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Hierarchical Evidential Reasoning-based Assessments of New Product Development Strategies

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Abstract: *This paper is geared toward the development of a hierarchical evidential reasoning-based model for manufacturers to determine the relative importance of decision factors for NPD strategy assessments. Incorporated the findings of focus group discussions and interviews with experts in Hong Kong, an assessment model of NPD strategies is devised using the Analytic Hierarchy Process (AHP) and the Evidential Reasoning (ER) approaches. The procedures are presented to illustrate how a list of fourteen decision factors be prioritised and the knowledge bases be established for modeling the strategy assessments. It was found that the risk and uncertainty, market competition, company growth, scale of market, distribution channel, manufacturing capability and technological R&D were important elements determining the NPD success. Using the proposed model, five distinctive evaluation grades of NPD strategies were introduced. The efficacy of the model depends on the establishment and customisation of a knowledge base which should be built and validated for individual companies. This paper contributes to identifying the decision factors and developing the assessment model of NPD strategies. The findings would drive the assessment initiatives of manufacturers towards the formulation and adoption of sustainable NPD strategies.*

Keywords: *Manufacturing, new product development, decision, strategy, AHP, evidential reasoning*

1. Introduction

Intense global competition and shifting patterns of world market opportunities compel companies to continually invest in new product development (NPD) (Gerwin and Ferris, 2004; Owens, 2007). The advance of new products and their development is widely recognised as an important source of competitive advantage (Owens, 2004; Rogers et al., 2005). The long-term survival of a business often hinges on its ability to successfully introduce new products into the marketplace. Mu et al. (2007) contended that the continuous development and market introduction of new products is an important determinant of sustained firm performance. Owens (2007) also argued that these new products and their successful development could be the lifeblood of a company.

NPD has become a central mechanism through which a company's strategy can be put into practice (Shepherd and Ahmed, 2000). Many recent studies (e.g., Rogers et al., 2005; Lettice et al., 2006; Lindman et al., 2008; Linzalone, 2008) have been carried out in order to understand the NPD process and its performance. Performance measurement is an important aspect of the NPD process. Without it, it is almost impossible to document the value of development efforts, to evaluate research programmes and to allocate resources diligently (Lettice et al., 2006). Successful strategic management of NPD is typically linked to such aspects as goal orientation and long-run planning, managerial approaches to technology and design and market orientation and innovativeness (Lindman et al., 2008). However, problems arise due to the multi-dimensionality of product development and the concentration on micro-level metrics i.e. the isolated project level. Product development also has relatively long timescales and is considered more volatile, unstructured and intangible than other areas of the business, such as manufacturing, which makes it harder to measure and manage (Lettice et al., 2006).

The Pearl River Delta (PRD) region including Hong Kong (HK) is one of the world's fastest growing manufacturing regions (FHKI, 2003). The small and medium-sized enterprises (SMEs) have dominated the industrial development of the region. Their successes in the 1990s were attributed to the highly responsiveness to fluctuating market opportunities, upholding the price-competitiveness and timely delivery, and also cost-

minimising through the specialisation-oriented and capacity-oriented subcontracting practices (Chin and Pun, 2000; FHKI, 2003). Today, the competition has been shifting from local and regional to global, and has become complex with higher customer expectation, market transparency, emerging new marketing channel and technology changes. The demands on lower price with better customer service lead to the squeezing profit margin between trading partners. As a result, non value-added activities and functions would ultimately be eliminated (Pun et al., 2008).

Many manufacturing enterprises in the PRD/HK region have stressed product innovation and NPD to meet the increasing demands of high value-added and quality products (FHKI, 2003). A recent study conducted by Mu et al. (2007) found that many Chinese managers have realised the importance of the coordination between management, engineering, marketing, technology, and commercialisation in developing new products in China. However, few studies were conducted on how the Chinese organisations (particularly the SMEs) develop new products (Cheng and Shiu, 2008; Mu et al., 2007) and formulate NPD strategies (Yam et al., 1996; Chin and Pun, 2000). This research contributed to propose a hierarchical evidential reasoning-based method on facilitating SMEs on NPD strategy assessments.

This paper begins with a review of factors as advocated in literature that affects NPD strategy formulation and practices in industry. It goes on to examine a list of fourteen elements under five decision areas, namely, corporate decisions, organisation aspects, marketing strengths, manufacturing strengths, and research and development strengths. Incorporated the findings of focus group discussions and interviews with experts in Hong Kong, a hierarchical assessment model of NPD strategies is devised using the Analytic Hierarchy Process (AHP) (Saaty, 1994, 2008) and the Evidential Reasoning (ER) approaches (Yang, 2006; Chin et al., 2009). The model development is then elaborated along with the prioritisation of decision factors and establishment of knowledge bases for modeling strategy assessment.

2. Factors Affecting NPD Strategies and Practices

The challenging characteristics of NPD have prompted a great deal of interest by the researchers and academicians contributing to the continuing broadening of the NPD management bodies of knowledge (Yahaya and Abu-Baker, 2007). Research studies on NPD management are now large and diverse. They are included in the areas of business and product strategy making (Christensen et al., 2004; Mankins and Steele, 2006), portfolio management (Cooper et al., 2000; Cauchick Miguel, 2008), new product process (Kang et al., 2006; Lettice et al., 2006; Linzalone, 2008), and strategic NPD management (de Brentani and Kleinschmidt, 2006; Hines et al., 2006; Yahaya and Abu-Baker, 2007).

There are two kinds of approaches, named as process and domain view, in NPD. The process view looks at the activities of domains simultaneously in development process, while the domain view investigates the activities of domains independently (Chakravarty, 2001; Kang et al., 2006). Mu et al. (2007) contended that the NPD process is a dynamic and iterative problem-solving process in which complex interactions are required to combine and exploit the technological and marketing capabilities of the firm to create product functions and features that meet market demands.

When NPD practices are in question, much the same basic factors as have been found elsewhere drive performance both at the country and firm level as the frequency of applied criteria indicates (Lindman et al., 2008). Technological, marketing/commercial and managerial/ organisational factors are considered important across all stages of the NPD process (Chin and Pun, 2000; Mu et al., 2007). For instance, the approach by which technology being managed is in general based on the management expectations that in addition, by seeking new and advanced technological knowledge new business opportunities can be opened (Lindman et al., 2008). NPD staff and departments use information technology (IT) to communicate with each other and with external and internal customers (Lettice et al., 2006). Regarding marketing factors, for instance, competitors not only introduce new products, but also establish the external benchmarks that provide the relative background that NPD occurs against (Lettice et al., 2006). Market orientation also implies how inherent market conditions are taken into account and how they impact on the final new product strategic decisions depending on the resources available and access to the marketplace (Lindman et al., 2008).

In a knowledge-intensive area like NPD, the levels of management hierarchy, organisational complexity, lines of report and communication are considered vital success factors in creating an environment that either encourages or inhibits innovation (Lettice et al., 2006). For instance, active and visible senior management commitment, early involvement of functional groups, the introduction of new work methods, early market/technical testing, and effective new product organisations (Owens, 2007). The quality of communication between the functional disciplines involved in NPD activities, perceived risks and complexity of using cross-functional NPD teams, and the complexity of the organisation's NPD activities all influence organisational support for cross-functional NPD teams (Boyle et al., 2005). Besides, changes in social and economic relationships have triggered a shift to people-centred business and management styles. Employees' skills and commitment are now considered to be key drivers of innovation and success (Lettice et

al., 2006).

Moreover, Lettice et al. (2006) advocated four categories of factors (namely human resource management (HRM), technological infrastructure (TI), organisational structures (OS) and competitive context (CC)) that would govern the NPD process. The key HRM measures might include the length of time it takes to fill a job vacancy, the amount of time staff spent in training classes and programmes, employee contribution to NPD targets. Key TI measures might include percentage of NPD staff with network access (as a measure of connectivity) and investment in new IT tools and software upgrades. Measures in the OS category might include: number of projects using cross-functional teams, hierarchical complexity, and number of employees rotated between departments. Relevant CC measures might include number of trade shows or conferences attended by employees and number of benchmarking activities undertaken (Lettice et al., 2006).

On the other hand, various reasons for delays in NPD are found, including poor definition of product requirements, technological uncertainties, senior management support, lack of resources, and poor project management. Major concerns raised included management and organisational style, lack of attention to detail, limited support for innovation, lack of strategic thinking, and poor manufacturing capabilities (Owens, 2007).

3. Decisions for NPD Strategies

Many studies have recently been undertaken to investigate the strategies and practices for NPD (e.g. Yam et al., 1996, Chin and Pun, 2000; Cravens et al., 2002; May-Plumlee and Little, 2006). Different approaches may vary with the business nature, company position, organisational resources and constraints. For adopting a proactive NPD approach, a firm attempts to explicitly allocate resources to identify and seize opportunities and preempts competition by being the first to the markets with innovative products (Chin and Pun, 2000). For instance, Cravens et al. (2002) proposed a framework of proactive cannibalisation that responds to changing customer value, as part of the process for building appropriate innovation strategies for the new competitive and technological environment faced by companies. May-Plumlee and Little (2006) also modeled apparel product development as a market driven process and integrated the consumer purchase decision in the model of proactive NPD integrating consumer requirements.

On the other hand, the reactive NPD approach relies largely on imitating the success and leading products in markets (Yam et al., 1996). A firm would wait until its competitors successfully introduce their products, and attempt to imitate them or develop similar products with modifications accordingly (Chin and Pun, 2000). Table 1 shows a comparison between proactive and reactive strategies used in relation to NPD.

Table 1. Proactive and Reactive NPD Strategies

Proactive Strategies	Reactive Strategies
Technological R&D	Defensive
Marketing research	Imitative
Entrepreneurial	Second but better
Acquisition	Responsive

Traditionally, many practitioners have regarded NPD as a high-risk activity that would interact with various political, financial, cultural, and organisational aspects (Chin and Pun, 2000). On one hand, relying heavily on reactive approach (e.g. imitative strategies) of product development has its limitations and constraints in a rapidly changing market environment. On the other hand, a host of uncertainty and risks (e.g., fragmented markets, shortened product life cycles, immature technology and fierce market competitions) also discourages manufacturers to devote proactively in product development (Mu et al., 2007; Yahaya and Abu-Bakar, 2007). Chin and Pun (2000) contended that the NPD strategy formulation process is associated with corporate objectives and business considerations, manufacturing practices and technical strengths of an organisation. Based on literature review, five major groups of decision criteria are identified pertaining to adopting proactive versus NPD strategies. These criteria are shown in Table 2, and explained separately as follows:

3.1 Corporate Decisions

The corporate decision criterion is concerned with the overall strategic posture of a company (Chin and Pun, 2000; Mu et al., 2007; Yahaya and Abu-Bakar, 2007). This encompasses the pursuit of company growth and financial strength with the considerations of business/operational risks and uncertainty. Growth opportunity is an enabling factor of NPD. A company's growth can be realised in terms of greater sales in existing or new markets and products. For instance, if the company expects high growth with product innovation, it is beneficial to adopt a proactive strategy in order to strengthen its R&D and marketing. Financial strengths of a company would hinge the composition of its long-term financing of debt, preferred stocks and common stockholders' equity, and which in turn would influence the adoption of NPD strategies. In complying with the uncertainties and risks, the stronger the financial strengths, the greater the ability of the company opts for proactive NPD, and *vice versa*.

3.2 Organisation Aspects

Recent studies show that manufacturers need to take a proactive role in developing new products and markets

Table 2. Groupings of Decision Factors of NPD Strategies

Decision Factors	Sub-factors	Relevant Reference Sources
Corporate Decisions (COR)	Risk and Uncertainty (RU) Company Growth (CG) Financial Strength (FS)	Chin and Pun (2000); Kayis et al. (2007); Kern and Kersten (2007); Mu et al. (2007); Olsen et al. (2008); Yahaya and Abu-Bakar (2007)
Organisation Aspects (ORG)	Teamwork Approach (TP) Innovative Design Atmosphere (IA)	Badrinarayanan and Arnett (2008); Boyle et al. (2005); Gerwin and Ferris (2004); Jespersen (2007); Lettice et al. (2006); May-Plumlee and Little (2006); Mu et al. (2007); Yahaya and Abu-Bakar (2007)
Marketing Strengths (MKT)	Scale of Market (SM) Distribution Channel (DC) Marketing Research (MR) Market Competition (MC)	Chin and Pun (2000); Iyer et al. (2006); Kang et al. (2007); Lettice et al. (2006); Mu et al. (2007); Vilaseca-Requena et al. (2007)
Manufacturing Strengths (MFG)	Manufacturing Capacity (MP) Manufacturing Capability (MB)	Cheng and Shiu (2008); Chin and Pun (2000); Lindman et al. (2008)
Research and Development Strengths (R&D)	Technological Research and Development (TR) Project Management (PM) Protection of Innovation (PI)	Iyer et al. (2006); Jin and Hong (2007); Kang et al. (2007); Kayis et al. (2007); Lettice et al. (2006); Magnusson and Johansson (2008); Martinez-Sanchez et al. (2006); Mu et al. (2007); Rogers et al. (2005)

(Plumlee and Little, 2006; Yahaya and Abu-Bakar, 2007). Successful introduction and development of products are often the result of team efforts, and are attributed to the establishment of cross-functional teamwork and the involvement of people from marketing, purchasing, manufacturing, engineering and R&D functions (Boyle et al., 2005). Having a structured teamwork process can facilitate a company to adopt the proactive NPD strategies. It is also important for manufacturers to institute necessary organisational systems and practices to promote and encourage creativity and innovation. Teamwork culture and interactive design atmosphere in the organisation are always reported as effective means to achieve product innovation (Badrinarayanan and Arnett, 2008).

3.3 Marketing Strengths

Several factors (such as the size of markets, the use of market research, the ownership of distribution channels and the extent of competitions) often constitute an integral part of marketing that may affect the NPD decisions and strategies of a company (Chin and Pun, 2000; Kang et al., 2007; Vilaseca-Requena et al., 2007). A pioneer that develops proactively innovative products may establish its dominance and maintain unassailable position in a market. However, many companies will naturally opt for reactive strategies if the market size is not sustainable for them to cover the high costs involved in NPD. Conduct of market research can help acquire the knowledge for making marketing decisions. The more experience the companies have in understanding markets and customers, the greater the ability they can manage their NPD strategies. Besides, in many circumstances, hiring and owning appropriate distribution channels contributes to the success of new products. A company's adoption decision on proactive versus reactive NPD strategies depends significantly upon its stance and relative power within the channel. Moreover, ease of product imitation from competitors also discourages many manufacturers to adopt proactive NPD. Smaller companies are even more vulnerable to strong competitions in markets, and may also be pre-emptive in any innovation plans (Chin and Pun, 2000).

3.4 Manufacturing Strengths

Both manufacturing capacity and capability are determinants of NPD strategies (Chin and Pun, 2000; Lindman et al., 2008). The former regards the ability of production to satisfy customer demands, and the latter is referred to the attainment of technical performance in terms of quality and costs. Due to the production requirements, a reactive NPD strategy often asks for high capacity to produce large volume of products on a timely basis. The success of the reactive approach relies largely on the capability of good-quality and low-cost manufacturing. On the other hand, a proactive NPD strategy stresses the product creativity, time-to-market and technical performance. Therefore, the requirement of manufacturing capacity and capability for proactive NPD is more flexible than that of the reactive one (Chin and Pun, 2000).

3.5 Research and Development Strengths

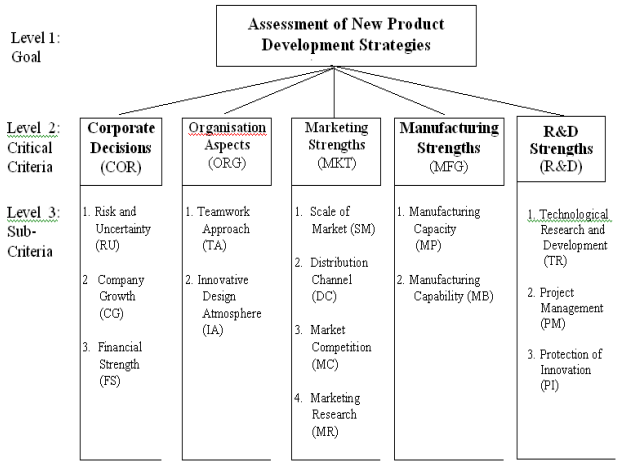
It is essential for manufacturers to invest technological research and development (R&D) and acquire products in relation to the criteria of manufacturing/operational feasibility and marketing/commercial potentials (Iyer et al., 2006; Kang et al, 2007; Mu et al., 2007). NPD demands technical expertise and competence, and necessitates co-operation efforts among various organisation functions. Sound project management can help manufacturers plan, organise and monitor the product development process (Jin and Hong, 2007; Rogers et al., 2005). Besides, suitable protection, such as patent and license production, of innovation can encourage pioneers to develop new products. In other

words, the protection of innovation also encourages manufacturers to adopt a proactive NPD approach (Cheng and Shiu, 2008).

4. Development of a Hierarchy of NPD Decision Factors

Considering the decision factors examined, the problem associated with the assessment of NPD strategies was structured into a hierarchy of factors as illustrated in Figure 1. Each hierarchy level has several decision factors, which are decomposed into another set of sub-factors in the next hierarchy level. A series of AHP-based personal interviews was conducted to confirm and prioritise the decision factors. The AHP methodology, as devised by Saaty (1994, 2008) involves the decomposition of a complex problem into a multi-level hierarchical structure of characteristics and criteria constituting the decision alternatives. The methodology was used to identify both qualitative and quantitative decision criteria, examine the competing objectives and assess their relative importance.

Figure 1. A Hierarchy of NPD Decision Factors



Six experts from the consumer electronics industry were invited as the evaluators. Three of them were representatives from industrial and government associations (namely, the Federation of Hong Kong Industries, the Chinese Manufacturers' Association and Hong Kong Productivity Council) and the others were from private companies. All evaluators were senior personnel in their organisations (such as directors, general managers and senior consultants), representing a wide spectrum of experience and expertise in industry. Each evaluator was asked to evaluate carefully and assign relative scales in a pair-wise comparison of the criteria of each hierarchy level. The computation of interview findings to determine the normalised weights of decision factors and sub-factors was made with the aid of a software tool, Expert Choice (DSS, 2009).

The geometric mean combined the pair-wise comparison judgment matrices that were obtained from each evaluator. Both local priorities (i.e. relative to the parent elements) and global priorities (i.e. relative to the goal) were then generated. The composite vector was used to determine the relative priorities of decision criteria, sub-criteria and choices of NPD approaches. Table 3 depicts a summary of the normalised weights and global weights of evaluator judgments. The overall inconsistency index of evaluator judgments was calculated as 0.07 that fell within the acceptable level of 0.10 as recommended by Saaty (1994). This indicated that most evaluators assigned their weightings consistently on examining the criteria and choosing the approaches.

Table 3. Contrasts Between Normalised and Global Weights of Evaluator Judgments

	Normalised *Weights*	***Global*** *Weights*
Critical Decision Criteria		
1. Corporate Decisions (COR)	**0.334**	**0.334**
2. Organisation Aspects (ORG)	0.083	0.083
3. Marketing Strengths (MKT)	**0.356**	**0.356**
4. Manufacturing Strengths (MFG)	0.089	0.089
5. R & D Strengths (R&D)	0.138	0.138
Decision Sub-Criteria		
1. Risk and Uncertainty (RU)	**0.439**	**0.147**
2. Company Growth (CG)	0.304	**0.102**
3. Financial Strength (FS)	0.257	0.086
4. Teamwork Approach (TA)	**0.675**	0.056
5. Innovative Design Atmosphere (IA)	0.325	0.027
6. Scale of Market (SM)	0.274	**0.098**
7. Distribution Channel (DC)	0.276	**0.099**
8. Market Competition (MC)	**0.322**	**0.115**
9. Marketing Research (MR)	0.127	0.045
10. Manufacturing Capacity (MP)	0.182	0.016
11. Manufacturing Capability (MB)	**0.818**	0.073
12. Technological R& D (TR)	0.247	0.034
13. Project Management (PM)	0.374	0.052
14. Protection of Innovation (PI)	**0.379**	0.052

By examining the normalised priority weights of decision criteria in level 2, the marketing strengths (i.e. with normalised weight = 0.356) and corporate decisions (= 0.334) were recognised as the most important criteria. These external and internal strategic initiatives are vital in determining the proactive NPD strategy as they guided the company to respond to the market and plan for future company development. Comparatively, other three criteria (i.e. the R&D strengths (= 0.138), manufacturing strengths (= 0.089) and organisation aspects (= 0.083)) were inclined to greater operational concerns in making the NPD decisions. These priority weights were employed to determine the relative importance of all the decision factors and the weighting of individual factors of the final assessment model. .

5. Development of an ER-based Assessment Model

5.1The Initial Assessment Model

Based on insights obtained from the literature review and the field data, an ER-based assessment model is developed. The model consists of the five categories of factors as described before: corporate decisions, organisation aspects, marketing strengths, manufacturing strengths, and research and development strengths, which are further expanded into 14 attributes. Table 4 shows a hierarchical table of 14 assessment factors, in which the weightings of individual attributes were determined by the AHP as described in previous sections.

Table 4. A Hierarchy of NPD Assessment Criteria

Criteria / Sub-criteria	Point Values	
1. Corporate Decision		334
1.1 Risk and uncertainty	147	
1.2 Company growth	102	
1.3Financial strength	86	
2. Organisation Aspects		83
2.1 Teamwork approach	56	
2.2 Innovative design atmosphere	27	
3. Marketing Strengths		356
3.1 Scale of market	98	
3.2 Distribution Channel	99	
3.3 Marketing Research	115	
3.4 Market Competition	45	
4. Manufacturing Strengths		89
4.1 Manufacturing capacity	16	
4.2 Manufacturing Capability	73	
5. R&D Strengths		138
5.1 Technological R&D	34	
5.2 Project management	52	
5.3 Protection of innovation	53	
Total:		1,000

Each NPD strategy, either proactive or reactive, needs to be assessed on the sub-criteria. Several conventional methods could be used to assess the strategies such as direct scoring and pairwise comparisons using average scores. Two main concerns in assessing the sub-criteria are the difficulties in clarifying the subjective nature of the attributes and the issue of "non-assessability". Although conventional methods are simple to apply, they are incapable of overcoming the difficulties. Also, a single score can only capture the average merit of a strategy rather than the diversity of its implications. As such, an average score will hide poor performances behind good ones and this is not desirable for identifying areas for improvement.

The Evidential Reasoning approach (Yang et al., 2006; Chin et al., 2009) provides an alternative way for this type of assessment on qualitative criteria where subjective judgments are often used. The ER model employs a belief structure to measure a subjective assessment. In the belief structure, a set of evaluation grades is defined to which a strategy can be assessed. A quantitative criterion of the model can be assessed numerically and such assessments can also be converted to the belief structure equivalently. An evaluation model is proposed. Table 5 shows the five grades of proactive NPD adoption status, and Table 6 depicts a proposed evaluation scheme for proactive NPD adoption.

In the ER-based assessment, a strategy is assessed by looking at whether it is sound, to what extent it is implemented and whether it is deployed systematically.

Although a percentage score could be given to a strategy, this could only be done by averaging the individual scores (on soundness, deployment and implementation) which may be different. For example, a

Table 5. Definitions of Evaluation Grades

Levels	Descriptions of NPD Status
Compliance	Organisations are used to adopting reactive NPD approach; not familiar with the concept, practices and tools and technique of proactive NPD. They are not aware of the necessity of adopting proactive NPD strategies, nor do their business nature, company position as well as organisational resources and constraints allow their adoption of proactive strategies. They reply on "me too" strategy or only doing OEM business with client's design specification.
Receiver	Organisations are those with some understanding of proactive NPD approach but still tend to adopt more reactive strategies. For instance, they may prefer the "second but better" approach to imitate the successful products of their competitors. Their company situation, marketing position as well as organisational resources and constraints do not allow them to adopt more proactive strategies.
Mixer	Organisations have adopted some proactive NPD strategies in their organisations, but they are still in the earlier stages of putting proactive approach in place. Their company position as well as organisational resources and constraints do not allow them to adopt proactive strategies into a large extent. These organisations adopt a combination of both proactive and reactive strategies for the time being.
Stirrer	Organisations are moving in the right direction and have made real progress in implementing proactive NPD approach, but there is still a long way to become a leader of product innovation. They are improving their business nature, growth strategies, organisational system, R&D competency and manufacturing capabilities to further implement the proactive NPD strategies
Challenger	Organisations have reached a point of innovation maturity in their organisations. The kind of culture, values, trust, capabilities, organisational systems, product planning and design practices, and resources have been developed to attain recognised standards of product innovation in the market. Continuous emphasis in developing innovative products has become a long-term policy and culture in the organisation.

Table 6. Proposed Evaluation Scheme for Proactive NPD Adoption

Elements	**Attributes**	**0%**	**25%**	**50%**	**75%**	**100%**
Current situation, including strategies, approach, systems, organisations, marketing, manufacturing and R&D etc. are inclined for proactive NPD.	• Formulation and structured deployment of appropriate strategies. • Sound approach developed and deployed. • Sound system installed and practices implemented.	• No evidence.	• Some evidence. • Implemented in about ¼ relevant areas.	• Evidence. • Implemented in about ½ relevant areas.	• Clear evidence. • Implemented in about ¾ relevant areas.	• Comprehensive evidence. • Implemented in all relevant areas.
Evaluation Grades: (Score or utility)		Compliance (0)	Receiver (0.25)	Mixer (0.5)	Stirrer (0.75)	Challenger (1)

Table 7. Elicitation and Representation of Subjective Judgments

A_1	Compliance	Receiver	Mixer	Stirrer	Challenger
Sound (1/3)	0.0	0.0	1.0	0.0	0.0
Deployment (1/3)	0.0	0.0	0.0	1.0	0.0
Implementation (1/3)	0.0	1.0	0.0	0.0	0.0
Weighted assessment	0.0	1/3	1/3	1/3	0.0

proactive strategy may be formulated, and the approach is very sound and deployed, but to a large degree it is not yet implemented in a structured way.

In order to capture and preserve different assessments on the three elements, distinctive evaluation grades are introduced, namely, "Compliance", "Receiver", "Mixer", "Stirrer" and "Challenger" into the assessment model, which may eventually be quantified using scores or utilities. The difference is that the assessor no longer needs to provide a single average score to represent his assessment. Instead, he can record his judgments as they stand. For instance, if there is evidence to show that a strategy A1 is sound ("Mixer"), if A1 is deployed in about ¾ relevant areas ("Stirrer") and if there is some evidence to show that A1 is implemented in its early stages ("Receiver"), then the original assessment of A1, denoted by S(A1), can be recorded as follows:

$S(A_1)$ = SOUND: {(assessed to the "Mixer" level, absolutely sure)};
DEPLOYMENT: {(assessed to the "Stirrer" level, absolutely sure)};
IMPLEMENTATION: {(assessed to the "Receiver" level, absolutely sure)}.

In the above recorded assessment, "absolutely sure" is a 100% belief that the assessor attaches to the assessment and can be interpreted as his subjective probability, which can be represented by a decimal number of 1.0. So, the assessment could be written in the following simplified format.

$S(A_1)$ = SOUND: {("Mixer", 1.0)};
DEPLOYMENT: {("Stirrer", 1.0)};
IMPLEMENTATION: {("Receiver", 1.0)}.

Supposed that the three elements (i.e., Sound, Deployment, and implementation) are given equal importance in the assessment of an approach and the weights of the three elements are normalised to unity, the weight for each element is 1/3. Then, the assessment can be re-written (see Table 7). For instance, the weighted assessment of A_1 can be re-written as:

$S(A_1)$ = {("Compliance", 0.0), ("Receiver", 1/3), ("Mixer", 1/3), ("Stirrer", 1/3), ("Challenger", 0.0)};

which reads that the approach (A_1) is to a degree (1/3) assessed to "Receiver" (implementation), to a degree (1/3) assessed to "Mixer" (strategy) and to a degree (1/3) assessed to "Stirrer" (approach).

Although the average score of the above assessment could be 50% if the grades are quantified as in Table 6, the above distribution recorded the original assessments without averaging and therefore is more realistic and informative. It indeed provides a panoramic view about the strategy. Note that the average mark of 50% could be related to very different assessments such as the following two distributed assessments:

$S(A_2)$ = {("Compliance", 0.0), ("Receiver", 0.0), ("Mixer", 1.0), ("Stirrer", 0.0), ("Challenger", 0.0)};

$S(A_3)$ = {("Compliance", 1.0), ("Receiver", 0.0), ("Mixer", 0.0), ("Stirrer", 0.0), ("Challenger", 1.0)};

In other words, with the same average score of 50%, A_2 is precisely assessed to the average grade ("Mixer") but A_3 is by no means assessed to the average grade at all. Rather, it is assessed to one extremely good grade "Challenger" on one hand and also to the opposite extreme grade "Compliance" to the same degree. In most situations, we may not regard the above three assessments: $S(A_1)$, $S(A_2)$, and $S(A_3)$, to be equivalent despite of their equal average score. Indeed, the strengths and weaknesses of A_3 are clearly reflected in the distributed assessment $S(A_3)$. However, this will not be the case if an average score of 50% is given to A_3 instead.

Therefore, it can be concluded that the distributed assessment is preferred to average scoring for assessment of NPD strategies. This is attributable to 1) the former carries much richer information than the latter, and 2) the main purpose of such assessment is to identify the strengths and weaknesses of each strategy for further improvement and business decision making. One unique feature of a distributed assessment is that the lack of evidence can be explicitly recorded. In such cases, the total belief degree will not be summed to one but less than one. The difference is referred to as ignorance, which is common in subjective assessment due to the lack of evidence or the assessor's inability to provide accurate judgments.

5.2 Development of Assessment Guidelines

Assessment based on defined grades could be conducted in a more consistent and reliable way if appropriate guidelines are provided about what should be looked at for achieving the grades. In our proposed assessment model, guidelines (or checklists) of all assessment attributes were developed based on literature reviews and the best practices learned from the industries. Expert focus group discussion and interviews were conducted to establish the knowledge bases. Due to the dynamic nature of the area of study, the assessments of NPD strategy elements are largely based on the intuitive competencies of the participants and experts. Table 8 shows part of the checklist items developed for the Organisation Aspects. The knowledge base can be used for a company assessing how they are addressing each of these attributes. A report is then produced along each of the 14 attributes and the results assessed and scored, together with an overall recommendation to the company whether they should proceed with proactive NPD and to what extent, varying from compliance to challenger, for the time being.

Table 8. Excerpted Checklist for the Organisation Aspects

2.1 Teamwork Approach a. How does the company develop effective teamwork in organisational environment? • Clear objectives: early involvement of the key internal functions and external organisations. • Good organisational relationship: integrating all relevant functions in the NPD process. • Clear and effective communication: facilitating communication among the different groups involved in the NPD process. • Methods and mechanism: establishing role and priority of project progress reviews. b. How does the company develop teamwork culture in the organisation? • Adopting a team approach for the whole organisation • Removing the tram from a dominant bureaucracy • Team empowerment and self-management • Attention to team selection and team formation • Recognition of people issues and support for training and leadership development • Use of tangible and symbolic team-based rewards
2.2 Innovative Design and Atmosphere a. How does the company develop innovative design? • Structuring organisation for favoring creativity and inventiveness. • Supporting unplanned product initiatives. • Choosing the appropriate people for critical innovative roles. • Eliciting and supporting new products and initiatives from employees. • Cross-functional product design and development team. • Rewarding entrepreneurial behaviour. • Soliciting new product ideas from outsiders. b. How does the company develop culture and atmosphere for innovation? • Management involvement: leadership commitment and involvement, corporate identification and unity. • Organisational structure: autonomy and flexibility. • Encouraging new idea development and entrepreneurship: challenge and belief in action, freedom and risk taking. • Making innovation policies shared and understood in the organisation: cross-functional interaction and freedom, trusts and openness, debates. • Defining performance measurement system: encouraging innovation, awards and rewards, innovation time and training.

5.3 The ER Approach

Using the assessment model (see Table 6), a distributed assessment of any sub-criterion A_1, denoted by $S(A_1)$, can be represented by:

$$S(A_1) = \{(H_1, \beta_{1,1}), (H_2, \beta_{2,1}), (H_3, \beta_{3,1}), (H_4, \beta_{4,1}), (H_5, \beta_{5,1})\}$$

where, H_n (n=1, …, 5) are assessment grades with H_1 standing for "Compliance", H_2 for "Receiver", H_3 for "Mixer", H_4 for "Stirrer" and H_5 for "Challenger". $\beta_{n,1}$ is a belief degree to which the sub-criterion A_1 is assessed to the grade H_n with $1 \geq \beta_{n,1} \geq 0$ and $\sum_{n=1}^{5} \beta_{n,1} \leq 1$. $S(A_1)$ reads that the sub-criterion A_1 is assessed to the grade H_n to a degree of $\beta_{n,1} \times 100\%$ (n=1, …,5). $S(A_1)$ is regarded as a complete distributed assessment if $\sum_{n=1}^{5} \beta_{n,1} = 1$, and an incomplete assessment if $\sum_{n=1}^{5} \beta_{n,1} < 1$ with the degree of ignorance explicitly represented by $(1 - \sum_{n=1}^{5} \beta_{n,1})$. The above model is referred to as the belief structure. It is desirable that the assessments of all sub-criteria should be complete. In self-assessment, however, it is inevitable that the assessments of some criteria will be incomplete due to the highly subjective nature of the process and the possible lack of evidence (Chin et al., 2009). The ER approach is capable of handling both complete and incomplete assessments in a consistent manner. It has been shown that numerical data can also been modeled using the belief structure through the equivalent transformation of information (Yang et al., 2006).

Other criteria can also be assessed using the belief structure. For example, the assessment of a sub-criterion A_2, denoted by $S(A_2)$, can be represented as follows:

$$S(A_2) = \{(H_1, \beta_{1,2}), (H_2, \beta_{2,2}), (H_3, \beta_{3,2}), (H_4, \beta_{4,2}), (H_5, \beta_{5,2})\}$$

After each strategy is assessed on the sub-criteria listed in Table 4 individually, the assessments are synthesised to generate combined assessments on each of the upper level criteria: *corporate decisions, organisation aspects, marketing strengths, manufacturing strengths*, and *research and development strengths*. After the upper level criteria are all assessed, the overall assessment of each strategy on the top-level criterion "Assessment of Proactive Product Development Strategies" can be generated. It is desirable to preserve the diversity of the assessments in the synthesis process for identification of various proactive strategy adoption status. The ER algorithm provides a sound process to meet the need.

The ER algorithm can be used to aggregate assessments either in a recursive fashion or at one go. The former is easier to understand, and the latter is desirable in situations where an explicit synthesis function is required. This paper only discusses the recursive algorithm. The discussion is limited for synthesising the assessments for a group of sub-criteria that is sharing the same upper level criterion, denoted by y. Supposed that there are L sub-criterion in the group, ω_k is the weight of the k^{th} sub-criterion. The weights for all the L sub-criteria are normalised to unity, i.e.

$$1 \geq \omega_k \geq 0 \qquad \text{and} \qquad \sum_{k=1}^{L} \omega_k = 1$$

The ER algorithm has the property of commutativity, so assessments can be combined in any order. It is therefore sufficient to show how two assessments are combined. The combined assessment can then be synthesised with another assessment and so on until all the assessments on the sub-criteria in the group are synthesised. Take for example the synthesis of $S(A_1)$ and $S(A_2)$ to generate a combined assessment $S(A_1) \oplus S(A_2)$. First, generate the basic probability assignments $m_{n,1}$ and $m_{n,2}$ as follows (Yang et al., 2006):

$$m_{n,1} = \omega_1 \beta_{n,1} \ (n=1, \ldots, 5) \text{ and}$$

$$m_{H,1} = 1 - \omega_1 \sum_{n=1}^{5} \beta_{n,1} = 1 - \omega_1$$

$$m_{n,2} = \omega_2 \beta_{n,2} \ (n=1, \ldots, 5) \text{ and}$$

$$m_{H,2} = 1 - \omega_2 \sum_{n=1}^{5} \beta_{n,2} = 1 - \omega_2$$

$m_{n,1}$ measures the relative degree to which the assessment $S(A_1)$ (evidence) supports a hypothesis that the upper level criterion y should be assessed to the grade H_n. $m_{H,1}$ represents the unassigned probability mass after only A_1 is taken into account for the assessment of y. $m_{H,1}$ and $m_{H,2}$ are each split into the following two parts (Yang et al., 2006):

$$\overline{m}_{H,i} = \overline{m}_i(H) = 1 - w_i,$$

$$\tilde{m}_{H,i} = \tilde{m}_i(H) = w_i(1 - \sum_{n=1}^{N} \beta_{n,i}(a_l)),$$

$$m_{H,i} = \overline{m}_{H,i} + \tilde{m}_{H,i} \qquad i = 1,2$$

$\tilde{m}_{H,1}$ measures the relative ignorance in the assessment $S(A_1)$ and it will not be zero if the assessment $S(A_1)$ is incomplete. The two assessments can be aggregated as follows:

$\{H_n\}$:

$$m_{n,I(2)} = K_{I(2)}[m_{n,1}m_{n,2} + m_{n,1}m_{H,2} + m_{H,1}m_{n,2}],$$

(n=1, …, 5)

$\{H\}$:

$$\tilde{m}_{H,I(2)} = K_{I(2)}[\tilde{m}_{H,1}\tilde{m}_{H,2} + \tilde{m}_{H,1}\overline{m}_{H,2} + \overline{m}_{H,1}\tilde{m}_{H,2}]$$

$\{H\}$: $\overline{m}_{H,I(2)} = K_{I(2)}[\overline{m}_{H,1}\overline{m}_{H,2}]$

$$K_{I(2)} = \left[1 - \sum_{n=1}^{N} \sum_{\substack{t=1 \\ t \neq n}}^{N} m_{n,1} m_{t,2}\right]^{-1}$$

where, $m_{n,I(2)}$, $\widetilde{m}_{H,I(2)}$ and $\overline{m}_{H,I(2)}$ are combined probability masses generated by aggregating $S(A_1)$ and $S(A_2)$. $K_{I(2)}$ is an normalisation factor so that $\sum_{n=1}^{5} m_{n,I(2)} + \overline{m}_{n,I(2)} + \widetilde{m}_{n,I(2)} = 1$. After the assessments on all the L sub-criteria are aggregated in the same fashion, a normalisation process is employed to generate the belief degrees for the assessment of y. The normalisation process is given by (Yang and Xu, 2002a, b):

$$\{H_n\}: \ \beta_n = \frac{m_{n,I(L)}}{1 - \overline{m}_{H,I(L)}}, \ n = 1, \cdots, N$$

$$\{H_n\}: \ \beta_H = \frac{\widetilde{m}_{H,I(L)}}{1 - \overline{m}_{H,I(L)}}$$

and the assessment for the upper level criterion y is given by $S(y) = \{(H_n, \beta_n), n = 1, \ldots, N\}$, which is still a distributed assessment. Average scores can also be defined for ranking alternative strategies. Due to the possible lack of evidence, a range of scores (score interval) rather than a point score is defined for a distributed assessment as follows:

$$u_{\min} = (\beta_1 + \beta_H) u(H_1) + \sum_{n=2}^{N} \beta_n u(H_n)$$

$$u_{\max} = \sum_{n=1}^{N-1} \beta_n u(H_n) + (\beta_N + \beta_H) u(H_N)$$

$$u_{avg} = \frac{u_{\max} + u_{\min}}{2}$$

Where, $u_{\max}$, $u_{\min}$ and u_{avg} represent maximum, minimum and average scores, respectively. Note that in the above equations it is assumed that the grade H_{n+1} is preferred to H_n.

Based on the ER approach and methodologies mentioned above, the degree to which a criterion is assessed, with respect to one of the five scoring grades, is directly dependent on the evidence that supports the judgment. With the ER approach, there is little compromise between the data collection process and effective evaluation, since the accuracy of the judgment is directly proportional to the amount of accumulated evidence. The major difference between the ER approach and the conventional scoring methods comes from the manner in which initial assessments are provided and aggregated. Instead of providing an average score accompanied by the description of strengths and weaknesses, the ER approach employs the belief structure to facilitate distributed assessment (or evidence-based mapping), consistent with the identification of strengths and weaknesses.

The words and terms used by the organisation in their application document may not coincide with the definition of the scoring grades and this can present difficulties in judging the evidence collected. This requires the interpretation and subjective judgment of assessors to categorise the evidence. For such a qualitative judgment, or in case that the assessors are unable to provide a precise judgment, the ER approach allows a user to define a degree of belief which is less than 1 (i.e. 100%). No other multiple criteria decision analysis approach can deal with this type of uncertainty (or ignorance) and this avoids making inappropriate assumptions and thus helps to reduce any inaccuracies. Each of the developed checklist items will then be judged using a belief structure. The degrees of belief in a distributed assessment for each of the checklist items are multiplied by the weightings of the item and totaled to produce a distributed assessment for the criteria associated with the checklist items.

5.4 The Assessment Feedback Report

According to the ER-based scoring, the final score together with a feedback report would be generated. The report consists of the overall score, sub-scores of all attributes, strengths and areas for improvement. The feedback is a crucial component of the self-assessment process, acting as a catalyst for action and providing helpful and objective information to trigger improvement. This also provides a logical and systematic way for a year-to-year comparison and a benchmarking tool for a group of companies within a corporation.

6. Conclusions

Nowadays, the keen global competition, rapid technological change and shifting patterns of global markets push manufacturers to strive for competitive NPD. For business growth and survival, a manufacturer should entice potential customers with products of better quality and lower price, and introduce new products faster than its competitors. Managing effective NPD is a must rather than an option for manufacturers in Hong Kong and elsewhere in other places. There is no quick fix or turnkey solution readily for competitive NPD. This paper contributes to identifying four decision criteria and 14 influential elements/sub-criteria of the NPD strategy formulation and developing an assessment model of strategy choices for manufacturers.

The study consolidated the expert evaluations with the aid of AHP and ER techniques. It was found that the risk and uncertainty, market competition, company growth, scale of market, distribution channel, manufacturing capability and technological R&D were important influential elements/sub-criteria leading to the adoption of proactive NPD approach.

The proposed model for assessing the feasibility of proactive NPD strategies is based on the evidential reasoning approach. The efficacy of the model depends on the establishment and customisation of a knowledge base which should be built and validated for individual companies. Although the findings from this study are within the specific context of manufacturing scenario in

Hong Kong, this study opens up a number of questions for further investigation. For instance, the assessments and aggregation would not be reliable or consistent without gathering sufficient evidence.

Further research is needed to identify specific factors and investigate the relevancy of the model to assess the NPD strategies and practices. It would be helpful to diagnose the study findings as a reference and use the study methodologies to conduct similar studies for other industries, regions and countries. Besides, flexible modifications of study instruments and methods should be applied to deal with possible variations of decision criteria and elements and the differences in the background and nature of industry sectors, market competitions, and government regulations and policies observed.

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