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INTEGRATED APPROACH TO MULTI-CRITERIA DECISION MAKING FOR SUSTAINABLE PRODUCT DEVELOPMENT

Abstract: *New product developments are a moving target which become increasing complex due to a number of factors some known and others unknown. NPD is an interdisciplinary activity that transforms a market opportunity and technological concept to a successful product. The key steps towards creating a winning product must include a robust product strategy taking into consideration the positioning options, its viability and adopting a flexible development approach. The lack of structure to the allocation of product development resources causes customer expectations to get lost, in the complexity of the product development process. The replication of strategy and methods for a successful product may not guarantee success. Fuzzy Multi-criteria decision analysis (MCDA) methods namely the analytic hierarchy process, analytic network process, technique for order preference by similarity to ideal solutions (TOPSIS) and Elimination and choice translating reality (ELECTRE) offer valuable tools to handle complex situations incorporating the imprecise and uncertain information. As each method has its strengths it may be proper to explore and adapt different techniques according to product for sustainable development. Company should be able to put together the combination of features and value that unlocks a profitable new market.*

Keywords: *New product development (NPD), Fuzzy Multi-criteria decision modeling (MCDM), TOPSIS, AHP, ANP, ELECTRE, GRA, Vikor, Goal programming*

1. Introduction

To create new products and services that significantly and positively impact a company's bottom line, companies must involve the customer fully and make use of insightful customer feedback and findings appropriately. Developing winning products is one of the biggest challenges facing the enterprises and entrepreneurs. Products are at the core of a company's business as they are the drivers of growth, engines of success and rank supreme in terms of the tangible output that defines an organization. The customers may not know what they want or may be reluctant to commit when needed or they may change their requirements mid-stream in the development process. According to Deloitte Touche Tohmatsu study (Deloitte, 2012), over 89% of

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manufacturing companies globally viewed new products as the leading driver of future growth.

Despite management support many projects fail to complete within budget, deliver within schedule, and fulfil quality expectations or financial goals. The key steps towards creating a winning product include defining of a robust product strategy after understanding the positioning options for the product concept. A flexible development approach must be adopted after assessing high-level viability in synchronization with potential lead customers (List, 2002). One particular situation has puzzled many companies is that even though it can be very successful in one project, it is difficult, if not impossible to sustain and replicate such success to other projects within the same organization.

According to Cooper and Kleinschmidt (Cooper and Kleinschidt, 2007) the critical success factors for new product development consists of Strategic product innovation strategy, Product-differentiated with unique benefits, value for the customer, product definition-before development, People culture and climate, accountable, dedicated, supported cross functional teams, role of senior management, international orientation and global products, Portfolio management and resource allocation, proficiently planned and executed launch, NPD process using Stage Gate approach, gates-funnels not tunnels. An important part before the launch of new product is to estimate the market size so that plans can be worked out and resources allocated.

There are various methods for estimating market size and take up rate which include:

1. Test marketing
2. Expeditionary marketing
3. Simulations
4. Monitoring and Response techniques
5. Delphi method
6. Forecasting
7. Pugh Concept Selection.

It is important for the success of new product development for companies to understand the customers and design products as per their needs. It must be realized that no matter how well-intentioned the company's internal expertise, when defining a product there is no substitute to direct customer interaction. After all the company exists to serve a customer need in a manner that satisfies the requirements of the stake holders, including employees and investors.

Following methods are being used to explore, understand and address customer needs, synchronize with industrial requirements and for validation:

1. Empathic design
2. Alien interviewing
3. Voice of customer, Vocalyst (MIT Sloan School of management)
4. Co-discovery conference (List. 2002)
5. Ethnography, ZMET (Zaltman Metaphor Elicitation Technique)
6. Information acceleration
7. Co-opting Customer Competence (Prahlad and Ramaswami. 2003)
8. Morphological Analysis
9. Kano's Model, Quality function deployment(QFD) (Karsak *et al.*, 2002; Soota *et al.* 2011; Wang and Chen, 2012)
10. KJ method
11. Conjoint analysis
12. Six sigma, Design for X etc

Rapidly altering products demand has resulted in companies resorting to different tools and methodologies for addressing the customer needs. As per Kano's model, consumers may be provided an opportunity to explore their own combination of products and services to satisfy their specific needs and desires. The multiple criteria decision making (MCDM) is an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter (Belton, and Stewart, 2002) There are methods that can help to define and implement a strategy for integrated approach, but which ones to focus on and how to apply them is not well defined.

2. Challenges to new product development

Developing winning products is one of the biggest challenges facing the enterprises and approximately half of all the new products fail in the marketplace (Lynn and Reilly, 2002). Products are at the core of a company's business as they are the drivers of growth, engines of success and rank supreme in terms of the tangible output that defines an organization. A company's vision and strategy are manifested in its products and their success is the sustenance an organization needs in order to survive and prosper. New products are proven to be the driving force behind change and renewal at the corporate level (Daugherty, 1992). Eisehnhardt and Tabrizi (Eisehnardt and Tabrizi. 1996) also postulate that regular product introduction into the marketplace is the most effective way of turning change into an endemic and continuous process.

New product development (NPD) is the true manifestation of a companys business strategy. The new innovations are enabling companies to gear up to attack almost all business verticals with intelligent solutions that could soon change the way business are being conducted. Converging technologies are causing industry boundaries to shift and blur changing the very nature of products and services. Digitization has enabled the combination of features and functions of traditional industries and products in a myriad of new ways (Prahlad and Ramaswami, 2003). In almost every industry the distinct identities of products, services, channels, industries and companies are rapidly disappearing. Companies are discovering that neither value nor novelty can any longer be successfully and sustainably generated through a company centric product and service focused perspective.

A new concept called co-creation is evolving in frontiers of experienced innovation which allows individual customers to actively co-construct their own consumption experiences through personalized interaction thereby creating unique value for themselves (Prahlad and Ramaswami, 2003). A telephone today is a multi-utility tool used as an surfing device, a text/multimedia messenger, an electronic organizer, camera, a handheld computer, etc. The introduction of `I-phone' by Apple and Tablets are enabling users synchronize with PC for organizing, texting, emailing, surfing, listening, and watching faster.

2.1 Product requirements a moving target

The new business environment today consists of high growth and innovative industries where organizations have to develop capabilities that allow them to be very flexible and agile, and at the same time, be able to incorporate new product and process technologies that enable them to develop and exploit better practices. This flexibility and agility calls for companies to increase their effectiveness, exploit synergies, and learn throughout the areas of their operations. Companies are able to encroach upon other industries to create new product space and expand the markets they serve (Prahlad and Ramaswami, 2003). Consumers can explore their own combination of products and services to satisfy their specific needs and desires. New product developments are a moving target which become increasing complex due to a number of factors some known and others unknown. The customers may not know what they want or may be reluctant to commit when needed or they may change their requirements mid-stream in the development process. The suppliers may fail to deliver to specifications or may try to encroach the position in the value chain. These factors result in uncertainty being almost a constant phenomenon throughout the development process and success being rarely a reasonably sure outcome.

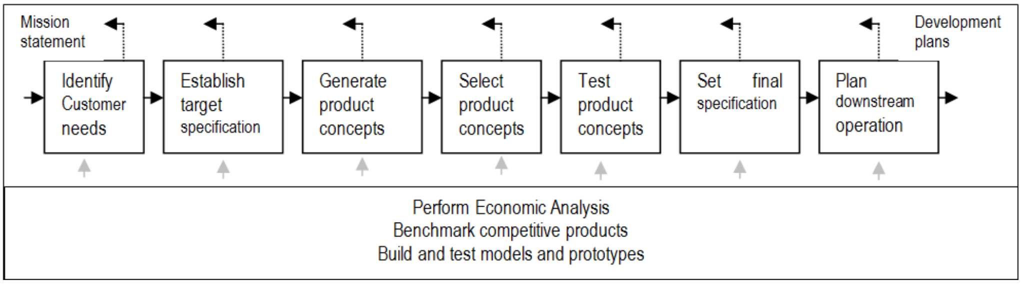

Figure 1. Front end activities in concept development phase

Most firms view new product development (NPD) as an end-to-end process that draws on marketing, engineering, manufacturing, and organizational development. The process has been used at Xerox and advocated by the Center for Innovation in Product Development (Seering, 1998). It summarizes the five external challenges on the outer square affecting product development and highlights opportunities for research. For example, speed to market might be more critical in the highly competitive world of Internet software. Front end activities in the concept development phase have been have been shown in the figure. Firms that continuously and efficiently generate new products that are in tune with their end customers needs and wants are more likely to succed. Direct communication with customers allows firms to learn from customers and tailor products to their requirements. An integrated approach of marketing, engineering, and process tools enables the end-to-end product development process to be both more efficient and effective.

3. Conception of ideas

A transformation can be seen in all the emerging areas of technology with disappearing boundaries between products and services. Companies are able to transcend upon other industries to create new product space and expand the markets they serve. Innovation is fueling the conversion of imagination into reality. Imagine a refrigerator that tells what's not in store, a wardrobe that informs which shirt is not back from laundry, a microwave that starts readying a hot stuff as soon as a person lands at home airport, a drug shelf that lets one know about which drug needs to be called in, a truck that tells which packet was left out, a pace maker that enables virtual visits by allowing physicians to check patients with implanted cardiac devices via internet, a vehicle which guides the passenger to correct path using satellite data has access to all internal sensors monitors vehicle functions to provide assistance as and when required, helps in tracking when stolen, can detect accidents site and find help. It is seen that relatively few products fail after product design specification has been compiled. This is obvious since only after the specification has been written, it is possible to identify the concept.

A wide variety of ideation methods have been proposed from to harness creativeity, as listed below:

1. Brainstorming
2. Synectics
3. Morphological analysis
4. Theory of Inventive programming(TRIZ)-Altschuler (Altschuler, 1996)

5. Strenghths-weakness-opportunities-threats (SWOT) analysis
6. Nominal group technique (NGT)
7. Lead users
8. Kanos model
9. Lateral thinking
10. Templates for product change
11. Idealyst (MIT Sloan School of management)
12. Vocalyst
13. Scenario planning, etc.

Altschuler (Altschuler, 1996) analysed tens of thousands of patents and noticed that their genius was in applying inventive principles to resolve tradeoffs between a limited set of competing physical properties. He organized the patents according to the fundamental tradeoffs they resolved, and created tables so that future designers could apply the inventive principles to similar problems (TRIZ).

Despite declaring the launch of new products and services as their top growth focus, most of the companies lack the capabilities for setting and executing a profitable growth strategy through innovation. A major reason is that their operational priorities and capabilities and plans for introducing new products are rarely aligned with their strategies for growth. But by building solid capabilities for creation, evaluation, and synchronization of innovation efforts, they are forging ahead on a path for profitable growth.

4. Sustain competitiveness

Introducing new products to markets is like venturing into unknown area. The majority of customers are reluctant to invest in nascent products as is visible from the history of adoption patterns across industries. The new products face considerable barriers to success having to demonstrate measurable improvements over the status quo to overcome the inherent skepticism of all new things. This suggests that the failure lies in the original market research in `concept vulnerability' or in the way final product is marketed [29]. The most common reason for product failure was found to be overwhelmingly due to inadequate market analysis. Research evidence suggests that companies waste upto one-third of the turnover on getting product right second or third time (redesign and firefighting). Conversely for the product success correct identification of existing demand was a common ingredient ‘although there were no easy explanations for what makes new product a success'.

A new product can address the needs of an existing market or be used to create a new market. Selling into an existing market requires more than just marginal improvements over the status quo value proposition. Customers typically opt for lesser value provided by stable products or companies. Simnilarly, selling into an as yet undefined market requires significant investments in educating potential customers on the product's potential value scheme. It can be ascertained that new products are more likely to be successful if the company understands user requirements and provides 'market pull’type products.

Developing new products that demonstrate the distinctive business approach is one of the few sustainable growth strategies which can be adopted. There should be clarity on what to build and what to buy. Components should be identified to develop internally and those to source externally and create the necessary supply chain relationships. To develop the product it is required to create the prioritized set of requirements, generate the project plans, and assemble the team with the ongoing feedback from lead customers. Finding the right lead customer is the critical first step and customer should have sufficient clout and dominance in the market being pursued so as to maximize exposure and potential demand for the new product.

5. Balancing trade-offs

New product development is a balancing act between what a company can deliver, when it can deliver, and how much money it can make. Developing new products that simultaneously satisfy customer requirements and corporate objectives is a difficult task. An organization has a number of basic functions one of them is to develop products that cater to a market need and provide the necessary return on their investment. The flexibility required to accomplish this, coupled with the inherent uncertainty of success, make developing winning products a risk-intensive undertaking that must be carefully planned for and managed. The successful product development is viewed by both industry and academia as an integrated process involving tradeoffs between time to market, production cost, development cost and customer satisfaction. Though each of these is required through the path of total quality management, yet none is viewed as a guarantee of success. NPD is about creating a value proposition, consisting of price, performance, and features that will resonate with the potential customers. Striking a balance between these is required to define a set of product requirements is complex due to a number of factors. Poorly defined customer needs, insufficient resources, lack of business strategy, poor execution, lack of executive support are major reasons for product failures.

6. Multi-Criteria Decision Making

Product planning is a complex issue which takes technical, economic, environmental and social attributes into account. The multiple criteria decision analysis is critical to evaluate new product development success (Ayag and Özdemir, 2011). Selection of the best product or alternative requires the consideration of conflicting quantitative and qualitative evaluation criteria. MCDM has also become a popular and common tool in the literature especially in problems with conflicting objectives. Multi Criteria Decision Making (MCDM) is an important branch of operation research with aim to design mathematical and computational tools for selection of the best alternative with respect to specific criteria by a decision maker or a group. MCDA provides different ways of disaggregating a complex problem, of measuring the extent to which options achieve objectives, of weighting the objectives, and of reassembling the pieces. Multi-attribute decision making (MADM) are normally problems with limited number of alternatives, with the alternatives being represented in terms of attributes. Multi Objective decision making (MODM) involve number of feasible alternative, through the use of decision variables, where the objectives and the constraints are functionally related to the decision variables. Comparison of MODM and MADM have been shown in table 1. MCDM classification has been shown in the figure 2 below. The MCDA methods can also be classified into the some broad categories form Value measurement models- AHP and multi-attribute utility theory (MAUT), Goal, aspiration and reference level models - Goal programming (GP) and TOPSIS, Outranking models-ELECTRE and PROMETHEE.

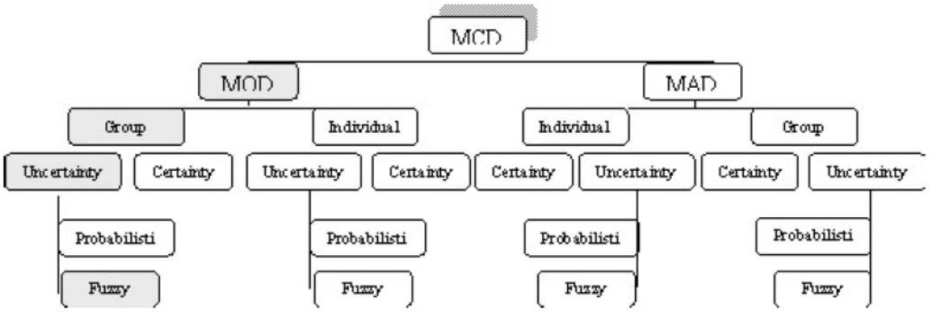

Figure 2. MCDM Classification (Azadi *et al.*, 2009)

Table 1. Comparison of MODM and MADM (Azadi *et al*., 2009)

Items	MODM	MADM
Deal with	Resource trait	Evaluation/choice
Nature of decision	Continuous	Discrete
Alternatives	Non-predefined	Predefined
Criteria defined by	Objectives	Attributes
Objectives defined	Explicitly	Implicitly
Attributes defined	Implicitly	Explicitly
Constraints defined	Explicitly	Implicitly
Alternatives defined	Implicitly	Explicitly
Number of alternatives	Infinite (large)	Finite (small)
Decision maker's control	Significant	Limited
Decision modeling paradigm	Process-oriented	Outcome-oriented
Problem solving by	Optimizing programming	Ranking

2.1 Product requirements a moving target

Some major MCDM techniques have been given below along with recent applications:

- *Analytic Hierarchy Process (AHP)* was found by Thomas L. Saaty (2000) and is a popular and widely used method for multi criteria decision making, which allows the use of qualitative as well as quantitative criteria in evaluation of alternatives.
- *Analytic Network Process (ANP)* was proposed by Thomas L. Saaty (2000) and it is a more comprehensive decision making Technique. It is an extension of AHP where it tries to solve the problem of dependence and feedback among criteria.
- *Fuzzy* logic concept was introduced by Zadeh, emphasizes on approximate values rather than precise ones. It is used in different applications along with various approaches like AHP, ANP, QFD, Topsis, etc.
- *Technique for Order of Preferences by Similarity to Ideal Solution (TOPSIS)* Hwang and Yoon developed TOPSIS for evaluating and chooses alternatives having the shortest distance from positive ideal solution and the farthest distance from the negative ideal solution.

- *Data Envelopment Analysis (DEA)* is used for framework for comprehensive performance measurement of multiple decisions making when having multi inputs and outputs.
- *Elimination and Choice Expressing Reality (ELECTRE)* was expressed by Roy (1991) and his colleagues at SEMA Consultancy Company and then evolved into ELECTRE I, ELECTRE II, ELECTRE III, ELECTRE IV, ELECTRE IS and ELECTRE TRI (ELECTRE Tree). This method consists of two sets of parameters: importance coefficient and the veto thresholds.
- *Grey Relational Analysis (GRA)* It was used by Deng (2005) initially and needs grey relational degree calculated based on changing alternatives into comparable sequences and defining an ideal target sequence.
- *Vikor method* was developed by Opricovic and its goal is to find the closest solution to ideal. It used for solving decision making problems with conflicting and non-commensurable criteria,
- *Decision Making Trial and Evaluation Laboratory (DEMATEL)* The DEMATEL method originated from the Geneva Research Centre of the Battelle Memorial Institute is especially pragmatic to visualize the structure of complicated causal relationships (Buyukozkan and Cifci, 6). It projects the relationships with matrices or diagraphs visualizing a contextual relation between the elements of the system and represents the strength of influence by a numeral.
- *Goal Programming is* an extension of linear Programming to solve problems containing multiple and usually conflicting objects.

Table 2. Major MCDM developments in chronological order along with author, year and applications

MCDM Technique	***Authors (Year)***	***Applications***
MADM Fuzzy	Belton and Stewart (2002)	Integrated approach to MCDA
	Rao (2006)	DSS for Machine group selection
	Rao and Patel (2010)	Material Selection using integrated MADM
	Kabir and Hasin (2011)	Quality improvement of synthetic fibre using fuzzy qfd
	Pohekar and Ramachandran (2013)	Renewable and Sustainable Energy Reviews
AHP ANP QFD Fuzzy	Triantaphyllou (2000)	Comparison of MCDM approaches
	Soota *et al*. (2008)	Product development using hybrid QFD
	Onut *et al*. (2008)	Hybrid Fuzzy MCDM Machine Tool Selection
	Soota *et al*. (2011)	Framework for New product development
	Ayag *et al*. (2011)	Intelligent fuzzy ANP for Tool Selection Industry

	Tadic *et al*. (2010)	ELV Dismantling Selection
	Shahraudi and Rauydel (2012)	Fuzzy ANP Topsis for auto supplier selection
Topsis Fuzzy	Kahraman (2008)	Fuzzy Modeling for Industrial Robots
	Rao and Patel (2010)	Decision making in Manufacturing Environment
	Kumar and Das (2012)	Alternative selection approach
DEA	Liu (2008)	Flexible manufacturing system(FMS) selection
Promethee	Chaterjee *et al*. (2014)	Effect of Normalization Norms in Flexible manufacturing system selection
Electra	Roy (1991)	Outranking for ranking alternatives
	Chatterjee *et al*. (2011)	Supplier selection using vikor and electra
COPRAS	Kaklaukas *et al*. (2006)	Selection of low e-tribute in retrofit of public building
WEDBA	Rao and Singh (2012)	Optimal facility layout design
Grey	Deng (2005)	Grey Approach to problem solving
	Rao (2013)	Grey approach
Vikor Method	Chatterjee *et al*. (2011)	Supplier selection using vikor and electra
	Rao (2013)	Vikor Method
DEMATEL	Rao and Padmanabhan (2006)	Industrial Robot selection
	Buyukozkan and Cifci (2011)	Novel hybrid MCDM approach to evaluate green supplier
	Wang and Chen (2012)	Collaborative product design and optimal selection of module mix
MAUT	Csaki *et al*. (1995)	WINGDSS for windows based group DSS
Preference selection index method	Maniya and Bhatt (2011)	Selection of Flexible Manufacturing system
Goal Programming	Karsak *et al*. (2002)	QFD, ANP for product planning
	Kumar *et al*. (2004)	Fuzzy vendor selection approach using optimal parameters

Multi-criteria analysis methods have been applied in various ways including Goal programming (Karsak *et al.*, 2002; Kumar *et al.*, 2004) and the Analytic hierarchy process (AHP), Analytical network process (ANP) (Agarwal *et al.*, 1991; Karsak *et al.*, 2002; Ravi and Mukherjee, 2006; Onut *et al.*, 2008; Saaty, 2000; Soota *et al.*, 2008; Soota *et al.*, 2011; Triantaphyllou, 2000), Topsis (Kahraman, 2008; Kumar and Das, 2012; Rao and Patel, 2010), Elimination and choice translating reality (ELECTRE) (Chatterjee *et al.*, 2011; Roy, 1991), Decision support system (DSS), etc. It has been used in variety of problems from tool selection (Ayag, and Özdemir, 2011) supplier selection (Chatterjee *et al.*, 2011; Kumar *et al.*, 2004), strategy evaluation of alternatives (Kahraman, 2008; Rao, 2013), location selection (Rao and Singh, 2012), robot selection (Agarwal *et al.*, 1991), product development (Kumar *et al.*, 2004; Soota *et al.*, 2011), Renewable and Sustainable Energy (Pohekar and Ramaschandran, 2004), etc. Belton and Stewart (2002) have used an integrated approach to multi criteria analysis. Fuzzy decision support system used in the early phases of the fuzzy front end of innovation in product development may yield significant results. The replication of strategy and methods for a successful product may not guarantee success.

One of the important aspects of solving MCDM problems is the precise evaluation of the information in quantitative or crisp form. However, MCDM problems may become very complex when the relative importance of decision criteria and scores of alternatives with respect to criteria are to be quantified precisely. Most of the real-life MCDM problems, often involve fuzzy information about the criteria and alternatives. Traditional MCDM methods namely weighted sum (WSM) and product model (WPM), Analytic Network Process (ANP), Technique for order preference by similarity to ideal solutions (TOPSIS) and Elimination and choice translating reality (ELECTRE) fail to handle the uncertainty of information. Fuzzy multi-criteria analysis methods offer valuable tools to handle such complex situations incorporating the uncertainty in case of subjective, incomplete, and vague information. As each method has its strengths and weakness it may be proper to explore and adapt different techniques according to product for sustainable development.

Triantaphyllou (2000) evaluated the relative efficacy of fuzzy MCDM techniques, namely Fuzzy WSM, fuzzy WPM, Fuzzy AHP, fuzzy RAHP, fuzzy TOPSIS, etc. Kahraman (2008) demonstrated the use of fuzzy AHP in multi-criteria supplier selection problem. Agarwal (1991) used it for computer aided Robot selection. Nagahanumaiah (2006) demonstrated the use of fuzzy AHP for manufacturability analysis of molds by rapid tooling methods, based on aspects like mold feature manufacturability, compatibility and cost effectiveness. Ayag and Ozdemir (2011) presented a MCDM model for machine tool selection problem. Onut [26] uses an integrated approach in fuzzy environment for the evaluation and selection of machining centers for a manufacturing company to rank the feasible machining centers. Wang and Chen (2012) stated a method, which contains Fuzzy MCDM rooted in Quality Function Deployment (QFD) integrating Fuzzy Delphi and Fuzzy DEMATEL with linear integer programming. This procedure was proposed as a means of collaborative product design and optimal selection of module mix.

MCDM technique both in the crisp and fuzzy environment is a popular and common tool in the literature especially in problems with conflicting objectives. It has the flexibility to be integrated with different techniques like fuzzy approach, goal programming, quality function deployment, neural network, genetic algorithm, etc. The application of hybrid approach provides opportunies to enable user to extract strength, eliminate weakness, keeping constraints in view, to optimize and to allows achiveing the goal in a better way.

7. Conclusion

The critical role of product development in the survival and success of business organizations and the need for managing it strategically is being recognized increasingly in both the academic and practitioner literature. To succeed, companies need to define a customer-focused product strategy, capitalize on the ideas, identify the areas they will focus on and where they have limitations, and develop a product using an iterative approach that maximizes flexibility. The new vision of product development is that of highly disaggregated process with people and organizations spread throughout the world. These plans and their implementation are critical to achieving success in the marketplace. The insights drawn may be helpful in constructing useful guidelines for specific situations and purposes. It is however noted that there is no defined method to ensure product development success. The fuzzy multiple criteria decision analysis has been widely used in both academic research and practices used to address critical and key issues in new product development strategy and success. There are methods that can help define and implement a strategy for integrated approach, but which ones to focus on and how to apply them is not well defined. However, exposure to a variety of different new product successes can provide insights on the range of success factors that if considered for any particular new product may positively affect its market performance and hence achieve the desired goal. The synergistic combination of the concepts and techniques along with some new developments has produced a process whose power is indeed far more than the sum of its parts.

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