + D_nW_n} \end{bmatrix} \quad (1)$$

$$P_{overall} = (FRA\ Score)_i * W_{(FAHP)i} * CC_{(FTOPSIS)i} \quad (2)$$

4. Conclusion and suggestions for future work

The study has introduced a novel method for the assessment of the LPDP under a common platform using a hybrid fuzzy model based on the integration of FRA, extended of FAHP and FTOPSIS algorithm. The Experts weighting scale, new computing method, and the Fuzzy Likert rating scale were introduced in this research study as an extension of the existing methods and for interfacing the methods to ensure its functionality of the model such that it is robust enough to be applied in other field for solving multi-criteria problems.

However, future research effort will be based on, characterizing in more details the Lean enablers and determining the feasibility of using them in performance assessment in an industrial scenario. Also, the verification and validation of the proposed model in solving mulita-criteria problems using a case study approach will be another challenge.

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