**Designing an integrated decision support system to link supply chain processes performance with time to market**

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**Abstract**

This study aims to evaluate the relative importance of critical performing supply chain (SC) processes instrumental in reducing the Time to Market(TTM) of a firm by taking the case of an apparel company. An integrated decision support system based on the Fuzzy Inference System (FIS) and Analytic Hierarchy Process (AHP) has been employed to prioritize the critical strategic factors and their relevant sub-factors essential for TTM. This approach also allows determining the degree of impact of each factor on the company’s TTM. The results show the instrumental role of Plan and Deliver in SC processes in reducing the TTM. Within Plan and Deliver, the role of demand forecasting error and service quality was found to be substantial in controlling TTM. The findings of the study can be helpful for the managers and decision-makers to identify the key areas at the operational level that need to be improved and has an impact on strategic level performance, i.e., TTM. The use of a decision support system to identify the critical supply chain processes and sub-processes is the major contribution of this study.

**Keywords:** Time to market; supply chain management; fuzzy inference system; Analytic Hierarchy Process; decision support system; apparel SC

1. **Introduction**

The onslaught of competition requires firms to uplift their supply chain (SC) performance to gain competitive advantage (Craighead, Blackhurst, Rungtusanatham, & Handfield, 2007; Bo et al. 2021), which further depends upon the responsiveness of an SC to meet the customers' demands (Green, Whitten, & Inman, 2012). Several studies (e.g. Jüttner, Christopher, & Baker, 2007; Laínez et al., 2010; Green et al., 2012) consider TTM - *the time a firm takes to introduce a new product to the market after sensing the market requirement*— a significant indicator of SC performance. In literature, capabilities that help reduce TTM are a well-known phenomenon (de Oliveira Mota et al., 2021). TTM focuses on delivering products to customers in the best possible time relative to competitors. Several firms are adopting a TTM-led-SC performance strategy—*a strategy where firms try to uplift SC performance by reducing the TTM*—to compete in the increasingly competitive markets.

The adoption of the TTM strategy allows firms to capture the customers immediately and uplift the company’s market reputation. Likewise, a firm with minimum TTM can immediately seize the market opportunities and take the early mover advantage. (Kozlenkova et al., 2015). The prolonged TTM can allow competitors to take advantage of market opportunities by offering new products, technology innovation, and reaching customers before you. The firms with the state of the art processes and best products can lose their market shares and reputation if their TTM is higher than that of their competitors.

The overarching problem that firms are facing is prolonged time to markets, diluting the supply chain and the overall performance of the companies. For Imran et al., (2018), a number of firms in developing countries across various industries are striving to reduce their prolonged lead times. They attribute prolonged TTM to the upstream supply chain management, especially the lengthy processes of customs clearance. Likewise, Khan et al. (2020) argue that reducing TTM is the biggest challenge for developing countries to survive in the international market. Some of the significant sources of high TTM are considered as the lack of integration (Mubarik et al., 2020), hodge-podge ERP systems (2019), poor relationship with suppliers (2020), poor supply chain visibility, poor specification, and standardization (Dobler 2005), and inefficient logistics management.

TTM is essential for both existing products and the development of new products according to the changing market needs. Introducing a new product to the market in the shortest possible time requires better control over the product development process, which requires effective integration of all the supply chain entities across the board. Nevertheless, one of the prime sources of increasing TTM could be the lack of intra-supply chain processes integration and ineffectiveness. It construes, besides external factors, firm-specific factors e.g., lack of intra and inter-process integration, a source of increasing TTM. It implies that the supply chain processes, divided into the plan, source, make, deliver and linked with a return to make a cycle, that a firm may have an effective collaboration with its suppliers, may not have required level of integration, co-operation, and alignment to manage the supply chain processes. This situation demands a study investigating as to the issues in intra and inter-supply chain processes that contribute to the increasing TTM and offer a solution to overcome this. The present study undertakes this task by following a case study-based approach. We take the case of an apparel company of Pakistan facing high TTM and explore the factor contributing to its TTM and as to how it could be controlled. The time from the product's planning phase until it reaches the market is approximately 12 months, significantly higher than competitors. The company needs to reduce its TTM by 04 months, bringing it to 8 months, to be competitive. The selected apparel company is Pakistan’s fashion retail brand dealing with a large variety of men, women and kids apparel. The company has product lines as well, which include accessories, and footwear etc.

The study's major contribution is to determine the critical performing SC processes that have direct impact on the performance of TTM. An integrated decision support system based on Fuzzy Inference System (FIS) and Analytic Hierarchy Process (AHP) has been developed to evaluate the performance of SC processes and to explore the direct relationship between the strategic factors and their relevant sub-factors. It leads to examine the extent to which each factor contributes to the TTM. The specific research question that this study will answer is :

*RQ: How to determine the critical performing SC processes that directly impact the performance of TTM?*

In order to solve the above-mentioned problem and to achieve objectives, the remainder of the paper is organized as follows. Section 2 will provide a review of the literature. Section 3 will describe the methodological steps and their implementation in a considered apparel company. Section 4 discusses the results, and at the end, section 5 gives the conclusion, managerial implications and provides future research direction.

**2.** **Literature Review**

**2.1 Time to Market: Definitions and Rationale**

For Swamidass (2000, p.1) , *“the elapsed time between the formulation of a product concept and its introduction into the market”* is time to market. Eurenius, and Teräväinen, (2020, p.4), reiterating the same definition, denotes TTM[[1]](#footnote-1) as, “*The length of time it takes from a product being conceived until it is available for sale.”* Since the emergence of quality-cost products, TTM has become the main focus for a firm to achieve customer satisfaction and a competitive position in the market (Al-Shboul 2017; Bianchini et al.,2019). One of the major reasons for Japanese automobile providers to capture the market shares was their TTM capabilities. It mainly requires cutting down the lead times and accomplishing the tasks in reduced time (Kulwant et al., 1994; Rajesh et al. 2021)). Integration among the SC processes and between the design and production department allows a smooth flow of information, which helps a firm to reduce TTM (Kumar & Kansara, 2018), and achieve early breakeven (Takeuchi & Nonaka, 1986; Hollins & Pugh, 1990; Poornikoo & Qureshi, 2019; Eurenius, & Teräväinen, 2020 ). The reduced cost and time compression provide an edge to the firm over competitors by improving its overall speed to the market (STM) ( Juliana 2006; Yeh & Lee, 2014). A variety of different methods have been introduced earlier by researchers for time compression, such as an SC integration model (Stevens, 1989), focusing on manufacturability and product complexity (Handfield, 1993), Systems dynamics modeling, analysis, simulation for SC re-engineering (Towill, 1997) and redesigning SC focusing on the supply and distribution side (Dev, Caprihan, & Swami, 2011).

For a firm to improve TTM, it needs to focus on increasing throughput by reducing lead time, process variability, and waste, which could be done through JIT and TQM. The concurrent engineering strategy, scheduling of activities parallel and simultaneously can also play an instrumental role in reducing lead-time. It requires identifying bottlenecks throughout the SC, such as procurement, manufacturing, and distribution. Particularly procurement lead times are a significant source of excessive lead times (Perry, 1990; Weiter, 1979). To explore the causes of prolonged TTM, it is essential to look upon internal supply chain processes and their ability to integrate and coordinate (Mubarik et al., 2021). Further, it is also important to know the relative importance of each supply chain process and sub-process in shortening time to market. Such practice must trace and address the hiccups within the processes. For example, planning, the first pillar of the supply chain, comprises of series of activities and sub-processes. Successful planning requires seamless integration of all those sub-processes.

Similarly, sourcing has at least three major sub-processes, including the selection of suppliers, the actual process of procurement, and relationship management. Identifying the bottlenecks and hurdles in the ways of these sub-processes of sourcing is vital for sourcing to be effectively performed (Ali et al., 2021). For effective prioritization and identification of the vital factor contributing to TTM, Multi-Criteria Data Management (MADM) approaches are employed. The proceeding subsection briefly delineates the relevant methodology adopted to explore the objectives of the study.

**2.2 Infusion of Fuzzy Inference system and AHP for TTM**

In recent years, the Fuzzy Inference System (FIS) has been widely used as a decision-making tool in SCM. In recent past, several decision support systems have been developed using FIS (see: Wang et al. 2019). The reason being that this tool helps assess multiple criteria at the same time for effective and more accurate decision making. One more advantage of using this technique allows the use of linguistic variables that are difficult to study. Asghari and Abrishami (2014) proposed a comprehensive approach to weight suppliers using FIS that permitted several criteria and sub-criteria. Fuzzy theory lets the decision-makers convert opinions to meaningful information (Amindoust & Saghafinia, 2017). A framework was designed using the FIS approach for supplier selection in the textile industry that incorporated the sustainability issue, a greatest concern in SCM.

Aggregation via FIS as an n-ary aggregations function is in its initial stages (Kerk et al., 2021). However, several authors used FIS to different aggregate variables and evaluate overall integrated performance. The application of FIS was extended by assessing the GSCM performance of firms (Pourjavad & Shahin, 2018). The study incorporated the tool of FIS to assess the performance of green practices in four different companies and proposed potential improvements in low solid/liquid wastes, low emissions, less energy/resource utilization, and reduction in toxic materials. Poornikoo and Qureshi (2019) used fuzzy logic rules to develop a system dynamic simulation model to reduce the bullwhip effect in a spare part SC. The application of FIS can also be found in overall SC performance evaluation (Khan et al. 2018; Khan, Chaabane, and Dweiri 2019); in the supply chain, performance evaluation based on SCOR® metrics (Lima-Junior and Carpinetti, 2020); in supplier sustainability performance evaluation and selection (Khan et al. 2018); in the evaluation of overall digital supply chain readiness of an organization (Khan et al. 2021); and in warehouse performance measurement (Khan, Dweiri, and Chaabane 2016).

Similarly, the Analytic hierarchy process (AHP) is also one of the prevalent decision-making tools. It involves/ calculates the use/effect of both tangible and intangible variables. AHP is a tool that comprises a nine-point crisp scale that helps analyze the priorities and preferences among qualitative variables. Many researchers have used it for effective decision-making in SCM, such as 3PL logistics selection (Gürcan, Yazıcı, Beyca, Arslan, & Eldemir, 2016). UmaDevi, Elango, and Rajesh (2012) used the AHP approach for vendor selection that involved multiple qualitative and quantitative criteria such as cost, agility, relationship, quality and Risk avoidance. Pathania and Rasool (2017) provided insights to important parameters for an e-commerce website’s service quality by using the AHP technique and thus helping the e-commerce businesses to focus on the critical factors affecting the service quality of a website.

AHP applications with other tools and techniques can be found in several researches such as for reverse logistics service provider selection (Jain & Khan, 2017); supplier selection (Dweiri et al. 2016); multi-million contractor selection (Khan and Hosany 2016); SC performance measurement and improvement (Rehman et al. 2018); and to rank desalination plant location criteria (Dweiri, Khan, & Almulla, 2018). Lesniak et al.,(2018, p.4 ) highlight, “ *although the aim of the AHP is to capture the decision maker’s knowledge; the traditional AHP cannot fully reflect the human way of thinking*”.They further suggest using FIS to improve the robustness of the AHP. Against this backdrop, this paper suggests using an integrated Fuzzy Inference System and Analytic Hierarchy Process (FAHP) approach to develop a framework for a reduced TTM. The fusion of FIS with AHP helps to control the vagueness in decision-making. The integrated approach has been applied earlier by many researchers in various SC domains. The use of an integrated approach minimizes the risk of subjective opinions. Govindan, Mangla, & Luthra, (2017) has employed the same approach to identify the SC performance indicators. Likewise, Kumar and Kansara (2018) used the AHP and FAHP approach to prioritize the barriers of IT applications in the sugar industry, thereby identifying unorganized sector, business environment, and lack of computer literacy as the significant limitations of implementing IT applications in the sugar industry. In addition to AHP, fuzzy is also integrated with several other methods such as ISM, DEMATEL, VIKOR, multi-objective optimization, COPRAS, as well (see: Nasrollahi et al. 2021; Arabsheybani and Khasmeh, 2021; Shaikh et al. 2020; Delaram et al. 2021), that shows its suitability and compatibility.

* 1. **Research Gap**

Besides external factors, firm-specific factors e.g., lack of intra and inter-process integration, a source of increasing TTM. It implies that the supply chain processes, divided into the plan, source, make, deliver and linked with a return to make a cycle, that a firm may have an effective collaboration with its suppliers, may not have required level of integration, co-operation, and alignment to manage the supply chain processes. This situation demands a study investigating as to the issues in intra and inter-supply chain processes that contribute to the increasing TTM and offer a solution to overcome this.

Further, reducing TTM requires identifying bottlenecks throughout the SC, such as procurement, manufacturing, and distribution. Particularly procurement lead times, which are a significant source of excessive lead times.

* The literature review indicates that research on evaluation and improvement of TTM in SCs is not well-developed and a relatively new research area.
* To explore the causes of prolonged TTM, it is essential to look upon internal supply chain processes and their ability to integrate and coordinate (Mubarik et al., 2021).
* It is also important to know the relative importance of each supply chain process and sub-process in shortening time to market.
* A great deal of literature can be found on strategies to reduce the TTM and role inter-organizational integration. Yet, thirst-quenching work is missing in emerging markets, identifying the importance of SC processes and sub-processes in reducing TTM.

Against this backdrop, this study develops a decision support system based on FIS-AHP methodology for an apparel industry from Pakistan.

1. **Methodology**

Considering the project's objective and to solve the problem stated in section 1.1, our proposed methodology is divided into two phases: understanding, identification, and validation of strategic factors of considered apparel company SC. The second is to develop a decision support system to evaluate the current performance of TTM of the ABC company and identify critical strategic factors that impact TTM performance. The proposed methodology and its steps are mentioned in figure 1 below.

ABC company Visit & Interview

**Step 1:** Understanding of SC Process Flow of Case Company

Literature Review &

Expert’s Opinion

**Step 2:** Identification and Validation of Strategic Factors of Case Company

**Step 3:** Development of Hierarchal Model

Using AHP

Decision Support System Development

**Step 4:** Development of Fuzzy Inference System

Company Quantitative Data

**Step 5:** ABC company TTM Performance

Evaluation

**Step 6:** Identification of Critical Strategic Factors

**Figure 1: Proposed Methodology**

**Step 1:** **Understanding of SC Process Flow of Case Company**

This step examines the whole SC of the considered apparel industry and understands how it operates. In order to carry out a detailed analysis, a thorough study of the company’s SC processes was conducted. The data was collected using qualitative methods such as visiting their facilities (production and warehouse) and interviewing the top employees from their SC department. By studying those processes, we could map out the process flow of the considered apparel industry.

In this paper, we only considered men’s apparel as this product line is a major product of a case company. Men’s apparel includes various products such as Kameez Shalwar, Kurta, Separate Shalwar, Sherwani, Special kurta, Waistcoat, Shawls, Footwear, Turbans unstitched collection for men. ABC Company offers these products as shelf products as well as make-to-order. Thorugh study of the process flow for an apparent product of the ABC company helped us identify the essential activities involved in transforming a product from raw material to the final product delivered to the customer. The process flow of ABC company is shown in figure 2.

Demand and Supply Planning

Design Planning and Development

Fabric Selection

Pre-Production Sampling

Production

Logistics and Warehousing

Retailing

Procurement and Sampling

Figure 2: Process Flow of Case Apparel Company (Men’s Wear)

The first step in making a product (men’s wear) is its planning, which includes what, how, and when to buy a product from the supplier. It also includes design planning, variety of designs, color schemes etc. After completion of the planning, the following steps take place:

1. **Demand and Supply Planning:** A team of members forecasts the demand by analyzing the previous year’s trends and the current market situation. Further according to it the supply of products is decided. The company, according to the demand, plans the material requirement and look after the capacity and supply requirement as per the need.
2. **Design Planning and Development:** During and before the pre-production sample stage, a group of designers work on the current trend and develop different designs considering the seasonal factors and fabric. Later the number of designs are confirmed and developed according to the number of collections that are supposed to be offered in future.
3. **Fabric Selection:** The Company looks for a durable, reliable and high-quality material of fabric. This is the reason their fabric selection criteria is strictly defined.
4. **Procurement for Samples:** Fabric is purchased in bulk quantity ordered 3 months before the sourcing is done locally and 5 months if the fabric is imported.The designer chooses the fabric material like whether it should be cotton, jacquard, khaddar, karandi etc., which mostly depends on the season. Further, the strength, quality, durability, price, cost etc. are considered once the fabric is selected. During this, a small piece of around 4.5 meters is taken for design development.
5. **Pre-Production Sample:** Production is cost-oriented. Products at ABC company are mostly modified as per the cost. Some of the major costs of this stage are; trim cost, making cost, overheads, taxes, fixed costs etc. are predicted through which the production friendliness of the product is examined.
6. **Production:** After completing all of the above requirements, the production process starts and takes around 3 months of duration.
7. **Logistics and Warehouse:** The Company has centralized warehouses of all three types of inventory i.e. raw material, work in process (WIP), and finished goods, which are stored and dispatched according to the demand plan. The overall inventory that ABC company maintains is ¼ of the annual sale (of one outlet). Further, the distribution team decides how and when the units are needed to be sent to the outlets according to their requirement. Mainly, 700 units are sent to the shops, and around 500 units are kept to replenish high sales stores.
8. **Retailing:** Once the time comes to fulfill the order of different outlets, the company sends the units using 3PL i.e., third-party logistics. The ABC company has a partnership with TCS/DHL through which they send their products to its destination. However, the company also uses the 2PL and 1PL modes of logistics.

**Step 2:** Identification and Validation of Strategic Factors of Case Company

Once we understood the process flow of the considered apparel case company, we reviewed the literature to identify strategic factors that fall under the basics SC functions, Plan, Source, Make, and Deliver. In order to validate identified strategic factors and its sub-factors, the validation process has also been taken out through ABC company experts. An evaluation team of experts from the ABC company was formed. The team consisted of 11 members with main stakeholders involved in multiple departments of SC such as planning, production, warehouse, etc. Each member has vast experience in the field of SC. The details of the expert team are mentioned in table 1 below:

Table 1: Experts Profile

|  |  |  |  |
| --- | --- | --- | --- |
| No. | Department | Position | Years of Experience |
| 1 | Planning | Planning Analyst | 6 |
| 2 | Manager SC (special products) | 8 |
| 3 | SC manager | 6.5 |
| 4 | Supply Planner | 4 |
| 5 | Purchasing / Procurement | General Manager Procurement | 14 |
| 6 | Assistant Manager Procurement | 5 |
| 7 | Production / Manufacturing | General Manager production | 17 |
| 8 | Assistant Manager Operations | 4.5 |
| 9 | Logistics | Manager Warehouse & Logistics | 7 |
| 10 | Manager Distribution | 7 |
| 11 | Assistant Manager Warehouse & Logistics | 3 |

Once the team has been formed, experts were asked to validate the identified strategic factors from the literature. After meeting with them, the following strategic factors were approved by them and it’s shown in table 2.

Table 2: Identified and Validated Strategic Factors

|  |  |  |
| --- | --- | --- |
| Domain / Criteria | Brief Description | References |
| Plan (P) |  | |
| Demand Forecasting Error (P1) | Forecasting error is the deviation of actual value from the projected value and is usual, especially when the time frame is long. | (Kamalapur, 2013; and  Stevenson, 2014) |
| Material  Requirements Planning  (P2) | MRP is a planning technique used by the management of a firm to better process the manufacturing operations. | (Melnyk & Piper, 1981; Wong & Kleiner, 2001);  (Cary and Brian, 2001) |
| Supply Planning  (P3) | Supply planning includes planning of the resources in a way that satisfy customer’s needs, such as quantity of materials procured, products produced, and of products distributed. | (Albrecht, 2009) |
| Source (S) |  | |
| Strategic Partnership with Supplier (S1) | Strategic supplier partnership recognizes favourable practices for the alignment and integration of SC. It allows organizations to unite with suppliers who are eager to work for SC effectiveness. | (Agusa & Hassan, 2008; Anderson & Katz, 1998; Tsai, 2006; Vereecke & Muylle, 2006) |
| Rejection Rate  (S2) | It measures the percentage of products received from suppliers that do not meet the compliance specifications and quality requirements. | <https://www.datapine.com/kpi-examples-and-templates/procurement> |
| On-time Deliver  (S3) | On-time delivery involves the concept of timeliness and proper quantity and requires that the right material is delivered to the right place in the right quantity. | (Bertelsen & Nielsen, 1997; Salhi & Christopher, 1994) |
| Cost  (S4) | Cost is the contracted price for certain goods and services. | <http://smallbusiness.chron.com/key-performance-indicators-purchasing-department-1066.html> |
| Make (M) |  | |
| Efficiency (M1) | Efficiency is an internal measure of performance that is based on doing things right. | (Borgström, 2005; Pfeffer & Salancik, 2003; Schmenner & Swink, 1998) |
| Quality Rate (M2) | It refers to the extent of producing defect free products that satisfy the customer requirements. Imposing quality to the SC processes leads to reduction in costs as well as improves resource utilization and process efficiency. | (Beamon & Ware, 1998; Choi & Rungtusanatham, 1999; Salhi & Christopher, 1994; Sila, Ebrahimpour, & Birkholz, 2006) |
| Capacity Utilization (M3) | Capacity utilization refers to the percentage of a firm’s plant that is being used during a production cycle**.** It is a measure of production performance and is directly proportional to the manufacturing productivity of a firm. | (Demeter, Chikán, & Matyusz, 2011; Francas, Löhndorf, & Minner, 2011; Shahidul et al., 2013; Tratar, 2010) |
| Deliver (D) |  | |
| Service Quality  (D1) | The level of quality provided in services to the customers for their satisfaction is known is service quality. | (Brown & Chin, 2004; Seth, Deshmukh, & Vrat, 2005) |
| Customer Services  (D2) | Identifying and fulfilling customer needs by being pleasant and responsive at the same time is known as customer service. | (Innis & La Londe, 1994) |
| Inventory Management (D3) | Inventory stocking is practiced by companies to achieve economies of scale, protect lead-time and demand uncertainty and to improve customer service. | (Baker, 2007; Sandelands, 1997) |

**Step 3:** Development of Hierarchal Model Using AHP

To prioritize the SC criteria and their sub factors for reducing TTM, AHP technique has been used, a multi-criteria decision-making (MCDM) framework that helps simplify situations that involve multiple criteria qualitative and quantitative aspects. AHP was developed by (Saaty 1980) and widely used MCDM technique. For details of step by step AHP procedure, readers are refer to see (Saaty 2008). As per the basic AHP procedure, a hierarchical model is first developed to reduce TTM, including the goals, strategic areas, and results. The goal represents the purpose of the problem that AHP would serve.

Our goal is to prioritize factors for reducing TTM to improve its core processes and increase its efficiency. This is defined as the first level of our AHP hierarchy. Using the goal, four basic strategic areas were identified in the second level of hierarchy that are plan, source, make and deliver to achieve the objective of the problem. 13 sub-factors were identified from the strategic areas out of which 3 factors are from Plan, 4 factors are from Source, 3 factors from Make and 3 factors are from the Deliver area. These sub-factors were explored because they play a vital role in improving the basic strategic areas. These sub-factors make up the third level of hierarchy. Whereas the final level of hierarchy involves the result that yields the top most important factors to reduce TTM. Figure 3 below shows the hierarchical model for prioritizing strategic factors to reduce TTM.

Plan

**Prioritizing the Critical Success Factor to Improve Time to Market**

Source

Deliver

Make

P1

P2

P3

M1

M2

M3

D1

D2

D3

S1

S2

S3

S3

Figure 3: Hierarchical Model for Prioritizing Strategic Factors to Reduce TTM

After developing the AHP hierarchal model, the next phase was to collect data regarding the pair-wise comparison. The expert groups were directed to assign pair-wise comparisons to the strategic areas and sub-factors used in the AHP model. For this, questionnaires (see Appendix A) were developed in which a nine-point Saaty scale (mentioned in table 3) was used to prioritize the factors. The data collection form consisted of five sections that compared main criteria and their relevant sub-criteria. The experts would assign a score to each comparison using this scale. This process continued till each levels of the hierarchy and a series of judgment matrices for the strategic areas and subfactors was obtained. Discussions were also held in case of any confusion.

Table 3: Saaty Scale (Saaty, 1980)

|  |  |  |
| --- | --- | --- |
| Intensity of  Importance | Definition | Explanations |
| 1 | Equal importance | Two activities contribute equally to the objective. |
| 3 | Weak importance of one over another | Experience and judgment slightly favour one activity over another. |
| 5 | Essential or strong importance | Experience and judgment strongly favour one activity over another. |
| 7 | Demonstrated importance | An activity is favored very strongly over another and its dominance is demonstrated in practice. |
| 9 | Absolute importance | The evidence favoring one activity over another is of the highest possible order of affirmation. |
| 2,4,6,8 | Intermediate values between the two adjacent judgments | When compromise is needed. |

In order to determine the relative importance of strategic areas and subfactors, the pair-wise comparison matrices are formed. The construction of pair wise matrices involved each lower level i.e. 3rd level attribute. An element in the higher level is said to be the governing element for those in the lower level since it contributes to it. Elements in the lower level are then compared to each other based on their effect on the governing element above. This yields a square matrix of judgment known as the pair-wise comparison matrix. These comparisons are done based on which element dominates the other. These judgments are expressed as integers.

The data (judgments from experts) was then entered into the expert choice (AHP) software which yields the importance weights for each strategic area and the factors. The results for one of the sections of the data collection form are mentioned below in table 4. The data collection form consisted of five sections that compared main criteria and their relevant sub criteria. Similar matrices were formed for each comparison section of each individual respondent.

Table 4: Section of filled pair-wise matrix

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Respondent # 1 (Sample)   |  |  |  |  |  | | --- | --- | --- | --- | --- | |  | Plan | Source | Make | Deliver | | Plan |  | 5 | 7 | 5 | | Source |  |  | 4 | 4 | | Make |  |  |  | 1/3 | | Deliver |  |  |  |  | |

The final results are shown in Table 5 below.

Table 5: Strategic Criteria and Sub - Criteria Weights

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Main Criteria** | **Importance Weight (AHP)** | **Sub- Criteria** | **Local Importance Weight (AHP)** | **Global Importance Weight (AHP** |
| Plan | 0.468 | Demand Forecasting Error (P1) | 0.731 | 0.34 |
|  |  | Material Requirements Planning (P2) | 0.165 | 0.08 |
|  |  | Supply Planning (P3) | 0.104 | 0.05 |
|  |  |  |  |  |
| Source | 0.146 | Strategic Partnership with Supplier (S1) | 0.528 | 0.08 |
|  |  | Rejection Rate (S2) | 0.244 | 0.04 |
|  |  | On time Deliver (S3 | 0.171 | 0.02 |
|  |  | Cost (S4) | 0.056 | 0.01 |
|  |  |  |  |  |
| Make | 0.057 | Efficiency (M1) | 0.334 | 0.02 |
|  |  | Quality Rate (M2) | 0.553 | 0.03 |
|  |  | Capacity Utilization (M3) | 0.112 | 0.01 |
|  |  |  |  |  |
| Deliver | 0.329 | Service Quality (D1) | 0.71 | 0.23 |
|  |  | Customer Services (D2) | 0.213 | 0.07 |
|  |  | Inventory Management (D3) | 0.077 | 0.03 |

Here local importance weight means that the importance of sub-criteria with respect to only “Plan” while global importance weight means the weight of sub-criteria with respect to all considered sub-criteria.

**Step 4:** Development of Fuzzy Inference System (FIS)

In order to evaluate the current TTM performance of a considered apparel company and to know the relationship and impact of a strategic factor on TTM performance, in this step, we developed a FIS-based decision support system. FIS comprises of four main components: a fuzzification interface, a knowledge base, decision-making logic, and a defuzzification interface (Dweiri 2006; Dweiri 1999) as shown in figure 4. FIS are oriented towards numerical processing, where conventional expert systems are mainly symbolic reasoning engines (Kandel, 1992; Zadeh, 1988). For four components of FIS explanation, readers are referred to (Dweiri and Kablan 2006).

Crisp Input

Fuzification Interface

Defuzzification Interface

Crisp Output

Knowledge Base (if-then rules)

DM Logic

Fuzzy

Fuzzy

Figure 4: Fuzzy Inference System

Source: (Dweiri and Kablan 2006)

In this step, experts were asked to develop fuzzy knowledge based (if-then rules). In this study, we have used triangular membership function as it is the most widely used membership function in FIS (F. T. Dweiri & Kablan, 2006; Khan et al., 2019, 2018). We have used three points scale i.e. Low (L), Medium (M) and High (H). Experts were asked to develop if then rules. Examples of developed if-then rules are shown in table 6.

Table 6: FIS Rule Based (example)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | TTM | | | |
| Plan | Plan Wt. | | | |
|  | **L** | **M** | **H** |
| **L** | L | H | H |
| **M** | L | M | H |
| **H** | L | L | H |

These rules can be interpreted as follows:

*if “Plan” value is “M” and its weight is “H”, then “TTM” will be “H”*

*if “Plan” value is “H” and its weight is “M”, then “TTM” will be “L”*

For this study experts developed a total of 153 rules, 36 rules for evaluate TTM performance and similarly for performance of Plan, Make, and Delivery 27 rules each and for Source, 36 rules has been developed. The value of the linguistic scale for membership functions used in FIS development are shown in table 7 below.

Table 7: Linguistic Term for TTM performance evaluation

|  |  |
| --- | --- |
| Low (L) | (0, 0.25, 0.50) |
| Medium (M) | (0.25, 0.5, 0.75) |
| High (H) | (0.5, 0.75, 1.0) |

Once the rules and membership functions has been developed, we entered all the inputs such as strategic criteria and sub-criteria weights that we got from AHP (see table 5) and actual value from a ABC company of the strategic criteria and sub-criteria (see table 8) into Matlab FIS tool box. Due to confidentiality of data, ABC company provide us their strategic performance criteria value In terms of percentage.

Table 8: Strategic Criteria and Sub-criteria Value (From Case Company)

|  |  |  |
| --- | --- | --- |
| Main Criteria | Sub- Criteria | Current Performance (Value) |
| Plan | Demand Forecasting Error (P1) | 0.9 |
| Material Requirements Planning (P2) | 0.9 |
| Supply Planning (P3) | 0.9 |
|  |  |  |
| Source | Strategic Partnership with Supplier (S1) | 0.8 |
| Rejection Rate (S2) | 0.5 |
| On time Deliver (S3 | 0.5 |
| Cost (S4) | 0.6 |
|  |  |  |
| Make | Efficiency (M1) | 0.4 |
| Quality Rate (M2) | 0.8 |
| Capacity Utilization (M3) | 0.7 |
|  |  |  |
| Deliver | Service Quality (D1) | 0.8 |
| Customer Services (D2) | 0.8 |
| Inventory Management (D3) | 0.7 |

The general structure of FIS is shown in figure 5 below.

**TTM Performance**

**Main Criteria**

**Sub-Criteria**

**Knowledge Base System (If-then Rules)**

Performance of “Plan”

P1, P2, . . . PN Value and Weight

**Performance of TTM**

Performance of “Source”

**Knowledge Base System (If-then Rules)**

**Knowledge Base System (If-then Rules)**

S1, S2, . . . SN Value and Weight

**Knowledge Base System (If-then Rules)**

M1, M2, . . . MN Value and Weight

Performance of “Make”

**Knowledge Base System (If-then Rules)**

Performance of “Deliver”

D1, D2, . . . DN Value and Weight

Figure 5: General FIS for overall TTM performance

**Step 5:** ABC company TTM Performance Evaluation

In this step, we will calculate the actual performance of the TTM of the considered case company. Considered apparel company is Pakistan’s fashion retail brand established in 2002, deals in huge variety of men, women and kids apparel as well as other product lines including accessories, footwear etc. Company has 100+ outlets across the country and has 20 outlets in UK, Australia, Canada, New Zealand, UAE, Qatar and USA. Company is enjoying the position among the top 5 in Pakistan in terms of sales. We first evaluated the performance of strategic sub-criteria using the strategic sub-factor values (as shown in table 8) and its importance weights (as shown in table 5). The structure of FIS to evaluate performance pf “Plan” is shown in figure 6 below.

Knowledge Base System (If-then Rules)

27 Rules and 6 Membership Functions has been Used

P1 Value = 0.9 Weight = 0.731

Performance of “Plan” = 0.50

P2 Value = 0.9 Weight = 0.165

P3 Value = 0.9 Weight = 0.104

Figure 6: Considered ABC company Results ‘Performance of Plan"

Similarly we have calculated the performance of other strategic sub-factor which comes out to be 0.424 for “Make”, 0.69 for “Delivery,” and 0.617 for “Source”. Once we have calculated the performance of strategic sub-factor performances, we have calculated the performance of TTM of case company. By using the performance values of strategic sub-factors from figure 6 and values of source, make, and deliver which are 0.424 for “Make”, 0.69 for “Delivery” and 0.617 for “Source” and importance weight of plan, source, make and deliver (see table 5), we calculated the TTM performance of the ABC company as shown in figure 8 below. The FIS structure of overall TTM performance is shown in figure 7 below.

**Weight**

P1 = 0.731

P2 = 0.165

P3 = 0.104

**Value**

P1 = 0.9

P2 = 0.9

P3 = 0.9

**TTM Performance**

**Main Criteria**

**Sub-Criteria**

**Knowledge Base System (If-then Rules)**

**Weight**

0.468

**Value**

0.50

**Value**

0.617

**Weight**

0.146

**Value**

S1 = 0.8

S2 = 0.5

S3 = 0.5

S4 = 0.6

**Weight**

S1 = 0.528

S2 = 0.244

S3 = 0.171

S4 = 0.056

**0.381 or 38.1%**

**Knowledge Base System (If-then Rules)**

**Knowledge Base System (If-then Rules)**

**Weight**

0.057

**Value**

0.424

**Value**

M1 = 0.9

M2 = 0.9

M3 = 0.9

**Weight**

M1 = 0.334

M2 = 0.553

M3 = 0.112

**Knowledge Base System (If-then Rules)**

**Weight**

D1 = 0.71

D2 = 0.213

D3 = 0.077

**Value**

D1 = 0.9

D2 = 0.9

D3 = 0.9

**Knowledge Base System (If-then Rules)**

**Value**

0.69

**Weight**

0.329

Figure 7 : FIS for Performance of TTM

The above-mentioned FIS shows that the current performance of TTM of a considered apparel company is 38.1 %.

**Step 6:** Identification of Critical Strategic Factors

Once the performance of TTM has been calculated of a considered case company, in this step we have identified critical strategic factors and their associated sub-factors through a developed decision support system. We can easily infer from figure 7 that the most critical strategic factor is “Plan” as its importance weight is 46.8% (highest among all factors). Also, its performance is low (50%) and second last after “Make”. Similarly, for sub-factors, demand forecasting error is the overall most critical sub-factors with an importance weight of 34% (see table 5).

1. **Discussion**

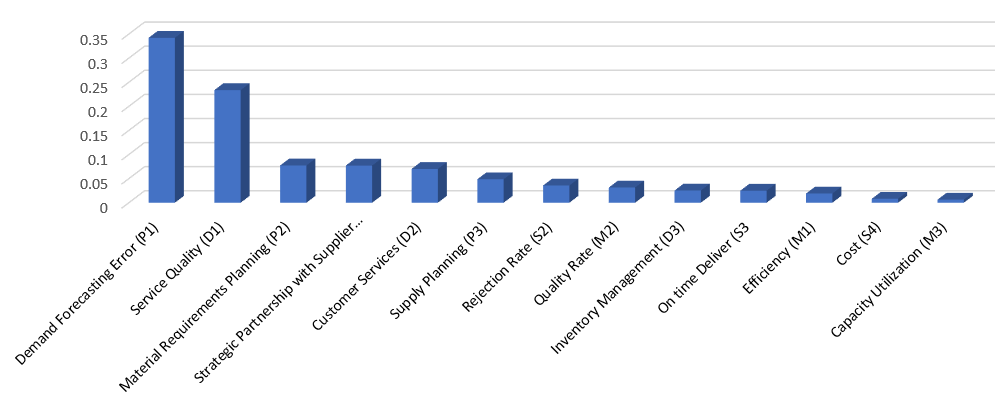
The decision support system helped the actual values (crisp input) and their relevant importance weights to process as per the rules and yield a crisp output value regarded as the performance value for the relevant criteria. Triangular membership functions were selected since it is the easiest and widely used function. Also, this type of function represents a smooth and unnoticeable transition across various states, which is natural and can be described more accurately using the triangular membership functions. Such membership functions are developed by defining the ranges and variability in data. Since the data provided by the company was in percentage form due to confidentiality issues, the range for the membership function was set to be 0-1. The crisp input (actual value combined with the importance weight for the relevant and sub criteria) was entered into the software. The input data is then converted into the degrees of memberships through a process known as fuzzification. Fuzzy IF-THEN rules are then applied to the membership function that transforms the fuzzy input into the fuzzy output. Using the process of defuzzification, a fuzzy output is then converted into a crisp output. A crisp output is one in integer or number form. Defuzzification can be done using multiple different methods but here, the weighted average method has been used.

The finding regarding the company under study shows that the overall TTM performance of ABC company is not satisfactory (38.1%) or inadequate. The company needs to focus more on its strategic factor “Plan” since it has the highest importance weight (46.8%) and has a major impact on overall TTM performance. Similarly, the least performing function is Make as its value is 42.4 %. This shows that ABC company must figure out why the make performance is low and what are the sub-factors that need special attention. This will help them to improve their overall TTM. During the planning phase, demand forecasting error is also the most important sub- factor (73.1%) that company needs to pay attention. If they will be able to improve the performance of both strategic factors, “Plan” and “Make” and sub-factory demand forecasting error, they will improve their overall TTM. Moreover, this will also help them to remain competitive and always ahead of their competitors.

1. **Conclusion**

The overall objective of this paper was to identify critical strategic factors that can reduce TTM of a company. We took an apparel company from Pakistan as a case for this study. In the first step the entire supply chain of the company was gleaned. It helped us in identifying flaws the entire process flow of ABC company. Further, to achieve the objective, this paper developed a decision support system based on a hybrid multi-criteria decision-making approach i.e., AHP and FIS. AHP was used to identify the most important factors among the considered SC functions and FIS was used to evaluate the current performance of TTM of the considered case company. A decision support system was developed into the Matlab software using the fuzzy “if-then” rules and the membership functions (Triangular). In doing so, this paper proposed an integrated decision support system based on FIS-AHP. The proposed system evaluated the current TTM performance of a considered apparel company in an emerging economy, Pakistan. The proposed system systematically integrated all the strategic criteria and their associated criteria based on four SC functions, plan, source, make and deliver. The proposed system helps in evaluating the performance of each main function and at the end it evaluates the overall TTM performance. It can be used as a framework at the early stages of the product development of any product.

* The results show the highest importance of Plan(0.46) among the four SC processes for reducing the TTM. Further Demand Forecasting Error (LW 0.73; GW0.34) appears as the most significant sub-process, which can profoundly influence the TTM of a firm.
* Deliver (0.329) appears to be the second most important SC process. The Service Quality (LW0.71; GW0.23) seems to be the most significant factor within deliver and the second most important factor among all sub-criteria factors.
* Source (0.146) and Make (0.057) appear to be the weak factors in the context of their relative affect on the TTM. The lower relative weightage of these factors do not undermine their importance in the SC process as the present study is only taking the relative significance from the perspective of TTM. Figure 9 exhibits of the relative significance of all sub-criteria factors based upon their global weights.

Figure 9: Relative Prioritization of Sub-criteria factors

We believe that this study is important and a starting point for decision-makers and researchers to know the strength and weaknesses of their entire TTM process and provides improvements opportunity.

**6. Implications**

This paper has several managerial implications and helps managers and decision-makers. Firstly, this study helps managers and decision-makers in identifying the critical and driving factor and sub-factor that has an impact on TTM performance. Secondly, the proposed decision support system allows decision-makers and managers to keep an eye on highly influential factor performance and take corrective action on time. Thirdly, proposed decision support system allows decision-makers and managers to perform sensitivity analysis and predict the performance of TTM, and set product launch date. This will also help them plan and execute their plans more organized and on time to launch the product. Further, we also suggest an effective integration of SC and marketing department to reduce their TTM. Marketing strategies and their alignment with different functions of SC determine overall performance of a supply chain. We also suggest companies to to integrate marketing strategies with supply chain strategies throughout the SC cycle to satisfy customer demand.

Despite the importance of TTM it is important to note that faster TTM may not be a guarantee of product success. There are examples where companies in the automotive industry with high-end products thrived in the market due to their superior product design and reliability, despite of slower TTM. It implies that shorter TTM at the expense of the product’s design quality or limited can prove fatal. Therefore, the manager must note that shorter TTM by attaining superior process capabilities can be key to success. Further, a well sought-after relationship with the supplier, strategic souring, comprehensive specification and standardization capabilities, and a well-mapped supply chain need to be looked for to reduce TTM.

**7. Limitations**

The result of this study is subjected to several limitations that can be overcome in the future as follows:

1. This study has been conducted at one of Pakistan’s largest fashion retail brands that deals in a huge variety of men, women and kids apparel and other product lines including accessories, footwear, etc. However, a developed decision support system considered only Men’s apparel. In future, other product variety can be consider and develop a similar decision support system.
2. Since the solution is based on the single apparel industry data, it might not be applicable for every product industry and cannot be generalized either. In the future, a generalized decision support system can be developed by considering similar product variety from other fashion retailers.
3. Provided data was in percentage (due to confidentiality); however, in the future, ABC company can run the developed decision support system with actual value and keep track of their TTM performance.

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1. *The term TTM has been used throughout the paper to represent focus of a firm to reduce time to market.* [↑](#footnote-ref-1)