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Full Length Research Paper

Identifying and prioritizing critical success factors for thin film transistor liquid crystal display (TFT-LCD) industry in new product development

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Taiwan's current thin film transistor liquid crystal display (TFT-LCD) industry provides a representative, real-world example of both the collaboration within, and the competition in technologies and capital orientation. To compete successfully in the market, companies in the industry require continuous technology innovations for new products. Further, a large amount of investment and output value in TFT-LCD industry becomes one of the most important industries which drove the relative industrial development. Hence, firms in Taiwan suffered difficult industrial environment. Companies compete with both Japanese and Korean companies, which are known as the leading manufacturers in TFT-LCD industry, and earn low or negative profits. The study uses analytic hierarchy process (AHP) to conclude the views of experts from industry, the government, and academic. The study conducted five critical success factors in new product development (NPD) for TFT-LCD industry: innovation of NPD strategy, application and exploitation of NPD strategy, supportive resource from CEO, establishment of cross-functional NPD team, and development of commodity survey planning. The results show that R&D strategy, and organizational contexts are the most important factors. Based on the factors identified, a hierarchy model of critical success factors is proposed, with which TFT-LCD firms can formulate action plans for NPD.

Key words: Thin film transistor liquid crystal display (TFT-LCD), new product development, analytic hierarchy process (AHP).

INTRODUCTION

In the past, Taiwan's high-tech manufacturers or traditional enterprises have been defined as original equipment manufacturers (OEM), especially, these firms, hoping to maintain competitive advantage in such rapidly changeable business environment and increase their uniqueness. The development and advance of complex technology must be closely integrated into firm's research and development (R&D) resources and to improve the efficiency of NPD.

After the system of WTO (world trade organization) operating, obviously, a form of global industrial division of labor is made and difficult to break down. Hence, firms that engage in continuing R&D to improve the added value of the products or to maintain its competitiveness has become more important than before. NPD is the term used to describe the complete process of bringing a new product or service to market. With the globalization of market competition and short-lasting product life, NPD must be completed in limited time to reduce the risk of uncertainty, and to ensure the success. Traditionally, NPD is the first stage in generating and commercializing new products process of product life cycle management used to maintain or add market share. Therefore, NDP plays a critical role among impact factors within the firm.

Production pattern, faster time and cheapness are three very important issues in NPD research. In other words, NPD teams must find the means for speeding

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time to market while also improving product quality, and reducing product costs and complexity to the firm's R&D resources efficiently. There are lots of challenges such as internal structure, technology, customers' demands, external competitors, consumer awareness, human resources and thinking of operating change in practice of NPD process. Hence, it is important to identify the critical success factors and their priorities in management of NPD process. Recently, the TFT-LCD industry is the most important economic investment in Taiwanese manufacturing industry. Additionally, TFT-LCD industry grows fast and increases the product value, in that the industrial output value exceeded 30204 million US dollar in 2010. In order to keep pace with abroad opponents, for manufactures such us Japan and Korea, holding the critical success factors in NPD is truly the most important strategy.

The study focuses on TFT-LCD industry which is qualified with competition in technologies and capital orientation, high R&D and faster innovation of new products. By using AHP to conclude the views of experts from the industry, the government and the academic community, we attempt to summarize and explore the critical success factors in NPD for TFT-LCD industry. The purposes of the study are as follows:

1. What are the critical factors which can successfully prompt NPD in TFT-LCD industry?
2. What is the priority of these critical factors in NPD for TFT-LCD industry?
3. Give a good reference in identifying the critical factors of NPD for TFT-LCD industry.

Characteristics of Taiwan's TFT-LCD industry

The TFT-LCD industry is the newly arisen one after semiconductor industry and became the key manufacturing industry in Taiwan. In order to keep pace with abroad opponents (South Korea and Japan), holding the key components is doubtlessly the most important strategy. It is necessary for Taiwan, second only to Korea, cooperating with Japan to reach the global number one place in TFT-LCD industry since Japan initiates and masters many related technologies.

In 1998, Taiwan accounted for only 1% of market share worldwide, but by 2004, its market share was over 40%. There are five major TFT–LCD manufacturers in Taiwan, the largest being Acer Unipac Optoelectronics Corporation (AUO), which evolved from a 2001 merger between Acer Display Technologies and Unipac Optoelectronics Corp. Others are Chi Mei Optoelectronics (CMO); Chung Hwa Picture Tubes Ltd. (CPT); Hann Star Display Corporation (HDC) and Quanta Display Inc (QDI).

In general, there exist some specific characteristics in development of TFT-LCD industry, such as unexpected demand fluctuation, customized product that each customer will designate the specific key components, long lead time of procurement, and short-lasting product life cycle. ITIS (Industry and Technology Intelligence Service of Taiwan) concludes into five characteristics: 1) capital-intensive – the barriers of entry and exit for manufacturers are high; 2) technology-intensive - intellectual property right (IPR) is a legal barrier to entry; 3) material costs account for a high proportion of total costs; 4) product life is short-lasting and production technology is fast-turnover; 5) the adverse rate, quality and size of product are the critical factors for the competition.

The characteristics of TFT-LCD industry, qualified with technology-intensive, capital-intensive, high R&D and faster innovation, just match with the attributes of NPD. A focus on TFT-LCD industry discussed further covers the literature and critical factors in NPD. Then, the research methodology (AHP) is described, and the results are reported. Finally, the results and implications for practice are presented.

CRITICAL FACTORS OF TFT-LCD INDUSTRY

NPD is characterized by a tremendous degree of complexity and uncertainty, in that no single development approach in TFT-LCD industry and NPD necessarily leads to a final successful product (Chen et al., 2006). Few researches in NPD have identified a number of factors that influence the process: technology (Song and Montoya-Weiss, 2001), product characteristics (Cohen and Bailey, 1997), project structure (Song et al., 1998), team member characteristics and patterns (Keller, 1986), team processes (Dyer and Song, 1998), organizational context (Keller, 1986; Pinto et al., 1993), and external environment (Souder et al., 1998). However, for TFT-LCD industry, we join the views of experts from industry, the government, and academic and explore five related factors. We further elaborate them in details.

Organizational contexts

In addition to NPD engineering and technical departments, organizational culture climate in all departmental units is the other consequent and influential factor. Organizational innovation is also a social process, as such, an organizational member needs to be in touch with others. Brown and Eisenhardt (1995) believe that the support of executives as well as the communication and cooperation in R&D team, will help to improve the ability and speed of NPD. Internal organization learning and sharing will contribute to the knowledge energy and enable firm to have better ability to innovate (Sethi et al., 2001). Cooper and Kleinschmidt (1995) mention that a company's overall new product performance depends on the following elements: the NPD process and the specific activities within this process; the organization of the NPD program; the firm's NPD strategy; the firm's culture and climate for innovation: and senior management commitment to NPD. The amount of resources not only directly related to the ad hoc innovation capability, but also indirectly affected employees' work motives. The more resources employees have, the more new ideas perform. Thus, organizational encouragement, supervisory encouragement and work group support may let employees focus on new idea and help to create high-performance innovation (Amabile et al., 1996; Yang, 2006). Chendler et al. (2000) found that organizational reward system has a significant impact on employees' innovative behavior. It can be seen as an important tool to understand and stimulate employees' capability. From literature, we summarize six major criteria for this construct. They are sufficient resources, CEO's recognition and support, creative organizational culture, team work, knowledge sharing, and technological R&D.

R&D strategic

The company's R&D strategy has a certain degree of impact on NPD. Cooper (1984a, b) thought that there were four concerned variables: 1) orientating the enterprise to a new product; 2) market characteristic adopted by the new product; 3) the enterprise's technological orientation and commitment; and 4) technological characteristic adopted by the new product. Firth and Narayanan (1996) defined a NPD strategy as having three aspects: 1) new embodied technology; 2) new market applications; and 3) innovation in the market. Based on these three aspects, his research led to a NPD strategy which are: 1) innovators; 2) investors in technology; 3) searching for new markets; 4) business as usual; and 5) middle-of-the-road. Song et al. (1998) utilized Ansoff's product market matrix model considering the growing in our current market and technology strategy. The results lead to incremental NPD. A development strategy that pursues a new market with a new product and technology will create a "real new product". A strategy involving a current market and new product or new market and current product is classified as a moderate innovation.
In order to simplify our study, we focus on technological strategy and define a NPD strategy as five types:

1) Leading innovative strategy: by concentrating on technology R&D, firm has an attempt to build a leading position and image in technology innovation.
2) Defensive strategy: in order to maintain the specific technology and market-leading position, firm has to further its R&D and innovation.
3) Exploited strategy: in order to expand the market share or opportunity, firms focus on redesign of products, engineering and processing.
4) Follow and copy strategy: in order to lower NPD costs, firms acquire technology from external.
5) Opportunism strategy: as long as there are profit and market opportunities, firms invest major technical inputs in NPD but just for a short-term, that is, the guerrilla strategy. These items form a NPD strategy.

R&D process management

NPD is a complex process and many of the activities to be accomplished are knowledge intensive. Among them, idea generation, product design, prototype and engineering are the most relevant (Carbonara and Schiuma, 2004). These activities involve a sequence of problem-solving cycles, which are typical of every knowledge creation process. Brown and Svenson (1988) considered NPD activities as a system, including input, process and output. For productivity of NPD, the evaluation system is divided into five stages: input, process, output, efficiency and results of the receiving system, as well as feedback of the results. Song et al. (1998) point out six basic activities for NPD. They are strategic planning, creative selection, market opportunities analysis, technological development, product testing, and product commercialization. Swink (2002) pointed out four directions to speed up NPD: 1) leadership, 2) organizational resource, 3) design capabilities, and 4) computer-aid tool. Due to FTF-LCD specific characteristic, we propose five stages: planning stage, product design stage, process design stage, validation stage, production and improvement stage.

R&D tools

In order to improve design quality, integrate technology, and reduce design operating time, many methods and tools are constantly developed. These include quality function deployment (QFD), Taguchi Method, design-oriented manufacturing / assembly-oriented design, robust design, module design, failure modes and effects analysis (FMEA), simultaneous engineering, reverse engineering and product planning. QFD provides a systematic process for integrating TQM into NPD activities. QFD combines various design engineering and managerial tools to create a customer-oriented approach to developing new products. QFD consists of two components which are deployed into the design process: quality and function. The "quality deployment" component brings the customer's voice into the design process. The "function deployment" component links different organizational functions and units into the design-to-manufacturing transition via the formation of design teams. Since a team problem-solving approach is appropriate for complex issues (Van de Ven et al., 1976).

"Taguchi method" uses the concept of loss function to assess quality, and uses experimental design to control nuisance and impact on product variability, and to improve product quality (Peace, 1993). This method has a better effect in dealing with product design variation than others. "Manufacturing-oriented/assembly-oriented design" is serially to turn input (material) into output (finished product). This process must be simple, fast and economic to complete all stages. Reverse engineering technology is established by using computer-aided design (CAD) model reconstruction, coupled with Taguchi method to shorten the design process, effectively and accurately. "Failure mode and effect analysis" (FMEA) is used in the initial production management. It is used as a design control tool, risk analysis-hazard analysis tool, risk management tools, and trouble shooting tool, used in the initial production management. Eekels (2001) proposed a methodology for product design and pointed out that the stage of product design should be conducted after a new product concept and accordingly, to prepare a written report for final design. The report should include the contents of 5 W (what, who, why, where, when), 2 H (how many, how much) and 6 M (men, method, machine, material, money, marketing). Thus, the proper use of methodologies and tools can effectively reduce costs, shorten the design process, improve product quality and accuracy, and increase NPD success rate.

R&D project management

According to literature project, teams can increase their chances of success by understanding and capitalizing on different behavioral type. Gordon and Anne (2001) suggested that the leader of a project team should understand the psychological patterns and personality characteristics of team members; such as, understanding members' extraversion-introversion can help work assigning, understanding members' sensing-intuition can ease to assist them to carry experimental observations or engage in a more comprehensive study, understanding members' thinking feeling can appropriately arrange them to do a causal or creative research, understanding members' judging-perceiving can help them to take on an appropriate design during NPD process. Thus, management and operation of team project will have a significant effect on performance of NPD. Besides, work and responsibility of NPD is related to cross-department, not just to R&D department. Therefore, harmonious climate in cross-functional team can increase its perfor-mance. Even for decentralized firms, cross-functional team can make the best use of information technology (such as intranet and internet, video conferencing, and GDSS) to communicate. As for data recording, data keeping, budget controlling and process timing, these are also indispensable to the success.

This study summarizes five main dimensions to examine and identify critical factors for NPD of TFT-LCD industry. There are 30 assessment criteria to conduct this study.

METHODOLOGICAL FRAMEWORK

Using the quantitative TFT-LCD industry, R&D critical success factors (CSF) as a reference, the CSF was designed to be executed in three steps, including: (P1) developing a decision hierarchy model for NPD; (P2) collecting data; (P3) determining the normalized weights. TFT-LCD R&D is becoming a complicated practice as the number of factors and elements affecting it increase. The AHP devised by Saaty (1994, 1996) is a powerful technique in solving fuzzy and complex decision problems. Fundamentally, AHP works by developing priorities for goals in order to value different alternatives. This multicriteria method has become very popular among operational researchers and decision scientists (Dyer and Forman, 1992).

Phase 1: Using a checklist and a brainstorming session to identify NPD factors; developing a decision hierarchy model to guide NPD in TFT-LCD industry

As shown in Figure 1, the model has three levels. Level 1 depicts the critical successful factors of NPD in the TFT-LCD industry. Level 2 consists of the critical NPD factors, and Level 3 describes the sub-factors of individual critical NPD factors.

NPD factors are hierarchically structured into two levels of critical items (the first level) and sub-items (the second level). The identification of NPD factors involves a vigilant scanning of the TFT-LCD industry environment in an effort to monitor, identify and detect the existing, new and potentially changed factors. Checklist and brainstorming are consequently combined to reduce the natural limitations of the standardized checklist approach, such as failing to list NPD factors that are unusual or unique to the specific case. In the brainstorming meeting, a small group of professionals consisting of government officials, R&D senior managers and independent scholars were invited with the aim of confirming and finalizing the NPD factors. The careful design helps to develop the CSF and significant NPD factors are overlooked in the following NPD survey stage.

Phase 2: Collecting data

AHP is a subjective method which does not require the involvement of a large number of experts (Cheng and Li, 2001). The use of small sample (10 or below) in AHP analysis has been adopted by abundant researchers (Bard and Sousk, 1990; Handfield et al., 2002). In this study, 15 evaluation experts, from the industry of TFT-LCD, participated in the AHP analysis. To ensure that the judgments made by the experts are consistent, the 20 sets of data were subjected to consistency tests which were conducted separately using the Expert Choice. The results of 12 sets of data suggested that the overall consistency of evaluator judgments fall within the acceptable ratio of 0.10 as suggested by Saaty (1994, 1996). The evaluation experts have, on an average, more than 5 years of TFT-LCD industry experience and they are both working at the upper management level.

The experts are experienced and we assume they are knowledgeable and can well represent the views and opinions of the industry. Table 1 summarizes the profiles of the experts who participated in the factor validation and prioritization. In this study, 15 senior TFT-LCO industry R&D managers and company owners were invited to join the survey. Since they are the individuals who develop strategies for organizations, they need to manage different aspects of the organizations. They acted as the assessors to prioritize the critical NPD factors and sub-factors affecting their deployment of NPD solutions. We adopted Saaty's nine-point scale to employ assignment relative scores to pair-wise comparisons amongst the categories and sub-factors. (Table 2). The evaluators would assign a score to each comparison using the scale. This process continued till all levels of the hierarchy, and eventually a series of judgment matrices for the critical factors and sub-factors was obtained.

Consistency ratio (CR) is calculated to evaluate the consistencies of the judgments. Saaty (1994) suggested that CR of 0.1 or below

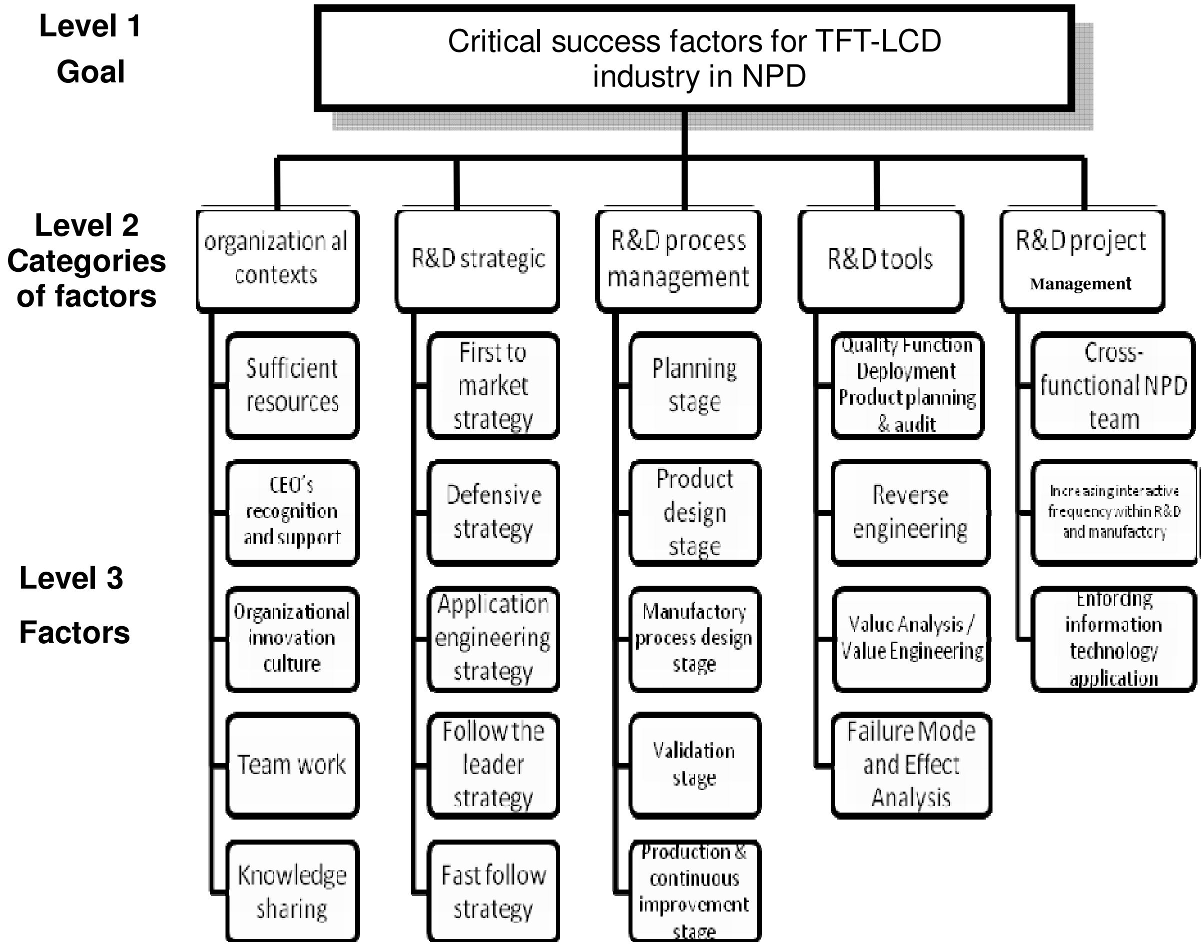

Figure 1. A hierarchy model of NPD in TFT-LCD.

is acceptable to ensure the consistencies of the judgments, while CR higher than 0.1 would be discarded. Finally, 20 sets of data were retained in the analysis, and the overall average CRs are lower than the maximum value of 0.1.

Phase 3: Determining the normalized weights

The scores obtained from individual assessors were translated into matrices and the normalized weighted averages were then calculated. The results prioritized the relative importance of the NPD factors affecting the adoption of TFT-LCD companies. The resulting priority weights determined the relative importance of individual factors and sub-factors, and in turn, identified the points on which organizations should put their efforts throughout the factors of NPD.

RESULTS AND ANALYSIS

Table 3 shows the local weights of the 5 categories and 25 factors calculated based on the AHP analysis conducted by TFT-LCD industry. As shown in Table 4, With respect to the goal of TFT-LCD NPD, R&D strategy (RDS) was the most categories with a normalized weight of 0.392 in Level 2. The second category was organizational context (OC = 0.212), third category was R&D methods and tools (RDMT = 0.196) and the last category was R&D process management (RDPM = 0.096). In Level 3, first to market strategy was the most important factor of NPD with a local weight of 0.356. The second important factor of cross-functional R&D team was 0.351 and the least important factor of organizational climate was fast follow strategy (FFS = 0.087). In Level 3 of OC, CEO recognition and support was the most impor-tant factor (CEORS = 0.312) and the less important factor was sufficient resources (SR) with a normalized local weight of 0.135. RDPM was the less important category with a normalized local weight of 0.254. Specialization planning stage (PS = 0.442) is the most important factor under RDPM. The second important factor was product design stage (PDS = 0.298) and the less important factor was production and continuous improvement stage (i.e. PCIS = 0.096).

In considering the global weight rankings in Level 3, as shown in Table 4, first to market strategy (FTMS = 0.356) mainly entered the market earlier than the late entrant.

Table 1. Profiles of the TFT-LCD industry experts.

Purpose	Expert number	Position	Years of experience
Factor validation	1	Government officials	10
	2	Government officials	12
	3	Government officials	8
	4	R&D senior managers	13
	5	R&D senior managers	15
	6	R&D senior managers	9
	7	Independent scholar	11
	8	Independent scholar	9
Factor prioritization (AHP evaluation)	1	Engineering manager	5
	2	Director	9
	3	Engineering manager	9
	4	Director	8
	5	Senior project manager	15
	6	Director	10
	7	Senior project manager	13
	8	Engineering manager	10
	9	Operation manager	9
	10	Engineering manager	10
	11	Operation manager	11
	12	Director	15

Table 2. Saaty's nine-point scale.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective Experience and judgment
3	Weak importance of one over other	Slightly favor one activity over another Experience and judgment
5	Essential or strong important	Strongly favor one activity over another An activity is favored very
7	Demonstrated importance	Strongly over another; its dominance 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
Reciprocals of above nonzero If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j* then *j* has the reciprocal value when compared with *i*		A reasonable assumption

Source: Saaty (1994)

Through its innovative technology, the first-mover is able to handle preemption of key factors and consumer transferring cost better than the late entrant; thus allowing the first-mover to perform better in some areas than the late entrant. Cross-functional R&D team was 0.351 and product planning and audit (PPA = 0.341) and planning stage (PS = 0.324) were the most influencing factors to the RDPM.

Table 3. The weights of NPD the 5 categories of factors and 25 factors.

Level 2		Level 3		
Category	**Global weight**	**Factor**	**Global weight**	**Local weight**
		Sufficient resources	0.135	0.027
		CEO's recognition and support	0.312	0.090
Organizational contexts	0.212	Organizational innovation culture	0.162	0.031
		Team work	0.157	0.028
		Knowledge sharing	0.226	0.043
		First to market strategy	0.356	0.137
		Defensive strategy	0.180	0.069
R&D strategic	0.392	Application engineering strategy	0.245	0.094
		Follow the leader strategy	0.132	0.051
		Fast follow strategy	0.087	0.034
		Planning stage	0.324	0.030
		Product design stage	0.298	0.028
R&D process management	0.096	Manufactory process design stage	0.170	0.017
		Validation stage	0.112	0.011
		Production and continuous improvement stage	0.096	0.007
		Quality function deployment product planning and audit	0.258	0.039
			0.341	0.051
R&D tools	0.196	Reverse engineering	0.156	0.022
		Value analysis / value engineering	0.122	0.019
		Failure mode and effect analysis	0.123	0.017
		Cross-functional NPD team	0.351	0.056
		Increasing interactive frequency within R&D and manufactory	0.114	0.017
R&D project management	0.104	Enforcing information technology application	0.120	0.016
		NPD scheduling time	0.158	0.035
		R&D diary book and reserving	0.151	0.019
		Budget controlling	0.106	0.008

Table 4. Prioritized global rankings of sub-factors.

Factor	Global ranking
First to market strategy	0.356
Cross-functional NPD team	0.351
Product planning and audit	0.341
Planning stage	0.324
CEO's recognition and support	0.312
Product design stage	0.298
Quality function deployment	0.258
Application engineering strategy	0.245
Knowledge sharing	0.226

Conclusion

This paper incorporates the judgments of clients and suppliers by using AHP to identify and prioritize the 5 categories of factors and 25 critical success factors in NPD for TFT-LCD industry. During investigation, we found that firms are vigorous in NPD to increase market opportunities and to maintain long-term viability. The results, based on the synthesized judgments, indicate that R&D strategy is the most critical factor category followed by organizational contexts, R&D tools. Of the 25 factors, the most critical is first to market strategy. Cross-functional NPD team and product planning and audit were prioritized as the second and third critical factors. The 5 categories of factors and 25 factors constitute a hierarchy model of critical success factors for TFT-LCD industry, with which clients and suppliers can establish or improve their critical success factors for TFT-LCD industry practices and in turn NPD.

In the global supply chain, Taiwan held the brilliant production capacity to shape the well-known competitive advantages and economic miracle. Recently, firms relocate out of Taiwan for low-cost production and gradually loose their original competitive advantage. However, in order to increase competitive advantage and acquire more sufficient resources, firms might probably alliance strategically or cooperate globally. In sum, the research presents four main managerial implications. First, it helps practitioners to be aware of the existence of the factors for TFT-LCD industry in NPD. Second, TFT-LCD industry is capital and technological orientation, and the characters of technology and product resulting in industrial structure is huge. Hence, TFT-LCD industry emphasizes on NPD and process capability. This study enables practitioners to realize the nature of the critical success factors so that they can investigate their current situations of NPD for improvement. Third, the prioritization helps practitioners understand the relative importance of the factors, which is helpful to them to set their improvement plans as they may not have sufficient resources to deal with all the factors at the same time. Finally, development of self-owned technology, TFT-LCD firms should seriously invest into developing key components and core technology, establishing their own independent technology, and acquire key technologies to improve their intellectual property right management procedure.

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