Analysis of Agility Performance of Supply Chain: A Case Study on Indian Automotive Manufacturer

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Abstract:
Manufacturing companies should understand the changing customer needs and expectations, access and defend the competitive pressure, anticipate and manage the uncertain demand and supply chain risk, and implement the appropriate technology to survive and excel in today’s marketplace. Therefore, they are moving away from mass production (i.e. lean supply chain) to one based on fast-responsiveness and flexibility, capitalizing on the rapid advancement in internet technologies and factory-on-demand mode of production (i.e. agile supply chain). It is observed that manufacturing companies in India in general and automotive supply chain in specific are compelled to cultivate supply chain agility for enhancing its performance level on continuous basis and comparing its supply chain agility performance with competitors to survive and sustain in the competitive business environment. Therefore, a methodology is proposed to evaluate the supply chain agility of a manufacturing supply chain and compare its performance level with competitors using Fuzzy Analytic Hierarchy Process and Taguchi Loss Function. A case study is developed and the proposed methodology is applied to Indian automotive supply chain for explaining the salient features of it.

Keywords: Supply Chain, Supply Chain Agility, Taguchi Loss Function, Fuzzy Analytic Hierarchy Process

1. Introduction
Supply chain agility enables an organization to enhance its daily operations and assists in diminishing costs, raising profitability as well as achieving competitive advantage [1], [2], [3]. Hoek et al. [4] identified four dimensions of agile supply chain practices as customer sensitivity, virtual integration, process integration and network integration. Its characteristics include but not restricted to responsiveness, flexibility, integration, competency, speed/quickness, robustness, pro-activity, innovative and cost efficient [5], [6]. It is a business-wide capability that embraces
organizational structures, information systems, logistics processes and in particular, mindsets [7]. It also addresses the rapidity of a firm in response to the key supply chain outcome measures, such as the reduction of manufacturing lead-times, the increase of new product introductions, and the improved level of customer service [8]. Manufacturing firm has to develop agility in its supply chain to satisfy ever changing customer needs and expectations, to absorb turbulent and volatile demand and to introduce quickly new products to survive, sustain and excel in the global and competitive business arena due to shifting technology, shorter product life cycle and customers who are more knowledgeable and well informed. Collin and Lorenzin [9] discussed about implementation of supply chain agility in mobile phone manufacturer. The agile companies like Zara (apparel supply chain: introduce new product only in 15 days), Seven-Eleven Japan (food supply chain: customer order is available within 12 hour at pick up sites), Dell Computers (Personal Computer (PC) supply chain for providing customized PC) and National Bicycle Industrial Company (Bicycle supply chain Japan: offers 11, 231,862 variations and delivers within two weeks at costs only 10% above standard price) have developed agility in their supply chain to become market leader [10],[11], [12]. Recently, a few studies have carried out by researchers and are reported in the literature. Malakouti et al. [13] empirically analyzed Agile Supply Chain Management (ASCM) drivers of SMEs in manufacturing-related services sector using structural equation modelling and found that entrepreneurial orientation, supplier relations, resource management, just-in-time (JIT) methodology and technology utilization positively influence ASCM while participative management style is not a predictor towards ASCM. Abdoli Bidhandi et al. [14] identified factors affecting agile supply chain and evaluated the effect of these factors on profitability in the context of Iran using the structural equation modeling technique. They found that among the supply chain agility factors, flexibility has the greatest impact on profitability followed by competency, responsiveness and speed. It is obvious that manufacturing companies require huge investments in different areas in order to enhance its supply chain agility. Therefore, supply chain agility performance of company needs to be studied, monitored and evaluated in comparison to its competitors. It will provide the right direction for investments to improve its supply chain agility. Therefore, a methodology is proposed to evaluate the supply chain agility of a manufacturing supply chain and compare its performance level with competitors using Fuzzy Analytic Hierarchy Process and Taguchi Loss Functions. A case study is developed and the proposed methodology is applied to Indian automotive supply chain for explaining the salient features of it.

2. Analysis of Agility Performance of Supply Chain

The measure problems of Supply Chain Performance Measurement (SCMPs) are lack of a clear connection with strategy and a clear distinction between metrics at different levels, lack of integration between financial and non-financial metrics, lack of comprehensive SC context, lack of identification of critical metrics etc. [15]. SCMPs are now experiencing a new life in business due to new technologies that has the capability to capture, integrate, share and analyze the information of multiple supply chain partners [16]. Many researchers have proposed various methods to analyze the performance of supply chain in general and agile supply chain in specific. Some of recent and relevant works carried is discussed. Routroy and Shankar [17] combined Fuzzy Analytic Hierarchy Process (FAHP) and Performance Value Analysis (PVA) to analyze an apparel supply chain supply chain performance along the time. The internet of things (IoT) can enhance SCPM, as it has the capability to enable real-time data collection, increase data efficiency as long as enable real-time communication within the supply chain (SC) [15]. Mishra et al. [18] critically evaluates 653 articles published over the past 22 years on green supply chain performance measures using the bibliometric and network analysis. They found that green supply
chain performance measures literature is growing exponentially, but the literature focusing on the assessment of the green supply chain performance is still underdeveloped and there is strong urge among developing economies for embracing green performance measures in supply chains. Soni and Kodali [19] presented a classification scheme for Indian manufacturing industry based on certain important parameters, i.e. Supply Chain Excellence Index (SCEI) and Business Performance Index (BPI). They found that as the BPI and SCEI of the supply chain grows, it tends to “mature” moving from undeveloped to capable to strategic or celebrity cluster. Mirghafoori et al [20] investigated the positive effects of supply chain agility on green performance in the Yazd ceramic tile manufacturing industry using structural equation modeling (SEM). They found that supply chain agility positively influences green performance by mediating organizational strategy, customer satisfaction, and financial performance.

3. Proposed methodology for the analysis of Agility Performance of Supply Chain
The combination of two different methods are reported in the literature to analyze the agility of the system in general and also few works have been observed for assessing and measuring supply chain agility in specific. The reported methods in the literature generally identify the agility performance dimensions and the performance along these dimensions are captured and analyzed in the specific environment to assess or compare the agility performance. However, hardly any method is applied to capture the loss incurred along the identified in terms of supply agility due to its non-performance. It was felt that this can be basis for developing a methodology to assess/evaluate supply chain agility considering importance of agility dimension taking input from multiple experts and find the loss incurred due to level of non-performance along different dimensions. Therefore, a methodology is proposed combing Fuzzy Analytic Hierarchy Process (FAHP) and Taguchi Loss Function (TLF) to assess agility level in different organizations. FAHP is used to calculate the impact of supply chain agility enablers on supply chain agility considering multiple experts’ judgement whereas Taguchi Loss Function associated with each SCAE amount loss incurred due to variation in target performance along that SCAE and finally, loss along SCAEs are summed to find total loss along different competing supply chains.

The step by step of algorithm is mentioned below:

Step 1 Construct single level hierarchy with SCAE considering multiple experts’ judgement and develop pair wise comparison matrix from each expert
Fix the number of experts and identify the SCAEs for the study environment. Develop Pair Wise Comparison Matrix (PWCM) for identified matrix according their importance (in a scale of 1 to 9 as mentioned in [21]). Also check the consistency [22] of the developed PWCM. Judgements are consistent if Consistency Ratio (CR) is greater than 0.1. If not, revision of judgements is required to make sure that CR stays within the acceptable range.

Step 2 Fuzzification of developed pairwise comparison matrices
The data collected in the form of PWCMs from the SCAEs are fuzzified by replacing their elemental values with the corresponding Triangular Fuzzy Numbers (TFNs) (as mentioned in Lee 2009). The TFNs corresponding to the comparison of a SCAE ‘i’ with other SCAE ‘j’ for an expert ‘k’ of SCAEs is denoted by (P_{ijk}, Q_{ijk}, R_{ijk}).

Step 3 Integration of fuzzified pair wise comparison matrices
The fuzzified PWCMs are integrated by means of geometric mean method by using the expressions shown below [23]. The resultant integrated matrix constitute of the elements in TFNs denoted by (a_{ij}, b_{ij}, c_{ij}).
Where, ‘s’ denotes the number of members in the SCAEs formed for the data collection.

Step 4  Determination of FSEs of SCAEs and Degree of Possibilities

The FSE for each SCAE ‘i’ denoted by $W_i$ is calculated [23], [24], [25], [26] as

$$W_i = \left( m^-_i, m^+_i, m^+_{i-1} \right)$$

$$= \left\{ \frac{1}{N} \sum_{j=1}^{N} a_{ij} \right\}, \left\{ \frac{1}{N} \sum_{j=1}^{N} b_{ij} \right\}, \left\{ \frac{1}{N} \sum_{j=1}^{N} c_{ij} \right\} \forall i = 1, 2, \ldots, N$$

Degree of Possibilities (DOPs) $\mu(F_i)$ [26] are calculated as

$$\mu(F_2 \geq F_i) = \begin{cases} 
1, & m_2 \geq m_1 \\
0, & m^-_1 \geq m^+_2 \\
\frac{[m^-_2 - m^+_2]}{[m^-_2 - m^-_1] - (m^-_1 - m^+_2)} & \text{otherwise}
\end{cases}$$

Step 5  Determination of weights of SCAEs

The minimum value among the DOPs ($\mu(F_i)$) of SCAE ‘i’ will be the weight of the SCAE. Then, the weight normalized of each SCAE is calculated.

Step 6  Selection of appropriate Taguchi Loss Functions along with target limits and appropriate functions for identified SCAEs

Categorize the identified SCAEs into three levels based on their nature (i.e. smaller the better or larger the better or nominal the best). Set the target limit (i.e. fix the lower limit for larger the better category and upper limit for smaller the better category whereas nominal the best category, fix both lower and upper limit) for each SCAE taking inputs from the experts’ judgment for the case environment and also select the appropriate functions (i.e. cubic, exponential and quadratic) are used.

Step 7  Determine the loss score along each SCAE

Calculate $k_4$ and/or $k_2$ using each of the functions for the SCAE under consideration. To calculate $k_4$ and/or $k_2$, loss (L) and the lower and/or upper limit have to be defined. The loss is taken 10 if the attribute limits are taken in the scale of 1-10 or else loss is considered in monetary units if the limit is taken in monetary units. Loss depends on the upper and lower limit.


- For smaller the better and loss (L) as 10, in cubic function \( k_1 = 10/y^3 \) where \( y \) is the upper limit, if the function is exponential, use \( k_1 = \ln(10)/y \) and if it is polynomial, \( k_1 = 10/y^2 \).
- If the attribute falls under larger the better category, calculate \( k_2 \) instead of \( k_4 \). Use the three types of functions to calculate \( k_2 \) and \( L \) as 10. The lower limit decided by the expert’s opinion.
- If the attribute falls under nominal the better, calculate \( k_2 \) and \( k_4 \). The lower and upper limit decided by the expert’s opinion.

Use the given functions to calculate \( k_4 \) and \( k_2 \) considering certain loss at lower limit and certain at upper limit. For example, in quadratic function, \( k_1 = c_1/(U-T)^2 \) and \( k_2 = c_2/(T-L)^2 \) where, \( c_1 \) & \( c_2 \) are loss associated with \( U \) i.e. upper limit and \( L \) i.e. lower limit.

**Step 8**  
Determine the total loss score for different automotive supply chains

Determine total loss score \( L \) for automotive supply chains for each SCAE using particular \( y \) value determined from the expert’s opinion i.e. specification limit for the particular company. \( L_{ij} \) is the loss score where ‘\( i \)’ denotes attribute number and ‘\( j \)’ denotes function number. Finally, rank the competing supply chains on the basis of total loss score and prepare the rank of the competing supply chains along each SCAE on the basis of the corresponding loss score.

4. **Analysis of Agility Performance of Supply Chain using Proposed Methodology**

In this section, the proposed methodology is applied to supply chain of three Indian Automotive Manufacturers (i.e. IAM AA, IAM BB and IAM CC and name of the companies are disguised for maintaining the confidentiality). For the purpose of data collection and analysis of agility performance of supply chain, methodology used was clearly explained to the experts. After discussing with experts, eleven Supply Chain Agility Enablers (SCAEs) (i.e. supplier’s flexibility (SCAE1), level of coordination between supply chain members(SCAE2), ability to respond rapidly to sudden changes (SCAE3), cross-functional team building capabilities(SCAE4), degree of automation and rapid changeover capabilities (SCAE5), information visibility (SCAE6), continuous skill upgradation through continuous training (SCAE7), production and delivery flexibility (SCAE8), flexibility and modularity in design (SCAE9), flexible workforce (SCAE10) and logistical capabilities (SCAE11) are identified. The importance of eleven SCAEs are captured on the scale of 1-10 (1 indicates the least performance and 10 indicates the best performance) on the basis of the experts’ judgement. To calculate the weightage of the SCAEs, FAHP algorithm was applied as discussed in the previous section. The fuzzified pair-wise comparison matrix of attributes for “Expert 1”, integrated fuzzified pair-wise matrix comparison of SCAEs for 3 experts and fuzzy synthetic extent and normalized weight of SCAE are shown Table 1, Table 2 and Table 3 respectively. The quadratic Taguchi Loss Function was used for the identified eleven SCAEs and their type (i.e. smaller the better, larger the better or nominal the best) (see Table 4). The agility losses were calculated for all the SCAEs for these three Indian automotive companies and the total loss was found by multiplying the weightage with its corresponding losses and summing all of these losses to calculate the total loss for a manufacturer. The company AA was found to have the least value of the total loss and was considered to have maximum supply chain agility in comparison to its competitors. Also performance of these three Indian Automotive Manufacturers along the SCAEs is evaluated and mentioned in Table 4.
5. Conclusions
A model is proposed using Fuzzy Analytic Hierarchy Process and Taugchi Loss Function to compare the agility performance different competing supply chains along different supply chain agility enablers. A case situation consisting of three Indian automotive manufacturer supply chains is developed and the proposed model was applied in order to explain the salient features of the proposed model considering multiple experts judgements. It was observed that Company AA has the highest agility in comparison to other two companies (i.e. Company BB was found to be third and Company CC was found to be second). The study presented an effective approach for measuring agility and this work can also be extended by introducing and applying new loss functions, analysis of mean (ANOM), analysis of variability (ANOVA) and design of experiment (DOE).

Table 1: Fuzzified pair-wise comparison matrix of attributes for “Expert 1”

| SCAE1 | (1, 1, 1) (0.25, 0.33, 0.5) (0.25, 0.33, 0.5) (1, 1, 2) (1, 1, 2) (0.25, 0.33, 0.5) (1, 1, 2) (0.25, 0.33, 0.5) (1, 2, 3) (1, 2, 3) |
|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SCAE2 | (2, 3, 4) (1, 1, 1) (1, 1, 2) (1, 2, 3) (1, 2, 3) (1, 2, 3) (3, 4, 5) (1, 1, 2) (1, 2, 3) (3, 4, 5) (3, 4, 5) |
| SCAE3 | (2, 3, 4) (0.5, 1, 1) (1, 1, 1) (1, 1, 2) (1, 2, 2) (1, 2, 3) (1, 2, 3) (1, 2, 3) (1, 2, 3) (1, 2, 3) (3, 4, 5) (3, 4, 5) |
| SCAE4 | (0.5, 1, 1) (0.333, 0.5, 1) (0.333, 0.5, 1) (1, 1, 1) (1, 1, 2) (0.25, 0.333, 0.5) (1, 2, 3) (1, 1, 2) (0.25, 0.333, 0.5) (1, 2, 3) |
| SCAE5 | (0.5, 1, 1) (0.333, 0.5, 1) (0.333, 0.5, 1) (0.5, 1, 1) (1, 1, 1) (0.25, 0.333, 0.5) (1, 2, 3) (1, 1, 2) (0.25, 0.333, 0.5) (1, 2, 3) |
| SCAE6 | (2, 3, 4) (0.5, 1, 1) (0.5, 1, 1) (2, 3, 4) (2, 3, 4) (1, 1, 1) (3, 4, 5) (1, 2, 3) (1, 2, 3) (3, 4, 5) (3, 4, 5) |
| SCAE7 | (0.333, 0.5, 1) (0.2, 0.25, 0.333) (0.2, 0.25, 0.333) (0.333, 0.5, 1) (0.333, 0.5, 1) (0.2, 0.25, 0.333) (1, 1, 1) (0.25, 0.333, 0.5) (0.167, 0.2, 0.25) (1, 1, 2) |
| SCAE8 | (0.5, 1, 1) (0.333, 0.5, 1) (0.333, 0.5, 1) (0.5, 1, 1) (0.5, 1, 1) (0.333, 0.5, 1) (2, 3, 4) (1, 1, 1) (0.25, 0.333, 0.5) (1, 2, 3) |
| SCAE9 | (2, 3, 4) (0.5, 1, 1) (0.5, 1, 1) (2, 3, 4) (2, 3, 4) (0.5, 1, 1) (4, 5, 6) (2, 3, 4) (1, 1, 1) (3, 4, 5) (3, 4, 5) |
| SCAE10 | (0.333, 0.5, 1) (0.2, 0.25, 0.333) (0.2, 0.25, 0.333) (0.333, 0.5, 1) (0.333, 0.5, 1) (0.2, 0.25, 0.333) (0.5, 1, 1) (0.333, 0.5, 1) (0.2, 0.25, 0.333) (1, 1, 1) |
| SCAE11 | (0.333, 0.5, 1) (0.2, 0.25, 0.333) (0.2, 0.25, 0.333) (0.333, 0.5, 1) (0.333, 0.5, 1) (0.2, 0.25, 0.333) (0.5, 1, 1) (0.333, 0.5, 1) (0.2, 0.25, 0.333) (1, 1, 1) |

Table 2: Integrated Fuzzified Pair-wise Matrix comparison of SCAEs for 3 experts

| SCAE1 | (1, 1, 1) (0.437, 0.55, 1) (0.437, 0.55, 1) (1, 1, 2) (1, 1, 2) (0.437, 0.55, 1) (1.26, 2.289, 3.302) (1, 1, 2) (0.437, 0.55, 1) (1.26, 2.289, 3.302) |
|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SCAE2 | (1, 1.817, 2.289) (1, 1, 1) (0.437, 0.55, 1) (0.437, 0.55, 1) (1, 1, 2) (1, 1, 2) (0.437, 0.55, 1) (1.26, 2.289, 3.302) (4.309) (1, 1.817, 2.289) |
| SCAE3 | (1, 1.817, 2.289) (0.5, 1, 1) (1, 1, 1) (1, 1.817, 2.289) (1, 1.817, 2.289) (1, 1, 2) (2.289, 3.302, 4.309) (2.289, 3.302, 4.309) |
| SCAE4 | (0.5, 1, 1) (0.382, 0.63, 1) (0.382, 0.63, 1) (1, 1, 2) (0.437, 0.55, 1) (1.26, 2.289, 3.302) (1, 1, 2) (0.437, 0.55, 1) (1.26, 2.289, 3.302) |
| SCAE5 | (0.5, 1, 1) (0.382, 0.63, 1) (0.382, 0.63, 1) (0.5, 1, 1) (1, 1, 1) (0.437, 0.55, 1) (1.26, 2.289, 3.302) (1, 1, 2) (0.437, 0.55, 1) (1.26, 2.289, 3.302) |
| SCAE6 | (1, 1.817, 2.289) (0.5, 1, 1) (0.5, 1, 1) (1, 1.817, 2.289) (1, 1.817, 2.289) (1, 1, 2) (2.289, 3.302, 4.309) (1, 1.817, 2.289) (1, 1.817, 2.289) |
| SCAE7 | (0.303, 0.437, 0.794) (0.232, 0.303, 0.437) (0.232, 0.303, 0.437) (0.303, 0.437, 0.794) (0.303, 0.437, 0.794) (0.232, 0.303, 0.437) (1, 1, 1) (0.275, 0.382, 0.63) (0.218, 0.281, 0.397) (1, 1, 2) |

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Table 3: Fuzzy synthetic extent and Normalized weight of SCAE

| SCAE  | 0.044  | 0.085  | 0.198  | 0.1   |
|-------|--------|--------|--------|-------|
| SCAE1 |        |        |        |       |
| SCAE2 | 0.068  | 0.133  | 0.285  | 0.136 |
| SCAE3 | 0.066  | 0.133  | 0.275  | 0.136 |
| SCAE4 | 0.041  | 0.086  | 0.188  | 0.099 |
| SCAE5 | 0.039  | 0.086  | 0.179  | 0.096 |
| SCAE6 | 0.064  | 0.136  | 0.26   | 0.138 |
| SCAE7 | 0.023  | 0.038  | 0.092  | 0.028 |
| SCAE8 | 0.038  | 0.088  | 0.173  | 0.096 |
| SCAE9 | 0.063  | 0.139  | 0.249  | 0.14  |
| SCAE10| 0.021  | 0.039  | 0.084  | 0.02  |
| SCAE11| 0.019  | 0.039  | 0.075  | 0.009 |

Table 4: Categorization and ranking of SCA and ranking of IAM supply chain

| SCAE   | Type | Ranking of IAMAA | Ranking of IAMBB | Ranking of IAMcc |
|--------|------|------------------|------------------|------------------|
| SCAE1  | L    | 1                | 2                | 3                |
| SCAE2  | L    | 1                | 1                | 2                |
| SCAE3  | L    | 3                | 1                | 2                |
| SCAE4  | L    | 1                | 1                | 2                |
| SCAE5  | L    | 1                | 2                | 3                |
| SCAE6  | L    | 1                | 2                | 3                |
| SCAE7  | L    | 1                | 2                | 3                |
| SCAE8  | L    | 1                | 3                | 2                |
| SCAE9  | L    | 2                | 3                | 1                |
| SCAE10 | L    | 2                | 1                | 3                |
| SCAE11 | N    | 1                | 2                | 1                |

Ranking on the basis of Taguchi Loss

1 3 2

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