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Scenario-driven modular design in managing market uncertainty

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Abstract: Many organisational environments are far from equilibrium. The strategic flexibilities of modular product designs can help organisations prepare for an uncertain future, but managers must develop ways to imagine possible futures in order to use such flexibilities to respond to them. This paper discusses a scenario-based approach to anticipating and responding to uncertain futures by developing modular products that increase a firm's chances of succeeding in multiple alternative futures. After introducing the theoretical basis of this study, a structured approach to operationalising the generation of future scenarios and the development of modular product designs is developed. The approach consists of four stages: (1) the generation of scenarios about future market needs, (2) the translation of those needs into goals for modular designs, (3) the modular design process itself and (4) the evaluation of the modular design process. The modular design process we discuss is a function-based design approach that is form independent and thus allows joint consideration of future market needs and the product functions that can serve those needs. We illustrate our proposed approach by applying it to generate scenarios and modular design criteria for the Closed Circuit Television (CCTV) market in the security equipment sector in Turkey.

Keywords: design capabilities; function-based design; market uncertainty; modular product design; modularity; scenario planning; scenarios; strategic flexibility.

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1 Introduction

Organisational environments today are far from a steady equilibrium (Foster, 2000). Increasingly, organisational environments seem to be characterised by dynamism, complexity, uncertainty, ambiguity, nonlinearity and aperiodicity (Stacy, 1995; Black and Fabian, 2000). The fundamental strategic question that arises within such market environments is, ‘What can an organization do in developing new products to create and/or maintain competitive advantage?’ The development of modular product designs may provide important strategic flexibilities that can improve a firm’s ability to respond to future events – for example, by using modular designs to configure new product variations and enable the rapid technological upgrading of products (Sanchez, 1995; Sanchez and Mahoney, 1996).

The configurability and upgradability of modular designs is not unlimited, however. Modular designs can only be developed to provide a range of product variations intended to serve a range of imagined futures (Sanchez, 1995). Managers must therefore find ways to imagine the possible futures to be served by modular designs. Scenario planning has been developed to provide a disciplined method for imagining possible futures

(Schoemaker and Amit, 1997). Scenario planning tries to interpret a complex and uncertain future in ways that enable managers to imagine specific kinds of alternative futures. In this paper, we undertake to show how scenario planning can be used as the driver of the development of modular product designs that can be configured and upgraded to respond to a range of imagined futures (Schoemaker, 1992; Schoemaker and Amit, 1997; Polat and Asan, 2005; Sonne *et al*., 2002; Gausemeier *et al*., 1998).

To this end, we draw on prior work on the competence analysis (Klein and Hiscocks, 1994; Asan and Soyer, 2003) of an organisation's skill base. We also extend prior work by Polat and Asan (2005) that proposes a methodology for generating broad future scenarios, identifying specific product scenarios within alternative future scenarios, and then defining specific capabilities that would be strategically important under the imagined product scenarios. In this methodology, product scenarios provide a useful way to think in a concrete way about the future and the possible product variations that a firm would find advantageous. More specifically, our study focuses on a product design methodology based on *modularity* for translating future customer needs into future products under conditions of uncertainty (Sanchez, 1995; 1999; 2004; Sanchez and Mahoney, 1996). We explain how modular product designs provide a way to respond to a range of possible future market needs by developing products with high levels of configurability and evolvability – and therefore why a modular design is an important capability in the competence of any firm facing significant future market uncertainty. (A detailed explanation of how to develop modular designs is beyond the scope of this paper. See Sanchez (2000), however, for a more detailed discussion of modular design processes.)

2 Modular design capability

We now define the concepts *design* and *modularity*. Design is the process of inventing objects whose technical structures enable them to perform desired functions for customers and users (Alexander, 1964). The structure of a design describes how a product is constituted, how the design works as it does, and what it does in delivering a fundamental customer benefit (Baldwin and Clark, 2000). The structure of a product design is described in turn by its *architecture* (Sanchez and Mahoney, 1996; Asan *et al*., 2004; Sanchez, 2004; 2008), which describes the kinds of functional components in a design and the ways the components interact in the design as a system of components.

Modularity enables the development of architectures that provide a way of interrelating components in a design so that some range of variations in each type of component can be substituted ('plugged and played') into the design to configure product variations (Sanchez and Mahoney, 1996; Sanchez, 1999). The interface specifications (Sanchez, 1999) in a modular product architecture define how components interact in the design and thus determine the ways in which components can be substituted into the architecture. Interface specifications in a modular architecture thus provide a set of *design rules* (Baldwin and Clark, 2000) governing the ways in which product variations can be configured within the architecture. Modular architectures are increasingly being used to create 'platforms' for leveraging product variations in markets for automobiles, consumer electronics, personal computers, software, power tools, household appliances and other products (Sanchez and Mahoney, 1996; Sanchez, 2004).

Because of their greater configurability, modular designs allow faster product evolution (O'Grady, 1999; Tsai and Wang, 1999), help to manage complexity (Baldwin and Clark, 2000), lower costs, increase product variety and improve a firm's strategic flexibility to respond to an uncertain future (Sanchez, 1995; 1997). A key premise for the arguments in this paper, therefore, is that a capability for creating modular designs should be an essential aspect of the competence of any company facing dynamic, uncertain market environments (Sanchez, 1995; Worren *et al.*, 2002).

Several studies support our view that product design/development capability is an important part of a firm's competence base (Deutsch *et al.*, 1997; Mäkinen, 2005; Eisenhardt and Martin, 2000; Helfat and Raubitschek, 2000; Danneels, 2002). What we now undertake to add to this view is that modular design capability can bring a firm four kinds of important advantages (Javidan, 1998; Prahalad and Hamel, 1990):

1. It helps to provide access to a wide variety of markets.
2. It makes a significant contribution to the perceived customer benefits of the end product.
3. It provides a capability that is difficult for competitors to imitate.
4. It stimulates collective learning in the organisation, especially about how to coordinate diverse production skills and integrate multiple streams of technologies.

Table 1 provides a more detailed listing of the benefits of modular product designs that contribute to the achievement of these advantages.

Table 1 Benefits of modular product design capabilities

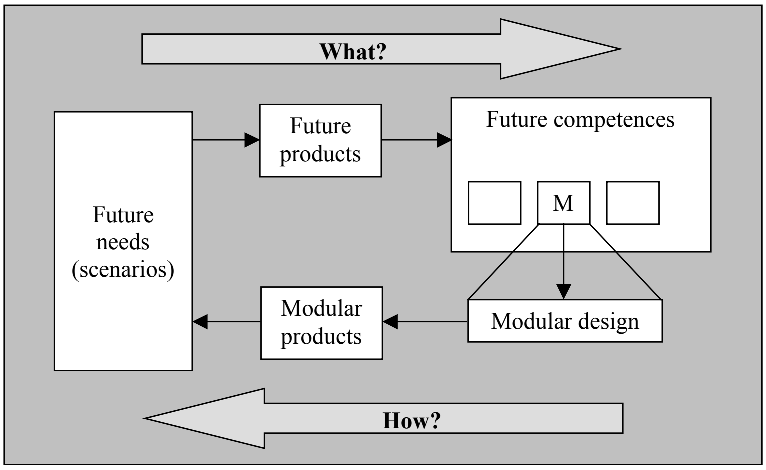
Increased variety in products. Increased ability to configure products to meet diverse customer needs by mixing and matching components (Sanchez, 1999; Schilling, 2000)
Reduced costs of product variety. Greater configurability of designs enables leveraging of products to support several product lines and businesses. Greater strategic flexibility (Sanchez, 1995)
Providing customised products (Pine, 1993), greater variety and low costs (O'Grady, 1999)
Faster introductions of higher-performing products (Sanchez, 2002b; Worren *et al.*, 2002)
Ability to reduce coordination cost and complexity of development process (Sanchez and Mahoney, 1996)
Improved architectural knowledge (Sanchez, 2002a)
Hidden design rules that may be hard to imitate (Baldwin and Clark, 2000)
Embedded hierarchical coordination of distributed component development teams (Sanchez and Mahoney, 1996)
Accelerated technological learning (Sanchez, 2002a–b)

Finally, we also note that the creation of a modular design capability can be quite challenging to firms. As a key capability, a modular design requires the integration of a variety of individual skills (Hamel, 1994); the development of architectural knowledge (Sanchez, 2000); a correct interface design and standardisation; the integration of know-how, know-why and know-what forms of knowledge (Sanchez, 1997); insights into the possible range of customer preferences (Sanchez and Heene, 2004); and other organisational knowledge and capabilities (Sanchez, 2000).

3 Scenario-driven modular design

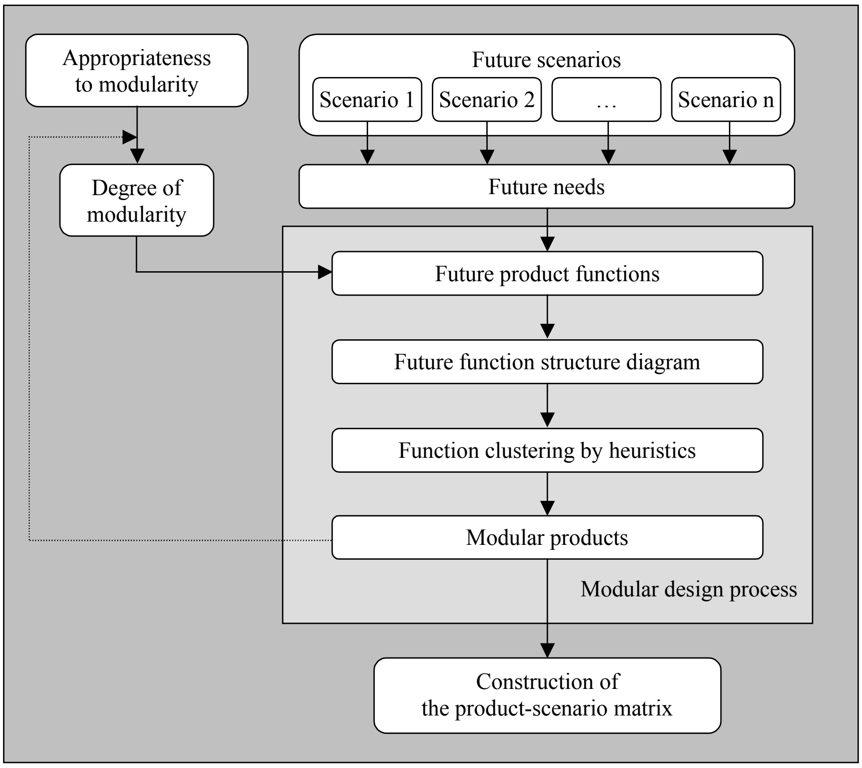
Scenarios provide a managerial tool for imagining multiple alternative futures and the products that markets may want in the alternative futures. Figure 1 illustrates an integrative model that encompasses scenario generation, modular design capability, and future design capabilities and activities. This model provides the framework for our research questions and research design. In the figure, the question 'What?' indicates the need to try to anticipate possible futures from the perspective of the present, while the question 'How?' indicates the need to understand how to begin in the present to prepare for an uncertain future. In this paper, we will explain how using scenarios can help anticipate the 'What?' and how modular design capability provides an important (and perhaps essential) answer to the 'How?' We also suggest how scenario generation and modular design help significantly to sustain a continuous cycle of competence identification, competence building and competence leveraging in the face of an uncertain future (Sanchez and Heene, 1996; 1997).

Figure 1 An integrative framework linking scenarios, modular design and future competences



The next section explains the theory that underlies this integrative model. We then develop a structured approach for implementing scenario generation and modular design, which we will refer to as 'Scenario-driven Modular Design' (SDMD), in which future market and technology scenarios are imagined, and future modular product concepts are defined to offer the greatest chance of success in the multiple imagined futures. Figure 2 summarises the specific steps in this process. In the first step, possible futures are imagined through a scenario-planning method, and these scenarios are transformed into "necessity scenarios" (Polat and Asan, 2005) that define the most likely future "core needs" of customers. In parallel with the first step, the potential for a modular design is assessed, and the modularity required to support various product concepts is evaluated. Identified future customer needs are then translated into future product functions, which are used to construct a function structure diagram. Applying some heuristics, subfunctions in the function structure diagram are clustered into modules. After all functional components (modules) in the product design are defined, a module-scenario matrix is constructed to help define future products. A consistency analysis is then performed to select the possible future products that have the greatest potential to be successful products in multiple alternative futures. In Section 4, we then illustrate these steps in SDMD through the example of Closed-Circuit Television (CCTV) in the Turkish market.

Figure 2 Steps in implementing a scenario-driven modular design process



3.1 *Constructing future scenarios*

A wide variety of methods can be used to generate scenarios; generally, the choice of methodology will depend on the problem, the resources available and the levels of sophistication of the planners and users (Raubitschek, 1988). In this study, a qualitative scenario-planning method proposed by Godet (1994) is adopted. This qualitative method comprises two steps (Godet, 1994; Godet *et al.*, 1999):

1 *Building the base* – This phase attempts to construct a base image of the past and present state of the firm as a system and its environment. The base image is constructed in three steps:

  - Define the firm as a system and its environment.
  - Determine the key variables.
  - Analyse the various actors' strategies.

Structural analysis is used to perform the first two steps. The third step aims to identify the mechanisms and the leading actors which have an influence on the development of the system.

2 *Scanning the range of possible future images and reducing uncertainty* – Possible future images of the firm and its environment are generated as a set of hypotheses based on the identified key variables and likely actors' strategies. Morphological analysis is then used to scan possible futures (possible combinations of variables and strategies). To reduce uncertainty and identify the most probable future scenarios, expert methods are used to assist managers in estimating subjective probabilities of the possible future images generated. Finally, likely or necessary pathways from the base image (present situation) to the identified future images are described.

3.2 Analysis of the appropriateness of modular designs

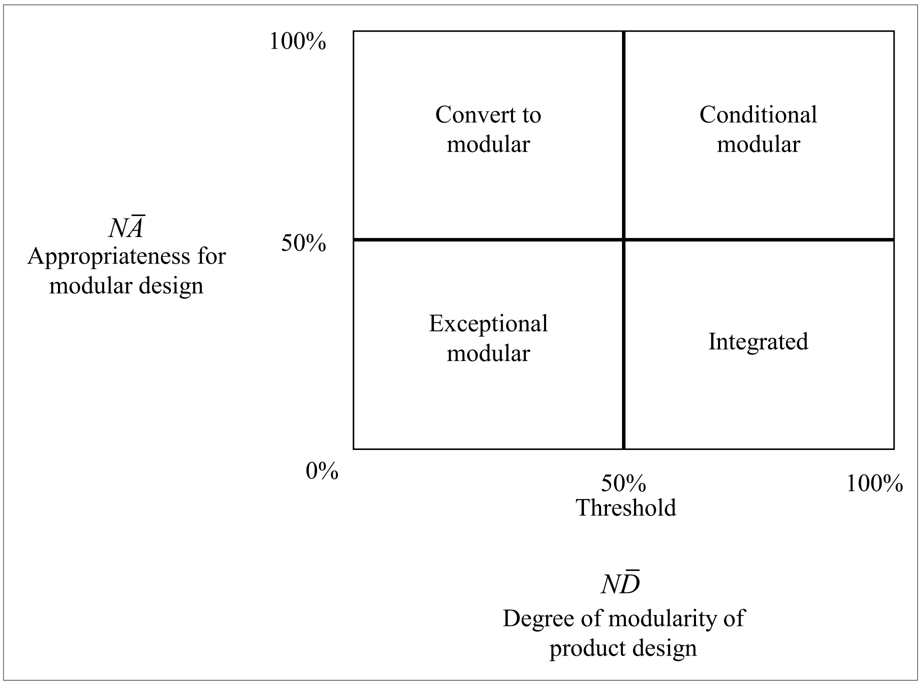
Although some researchers argue that modular designs constitute a new and superior paradigm for the design of all kinds of products (Sanchez, 2008), others have suggested that modular designs may not be the solution to all design problems (Baldwin and Clark, 1997). Some studies have also argued that there are trade-offs between modular designs and integrated designs (Erens and Verhulst, 1997), usually focusing on posited trade-offs between greater product variety and higher-performing products. Thus, we propose that a useful next step is to analyse whether and why a product or product family should have a modular design. Asan *et al.* (2004) developed a questionnaire based on the interfirm product modularity model proposed by Schilling (2000) to address this question. In the questionnaire, important external factors such as market and technology trends and internal factors such as component synergies and firm capabilities are assessed to derive an overall score ($\overline{NA}$) on a 100-point scale. The score derived approximately indicates the *appropriateness* of a modular design for a given product concept, with a score of 100 indicating the highest possible level of appropriateness for a modular design. Product concepts and families with greater-than-average scores will generally be judged appropriate for modular designs.

3.3 Evaluation of the degree of modularity

Modularity is not a dichotomous variable (Ulrich and Eppinger, 1995), and most product designs can be classified along a continuum from highly modular to highly integrated (Worren *et al.*, 2002). The next step after determining the need for a modular product design in the future is to determine how modular a firm's current design of such a product is. In the approach we present here, we adopt a questionnaire developed by Asan *et al.* (2004) to evaluate the degree of modularity of a product's current design. The questionnaire assesses the degree of modularity indirectly by determining if any modular design rules have been used in creating the product design, and assesses modularity directly by evaluating the designs of current products.

An overall score ($\overline{ND}$) is calculated on a 100-point scale to obtain the degree of modularity of current product designs (or proposed designs). Current product designs that score over an average of 50 points may be considered for revision or upgrading of their modular architectures if such changes could adequately configure the products needed to serve future customers needs. A product design that scores low on its current degree of modularity, but high in the degree of appropriateness for a more modular design to meet future market needs, may have to have its architecture converted from an integral design to a more modular design. (A firm's current product design may also be benchmarked against competitors' or best-practice firms' product designs on the dimensions of degrees of modularity and appropriateness.) The four possible outcomes from applying this test for the degrees of current modularity and appropriateness for future modular designs are shown in Figure 3.

Figure 3 The $N\bar{A} - N\bar{D}$ decision matrix



The four outcomes shown in Figure 3 can be elaborated as follows:

1. If $N\bar{A} \geq 50\%$ and $N\bar{D} < 50\%,$ this combination is named 'Convert to Modular', and the architecture of a current or proposed product or product family should be converted to a modular architecture.
2. If $N\bar{A} \geq 50\%$ and $N\bar{D} \geq 50\%,$ this combination is named 'Conditional Modular', and in this case an additional constraint should be considered. If $N\bar{A} \geq N\bar{D},$ a modular architecture will be appropriate in the future. Because the product is already quite modular $(N\bar{D} \geq 50\%),$ however, an increase in the degree of modularity of the current design could be considered. On the other hand, if $N\bar{A} < N\bar{D},$ the current degree of modularity of the design should be maintained.
3. If $N\bar{A} < 50\%$ and $N\bar{D} < 50\%,$ this combination is named 'Exceptional Modular', and additional information on firm strategy and competitive conditions will be needed to make a decision. For instance, depending on the firm's strategy at different

stages in the Product Life Cycle (Sanchez and Heene, 2004, Chap. 9), there may be advantages in changing the architecture into a more modular one – for example, to allow rapid performance upgrading in the 'rapid growth' stage of the Product Life Cycle, or greater product variety and differentiation in the 'maturity' stage. If $N\bar{A} < N\bar{D}$, the current architecture may be sufficient to meet future needs, or may even be considered for conversion into a more integral design.

4 If $N\bar{A} < 50\%$ and $N\bar{D} \geq 50\%$, this combination is named 'Integrated'. Although the current architecture of the product or product family is to some degree modular, there may be advantages in having a more integral design in the future – *e.g.*, to reduce the cost of improving performance. In this case, the product architecture could be changed to a more integrated design.

3.4 Identifying future needs

Since a fundamental goal of modular design is to provide a firm with modular product designs that are robust in their ability to be used across as wide a range of future scenarios as possible, it is essential to clarify the future market needs that modular product designs must serve in each imagined scenario. For example, in scenario analysis in the security industry, future market needs can be explored by asking questions like 'What specific security threats do we need to eliminate or prevent?' for each imagined scenario. It may therefore be useful to involve industry experts – especially customers – in such exercises.

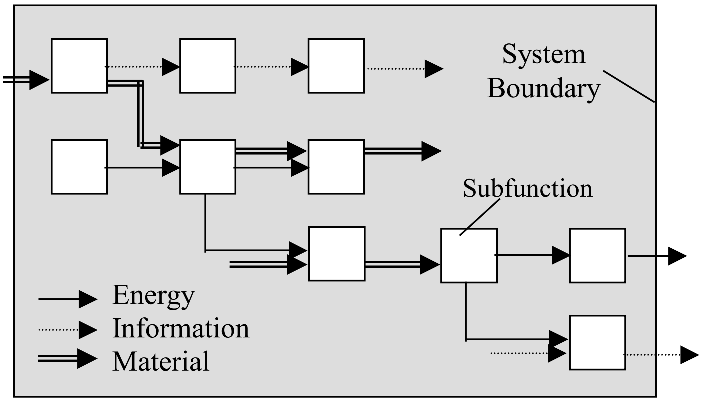
3.5 The modular design process

The next step in our modular design process is to extract from the identified future market needs a set of product functions that can be effective in serving those needs and that can be offered to customers through a modular architecture (Sanchez, 1999). Possible approaches to defining and designing modular products include focusing on structure (Baldwin and Clark, 2000), function (Otto and Wood, 2000), customer needs (Yu *et al.*, 1999), or sources of perceived product differentiation (Sanchez, 1999). In this study, we suggest a function-based approach to defining a modular architecture, because it is *form independent* – independent of how the function is performed (Dahmus *et al.*, 2001) and therefore independent of the specific forms of future products that can be configured from the architecture.

3.5.1 Function-based design

Functions are the operations or activities performed by a product (Otto and Wood, 2000). In function-based design methods, the functions of products or product families are represented schematically. Depending upon the nature of the system to be described, function trees, function structure and other function-logic diagramming methods can be used to illustrate links among functions and subfunctions (Zamirowski and Otto, 1999). The function structure diagram shown in Figure 4, for example, has proved to be an effective functional modelling method for electromechanical systems (Pahl and Beitz, 1996). The aim of this function diagramming method is to identify the types of components needed to provide a desired set of functions, and to identify both the common and differentiating modules (Sanchez, 2004) required to leverage a range of anticipated product variations within a product family. Determining all possible component variations needed to provide all desired functions and subfunctions can be quite a complex combinatorial problem; therefore some heuristic methods have been developed to help define modular product function structures (Zamirowski and Otto, 1999; Stone *et al.*, 1998).

Figure 4 A product function structure diagram



The steps in function-based design analysis are summarised below (Otto and Wood, 1998; 2000):

Step 1 Create a black-box model (identifying the global function of the overall product and the product's input and output flows of materials, energy and information).

Step 2 Identify the customer needs for such a product.

Step 3 Develop an activity diagram (process description) to analyse the functions that must be delivered to the user by the product and to specify the development process through which the product design will be created and realised.

Step 4 Using the process description and analysis of customer needs, formulate a hypothesised function structure for the product.

Step 5 Combine various function structures generated to form the family function structure (for product families).

Step 6 Apply function and variety heuristics to define the modular product structure and family function structures.

Step 7 Select the most appropriate modular architecture(s) from among those generated through the preceding steps.

3.5.2 Modularisation rules (function and variety heuristics)

Stone *et al.* (1998) have identified three types of heuristic methods that can be applied in defining modular product function structures:

1 a dominant flow heuristic, which analyses flows through a product function structure, following flows until they either exit from the product as a system or are transformed into another flow

2 a branching flow heuristic, which examines flows that branch into or converge from parallel function chains

3 a conversion-transmission heuristic, which examines flows to ascertain where one type of flow is converted to another.

This heuristic approach have been proposed to identify component types in the function structure of a single product. When analysing a product family, additional rules can be applied in defining components (Zamirowski and Otto, 1999). The product family heuristics help to identify *common functions*, with similar flows and functions that appear multiple times in the function structures of a portfolio of products (*e.g.*, a product family), and *variant functions* that are unique to a single product variation or subsets of product variations. Through the application of such heuristic rules, various types of components can be identified and described and a desirable range of variations for each type of component proposed (Gonzalez-Zugasti and Otto, 2000; Sanchez, 2000).

3.6 Construction of the product-scenario matrix

Once component types and desired variations of individual component types are identified, to create a modular architecture, interfaces between components must be specified to allow the 'mixing and matching' of component variations with the architecture to support the configuring of future product variations. Even in a product structure with relatively few component types and few variations within each component type, the combinatorial set of future product variations can become very large.[1] Of course, some product variations that could be configured within a modular architecture may not be commercially viable product variations because of imbalances among the performance characteristics of the component variations. For example, a personal computer with a high-capacity memory that is limited in its usefulness by a slow microprocessor may not offer a 'package' of performance benefits that is attractive to consumers (Sanchez, 1999).

Thus, the aim in this stage is to eliminate inconsistent combinations of component variations (modules) in order to reduce the actual number of product alternatives to those that appear to have the best chance of being commercially viable across all future product scenarios. To accomplish this, three steps are taken. First, a module-scenario matrix is developed to determine the range of possible modules that will actually be useful in meeting future market needs as defined through the scenarios generated. Then a consistency analysis is carried out to identify commercially feasible module combinations in possible future products. Finally, a product-scenario matrix based on the outputs of the previous steps is developed to identify the most robust future product variations (*i.e.*, the product variations that appear commercially viable across all or the largest possible range of scenarios).

In the module-scenario matrix, the columns represent future scenarios (bundles of imagined future market needs) and the rows represent the module variations available. A binary scale (0 or 1) may then be used to assess whether a given module variation would be viable in a particular scenario, where '1' means that a module variation would be viable in a given scenario, and ‘0’ indicates that it would not. Table 2 illustrates a hypothetical module-scenario matrix. Here y_i refers to the i-th module type, where $i = 1,\dots,n$ and $y_i^1,\dots,y_i^{n_i}$ refers to the possible variations of the i-th module type. The various scenarios included in the module-scenario matrix are displayed in the top row of the matrix (and are formally defined in our discussion below as $x_{ih}^{n_i}$, where h indicates specific scenarios). The greater the number of scenarios that can be served by a given module variation, the more desirable it will be to include that module variation in the modular architecture to be used in configuring future product variations.

Table 2 A hypothetical module-scenario matrix

Module	*Instance*	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
y_1	y_1^1	1	1	0	1
	y_1^2	0	1	1	1
y_2	y_2^1	1	0	0	0
…	…	…	…	…	…
y_m	y_m^1	1	0	1	1

In the next step, we use the approach of Tietje (2005) to select the scenarios for which one or more modular architectures will be prepared. All possible future product variations under each selected scenario are then analysed to determine the technical compatibility and commercial viability of the combination of component variations in each product variation (von Reibnitz, 1992; Gausemeier *et al.*, 1995; Tietje, 2005). In this study, we apply a consistency analysis to select *consistent and desirable future product variations* (*i.e.*, combinations of module variations). The consistency of a future product architecture as a whole can be estimated by assessing the consistency of the available variations of all pairs of module types. To assess pairwise consistency, different scales have been proposed in the literature. We adopt here the nonnegative five-point scale defined by Gausemeier *et al.* (1995), in which the value 1 is assigned to totally inconsistent pairs of module variations, the value 2 to partially inconsistent pairs of module variations, the value 3 to component pairs that are structurally independent of each other, the value 4 to component pairs that effectively support each other and the value 5 to component pairs that strongly support each other. (To facilitate this process, a symmetric matrix may be constructed to show consistency between all component pairs, but in the interest of brevity we do not show such a matrix here.)

Given each of the n module types y_i, $i = 1,\dots,n$ and possible variations of each module type $y_i^1,\dots,y_i^{n_i}$, k can be defined as the combinatorial number of future product variations based on the n_i numbers of each of n component types. In addition, a future product variation P_k can be represented by a vector $P_k = (y_1^{m_1},\dots,y_n^{m_n})$, where m_i represents one variation of module type n (Tietje, 2005). We may then also define a consistency index ‘C’ for a given module type, as follows:

$$C := c(y_i^{m_i}, y_j^{m_j})_{i,j=1,\dots,n;m_i=1,\dots,n_i;m_j=1,\dots,n_j} \tag{1}$$

where:

$y_i^{m_i}$ = m_i-th variation of the *i*-th module type

n_i = number of variations of the *i*-th module (Tietje, 2005).

We may then calculate an overall consistency index c^* for each future product architecture P_k as follows (Tietje, 2005):

$$c^*(P_k) = \sum_{i=2}^{n} \sum_{j=1}^{i-1} c(y_i^{m_i}, y_j^{m_j}). \tag{2}$$

Finally, to eliminate product architectures with extensive instances of inconsistent module combinations and thereby to reduce the number of alternative product architectures that must be evaluated in greater detail, the set of future product architectures may be filtered by their consistency values c^*. Different criteria may also be defined to choose a subset of product architectures P^* that meet a minimum consistency threshold value c^*_{min}. In this study, we generated a scenario-module matrix and a derived consistency matrix, from which were selected 50 future product architectures with the highest level of consistency among the component pairs and no pairs with total inconsistency.

In the last step, to construct the final product-scenario matrix, the most robust future product architectures should be identified, and the extent to which those architectures are capable of configuring product variations that can serve alternative market future needs (scenarios) should be assessed. These steps generate the inputs for the construction of the product-scenario matrix, which is illustrated in Table 3. Each product element in the product-scenario matrix can then be calculated as:

$$z_{th} = \sum_{(i,n_i) \in R} x_{ih}^{n_i} / n \quad \text{for each h = 1,…,H and t = 1,…,T} \tag{3}$$

where z_{th} defines the average value of how well the *h*-th scenario is met by the *t*-th (t ≤ 50) future product. The set *R* then defines all the pairs (i^*, n_i^*) of module types and variations which are included in the *t*-th final future product architecture vector (P^*_t).

Table 3 A hypothetical product-scenario matrix

Future products	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
$P^*_1 = (y_1^1, y_2^1, y_3^1, \ldots, y_m^1)$	0,5	1	0,7	0,3
$P^*_2 = (y_1^2, y_2^1, y_3^2, \ldots, y_m^1)$	1	0,9	1	0,8
…	…	…	…	…
$P^*_{50} = (y_1^1, y_2^1, y_3^3, \ldots, y_m^1)$	0,2	0,7	0	1
S_h	0,3	0,9	0,7	0,4

Product architectures that would work well in serving all future scenarios are considered ‘robust’ (*e.g.*, P^*_2 in Table 3). These product architectures are the most likely to be successful in the future. In addition, an index reflecting the extent to which all identified future market needs (scenarios) can be served by a given future product architecture can be calculated as:

$$S_h = \sum_{t=1}^{T} z_{th} / T \tag{4}$$

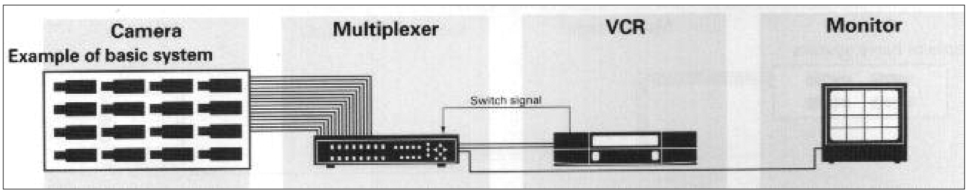
where S_h refers to the average value of satisfaction for the *h*-th scenario. Table 3 shows that Scenarios 2 and 3 can be significantly satisfied by the identified set of product architectures, but neither Scenario 1 nor 4 would be well served by the identified architectures. In the latter cases, either the identified modular product architectures need some modifications to their sets of component variations, or the development of those architectures must be deferred until technological progress enables the achievement of greater technical consistency among the component variations proposed for each architecture.

4 Application of the methodology

We now demonstrate the application of the proposed methodology to the analysis of possible future CCTV systems in the security equipment market in Turkey. According to the research report 'World security products and systems'(Freedonia Research Group, 2002), the fastest growth for security equipment is forecast to be in the world's developing regions, and CCTV will be one of the most rapidly growing electronic security products. At this point, it may be useful to give a short description of a CCTV system.

CCTV is a television system that transmits signals over a closed circuit of electrical conductors, fibre optic cables, or wireless carriers. CCTV systems can overtly or covertly monitor a process or area from a remote location and can record video images of a scene for later viewing.[2] Probably the most widely known use of CCTV is in building security systems for retail shops, banks, government establishments, offices, *etc.* (Constant and Ridgeon, 2000). A CCTV system consists of several primary components: camera, lens, monitor, video recorder, combiner (switcher, quad, multiplexer), coaxial cable, system controller and sensors. Our study analyses CCTV product architectures at this high design level of primary components. Figure 5 illustrates a basic CCTV system.

Figure 5 A basic CCTV system



Source: CCTV Systems Catalog (2001)

4.1 Determining the appropriateness for modularity and the degree of modularity

A questionnaire of the type previously described was sent to experts in this market (both engineers and academicians) and used to assess the appropriateness of CCTV systems for modular designs. Based on this questionnaire, an overall score of $\overline{NA} = 66,5\%$ was obtained, which indicates a fairly high level of appropriateness for modular designs.

(We note that one factor that tended to lower this score was the concern of some of the experts about customers' ability to evaluate, choose and assemble the various available components for a CCTV system.) A second questionnaire of the type previously described was used to determine the desirable degree of modularity. The overall degree of modularity based on our experts' assessments was $N\bar{D} = 80\%$, indicating that a high degree of modularity would be desirable in future product designs.

The combination of the results $N\bar{A} = 66,5\%$ and $N\bar{D} = 80\%$ positions CCTV systems in the Conditional Modular quadrant of Figure 3. Additionally, we determined that $N\bar{A} \leq N\bar{D}$, indicating that it would be advantageous to maintain the basic current architecture of the product, a result more or less to be expected because of the widespread success of the modular structure of current CCTV systems. However, our analysis also showed that the current modular architecture could be improved to better serve future market needs, suggesting the need for a modified modular architecture with a similar degree of modularity.

4.2 Constructing future scenarios

Scenarios developed by Polat and Asan (2005) concerning the security equipment sector in Turkey were used to identify potential future market needs. The scenarios were used to identify a range of possible security threats in the next ten years. The scenarios – given the names 'Biological Complexity', 'Provocative', 'Reign of Mechanics' and 'Tiny-Mini' – are presented below and are abbreviated versions of the original scenarios generated in their study.

4.2.1 Scenario 1: Biological Complexity

One reason security threats can be expected to increase in the future is the rapid development of technology. New kinds of biotechnologies will be developed and used in security products and systems to increase their reliability. The use of biosensors to identify individuals can be expected to become common in a few years. The widespread introduction of biosensor technology into security systems may create the rather grisly possibility that criminals will try to obtain the relevant organs or parts of the human body (fingers, eyes, ears) that are unique to a given person and that will enable them to decode targeted security systems. This development will cause vital threats to people whose human organs can be used to gain access to secured areas, and raise the potential for security systems to be breached.

As biosensor technology advances, security systems will become increasingly individualised. The trend will also be supported by the increased use of computer technology in home security systems, transport systems and communication technology. Travel and communication will become much more technologically complex. New uses of electronics in security systems will increase product complexity, which will in turn reduce product reliability (at least initially), increase product sensitivity to use conditions and increase the difficulty of maintaining security systems. These developments can be expected to encourage efforts to breach security systems, as criminals systematically seek to discover the weaknesses of various security systems in use. Also, actions intending to breach or circumvent security systems will be more sophisticated and more organised. A technology race between the developers of security systems and criminals interested in defeating security systems can easily be imagined.

High rates of immigration into and high urbanisation of the areas that are major markets for security systems will contribute to these problems. Buildings and roads will become more crowded, which will make carrying out robberies and other kinds of crimes easier. Security in streets, parks and other public places will also become an important concern.

4.2.2 Scenario 2: Provocative

Terrorism can be expected to increase and to become an important security concern for governments, corporations and private individuals, especially in crowded cities. Terrorists can be expected to find increasingly clever ways to alter their appearance and to try to conceal their identities, leading to new needs for better identity detection systems. This will lead to much more controlled environments in which all kinds of people will be subjected to increasingly frequent and strict tests of identity.

4.2.3 Scenario 3: Reign of Mechanics

Mechanical means of increasing security will continue to be important because of their low cost and simplicity, but will become increasingly easy for criminals to overcome. Physical assaults on individuals may increase as the growth of urban areas creates more places where criminals can conceal themselves.

4.2.4 Scenario 4: Tiny-Mini

Miniature electronics and tiny integrated systems of many types will become common. Criminals can be expected to begin using programmed robots to breach security systems and carry out crimes. The worldwide availability of internet connections, especially through mobile telephony, will give criminals new means to control remote devices, which will pose an array of new security threats.

4.3 Identifying future needs

Using the scenarios given above, a group of experts was asked to identify the needs (Ni) that the market will experience as a result of the desire to overcome these threats, and the product characteristics (Fi) of a CCTV system that could fulfil these needs. Thus, for each future need, a matching *function-based characteristic* of a CCTV system was identified. We list below a sampling of the market needs and the corresponding functional characteristics identified by the panels of experts under each of the four scenarios.

4.3.1 Market needs and corresponding product characteristics emerging from the Biological Complexity scenario

1. There will be a need for CCTV systems that are resistant to destruction by laser beams (a current means of disabling TV cameras and sensors). (N1)

   Future CCTV systems will therefore need to have functions of laser recognition, laser shielding and laser-beam diffusion (neutralisation). (F1)

2 So that a stolen human finger or other organ will not be sufficient to breach a security system, biosensing will need to scan an entire human being as a whole. (N2)

Several modes of scanning rays based on a number of technologies will have to be used. (F2)

3 Security systems must be able to monitor a broad area, detect rapid motion and react quickly. (N3)

Future CCTV systems must be free-rotating in all directions, have sensors capable of detecting high-speed motion, and capture video images in all directions of rotation. (F3)

4 Precautions must be taken to counteract the increasing technical sophistication of criminals seeking to breach security systems. (N4)

Product architectures must be designed to accommodate continuous technological upgrading to stay one step ahead of sophisticated criminals. (F4)

4.3.2 Market needs and corresponding product characteristics emerging from the Provocative scenario

5 Security system users – especially governments – will need better ways to identify potential perpetrators of security breaches among people routinely observed by security systems. (N5)

Future security system products must be able to quickly access a database with visual characteristics of people who are security risks, so that potential terrorists and other kinds of potential aggressors can be identified. (F5)

6 There will be a growing need to proactively discover the hiding places of potential criminals and to track them as they move about. (N6)

Future security systems must be able to receive data from satellites and transfer data to monitors and cellular phones. Surveillance systems will have to be able to communicate with surveillance satellites to facilitate rapid viewing of specified areas. (F6)

7 The need will grow to detect potential threats in urban areas and take precautionary or preemptive actions to protect citizens. (N7)

Future security systems should be able to deter criminals from perpetrating crimes by using loudspeakers to broadcast voice warnings from monitoring stations. To detect an observed person who may be preparing to commit a crime, security systems must be equipped with sensors capable of recognising colours, body heat, sound and other aspects of the human body that may signal when a person is preparing to commit a crime. (F7)

4.3.3 Needs and corresponding product characteristics emerging from the Reign of Mechanics scenario

8 Security systems must be effective in monitoring parks and other open areas in the city centres. (N8)

Future security cameras must be capable of being hidden or camouflaged and must have night-vision capabilities. (F8)

9 Security systems must be able to monitor every point in a secured area at all times. (N9)

Future CCTV systems must be able to detect motion, analyse the speed of motion, freely rotate in all directions to follow moving objects (people) and take pictures in all directions of movement. (F9)

4.3.4 Needs and corresponding product characteristics emerging from the Tiny-Mini scenario

10 There will be a growing need to defend security systems from attacks by robots and other technological weapons developed by criminals. (N10)

Future security systems must be capable of being frequently reconfigured to alter the way a system functions. Monitoring devices and software for interpreting visual and other data obtained by sensors must accommodate a changing array of sensing technologies to identify the form and interior constitution of objects so that sophisticated technological weapons can be identified. (F10)

11 There will be an increasing need for reaction support systems to initiate further security precautions as soon as security threats are detected. (N11)

Future CCTV systems must include expert systems that can proactively decide or recommend what kind of reaction should be taken (where to zoom a security camera, in which direction to rotate, *etc*.). Artificial intelligence software must be developed to help security systems learn from experience. (F11)

12 Future security systems should be able to monitor many sites at the same time and at lower cost. (N12)

Future security systems will need to incorporate wireless communication and probably internet connectivity to link many sites in different parts of a city, so that a few security personnel in one monitoring centre can manage a network of secured sites. (F12)

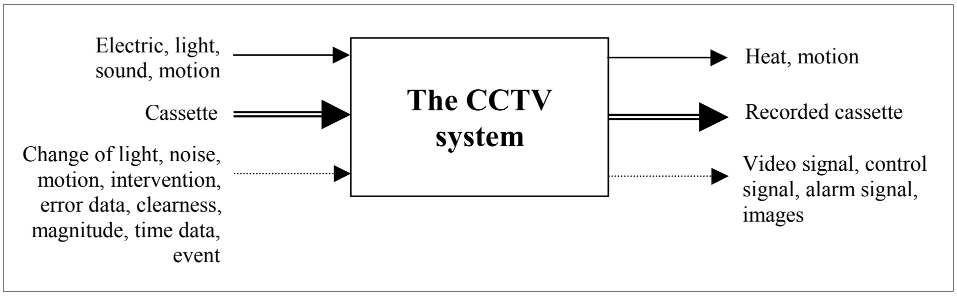
13 There will be a growing need to be able to trace people who have been kidnapped and to provide individuals with personal surveillance capabilities. (N13)

Security systems must include compact miniature cameras for individuals to wear that can both provide individuals with surveillance of their immediate surroundings and transmit images to monitoring stations. (F13)

4.4 The modular design process

Once the desirable functional characteristics of future CCTV systems have been identified, the next stage is to review the current design of a CCTV system to determine how new or improved components that can serve identified future needs could be incorporated into a future modular product architecture. In function-based modular design, a black-box model is constructed to provide a first mapping of the basic component inputs and outputs (material, energy and signal flows) that will be needed in a future modular architecture (Otto and Wood, 2000). Figure 6 illustrates a black-box model of a CCTV system.

Figure 6 A black-box model of a future CCTV system



We elaborate this black box into a more detailed representation of its interlinked functions and subfunctions to understand more fully the functional structure of the future architecture. In this process, we identify the types of functions and the inputs and outputs of each function in the future architecture. For a systematic transformation from the black-box model into a functional structure, an activity diagram is constructed. The activity diagram for our CCTV system, shown in Figure 7, summarises the activities that a CCTV system must perform and presents a high-level view of functions through a network layout showing sequential and parallel tasks (Otto and Wood, 2000). The first step is to map identified future needs to subfunction sequences by identifying associated flows. For example, consider the future need 'monitor a broad area, detect rapid motion and react quickly' (N3), which requires a product function in which special sensors detect the speed of motion (F3). Such sensors require flows of electrical energy (inputs) and motion (outputs). Following the flows of electricity and motion through the function chains, we identify the subfunction 'detect motion' as directly contributing to meeting need N3.

In the next step, function chains for all customer needs are combined to represent the entire product and to create an overall product function structure. Because of the large size of the resulting diagram, only a part of the function structure diagram for the CCTV system is represented in Figure 8. In the last step, several of the function and variety heuristics previously discussed were used to identify module types and to modularise the function structure. More precisely, the heuristics shared function, branching flow, conversion-transmission, and variant function were used in our analysis. Thirteen required functional modules were defined: image capturing, adjustment, image converting, lens adjustment, sensing, connection, combiner, reaction, learning intelligent database, remote control, recording, storage and monitoring. Figure 8 illustrates the first six of these modules.

Figure 7 Activity diagram for a CCTV system

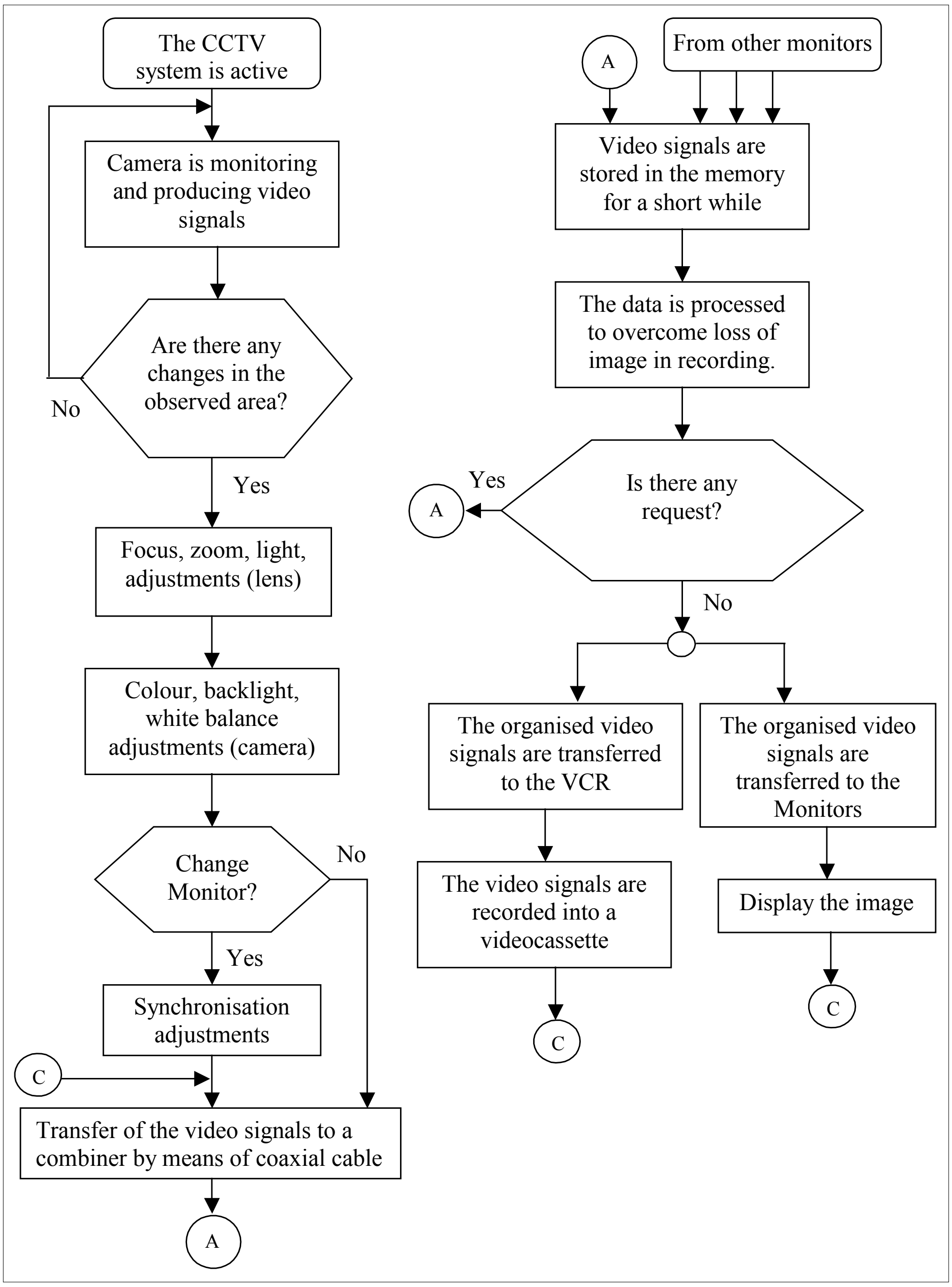
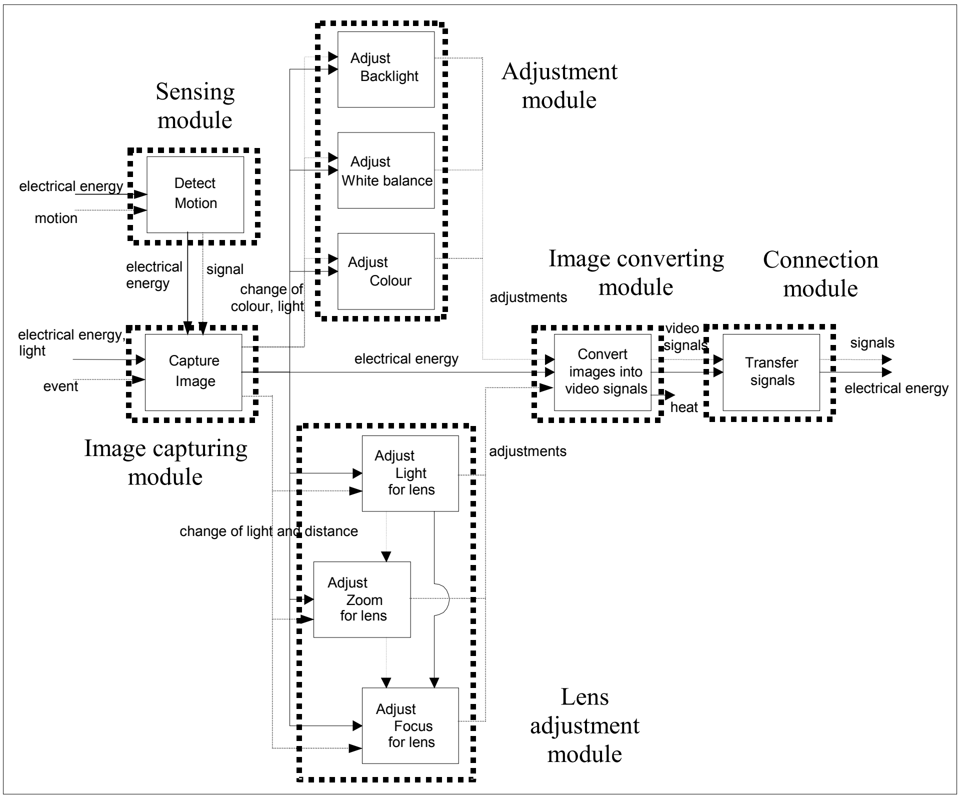


Figure 8 Partial elaboration of the function structure diagram of a future CCTV system



4.5 The module-scenario matrix

With the participation of product experts, two alternative variations for each module type were developed to support the configuration of useful future product variations. To identify a robust future product architecture, we constructed a module-scenario matrix to determine the adequacy of the identified module variations to serve the identified future market needs. All 13 module types, each with two variations, were arrayed against the four scenarios identifying future market needs and scored using a binary scale, as shown in Table 4. The data presented in the module-scenario matrix indicate the robustness of the identified future product variations to meet the future market needs identified in the four scenarios. The module variations y_1^1, y_3^2, y_4^1, y_5^2 and y_9^1 were identified as the most robust across all four scenarios and thus will most probably be included in future products.

Table 4 The module-scenario matrix

Module	*Instance*	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
Image capturing module	y_1^1	1	1	1	1
	y_1^2	1	0	1	0
Adjustment module	y_2^1	1	1	0	1
	y_2^2	0	0	1	1
Image converting module	y_3^1	1	1	0	1
	y_3^2	1	1	1	1
Lens adjustment module	y_4^1	1	1	1	1
	y_4^2	1	1	1	0
Sensing module (*e.g.*, biological, laser)	y_5^1	1	0	0	1
	y_5^2	1	1	1	1
Connection module (*e.g.*, cable, wireless)	y_6^1	1	0	0	1
	y_6^2	0	1	1	1
Combiner module (*e.g.*, switcher)	y_7^1	0	0	0	1
	y_7^2	1	0	1	1
Reaction module (*e.g.*, visual, verbal)	y_8^1	0	1	0	1
	y_8^2	0	1	0	1
Learning intelligent database module	y_9^1	1	1	1	1
	y_9^2	0	1	0	1
Remote control module (*e.g.*, satellite, internet)	y_{10}^1	0	1	1	1
	y_{10}^2	0	1	0	1
Recording module	y_{11}^1	1	1	0	1
	y_{11}^2	1	1	0	1
Storage module	y_{12}^1	1	1	1	1
	y_{12}^2	0	1	0	1
Monitoring module	y_{13}^1	1	1	1	1
	y_{13}^2	0	1	0	1

Table 5 The product-scenario matrix

*P**	*c**	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}	y_{12}	y_{13}	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Average*
1	294	1	1	2	1	2	2	2	1	2	2	1	1	1	0,69	0,92	0,62	1,00	**0,81**
2	294	1	1	2	2	2	2	2	1	2	2	1	1	1	0,69	0,92	0,62	0,92	0,79
3	294	1	1	2	1	2	2	1	1	2	2	1	1	1	0,62	0,92	0,54	1,00	0,77
4	294	1	1	2	2	2	2	1	1	2	2	1	1	1	0,62	0,92	0,54	0,92	0,75
5	293	1	1	2	1	2	2	2	2	2	2	1	1	1	0,69	0,92	0,62	1,00	**0,81**
6	293	1	1	2	1	2	2	2	1	2	2	1	2	1	0,62	0,92	0,54	1,00	0,77
7	293	1	1	2	2	2	2	2	2	2	2	1	1	1	0,69	0,92	0,62	0,92	0,79
8	293	1	1	2	2	2	2	2	1	2	2	1	2	1	0,62	0,92	0,54	0,92	0,75
9	293	1	1	2	1	2	2	1	1	2	2	1	2	1	0,54	0,92	0,46	1,00	0,73
10	293	1	1	2	1	2	2	1	2	2	2	1	1	1	0,62	0,92	0,54	1,00	0,77
11	293	1	1	2	2	2	2	1	1	2	2	1	2	1	0,54	0,92	0,46	0,92	0,71
12	293	1	1	2	2	2	2	1	2	2	2	1	1	1	0,62	0,92	0,54	0,92	0,75
13	292	1	1	1	1	2	2	2	1	2	2	1	1	1	0,69	0,92	0,54	1,00	0,79
14	292	1	1	1	1	2	2	1	1	2	2	1	1	1	0,62	0,92	0,46	1,00	0,75
15	292	1	1	1	2	2	2	1	1	2	2	1	1	1	0,62	0,92	0,46	0,92	0,73
16	292	1	1	1	2	2	2	2	1	2	2	1	1	1	0,69	0,92	0,54	0,92	0,77
17	292	1	1	2	1	2	2	2	2	2	2	1	2	1	0,62	0,92	0,54	1,00	0,77
18	292	1	1	2	2	2	2	2	2	2	2	1	2	1	0,62	0,92	0,54	0,92	0,75
19	292	1	1	2	2	2	2	1	2	2	2	1	2	1	0,54	0,92	0,46	0,92	0,71
20	291	1	1	2	1	2	1	2	1	2	1	1	1	1	0,77	0,85	0,62	1,00	**0,81**
21	291	1	1	2	1	2	1	1	1	2	1	1	1	1	0,69	0,85	0,54	1,00	0,77
22	291	1	1	2	2	2	1	1	1	2	1	1	1	1	0,69	0,85	0,54	0,92	0,75
23	291	1	1	2	2	2	1	2	1	2	1	1	1	1	0,77	0,85	0,62	0,92	0,79
24	291	1	1	2	1	2	2	2	1	2	1	1	1	1	0,69	0,92	0,69	1,00	**0,83**
25	291	1	1	1	2	2	2	2	1	2	2	1	2	1	0,62	0,92	0,46	0,92	0,73
26	291	1	1	2	2	2	2	2	1	2	1	1	1	1	0,69	0,92	0,69	0,92	**0,81**

Table 5 The product-scenario matrix (continued)

*P**	*c**	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}	y_{12}	y_{13}	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Average*
27	291	1	1	1	1	2	2	1	1	2	2	1	2	1	0,54	0,92	0,38	1,00	0,71
28	290	1	2	2	2	2	2	1	2	2	2	1	1	2	0,46	0,85	0,54	0,92	0,69
29	290	1	1	2	2	2	2	1	1	1	2	1	1	1	0,69	0,92	0,62	0,92	0,79
30	290	1	2	2	2	2	2	2	2	2	2	1	2	2	0,46	0,85	0,54	0,92	0,69
31	290	1	2	2	1	2	2	2	2	2	2	1	1	2	0,54	0,85	0,62	1,00	0,75
32	290	1	1	2	2	2	2	2	1	1	2	1	1	1	0,77	0,92	0,69	0,92	**0,83**
33	290	1	2	2	1	2	2	1	2	2	2	1	2	2	0,38	0,85	0,46	1,00	0,67
34	290	1	1	2	1	2	2	2	1	1	2	1	1	1	0,77	0,92	0,69	1,00	**0,85**
35	290	1	2	2	2	2	2	1	2	2	2	1	2	2	0,38	0,85	0,46	0,92	0,65
36	290	1	2	2	1	2	2	1	2	2	2	1	1	2	0,46	0,85	0,54	1,00	0,71
37	290	1	1	2	1	2	2	1	1	1	2	1	1	1	0,69	0,92	0,62	1,00	**0,81**
38	290	1	2	2	2	2	2	2	2	2	2	1	1	2	0,54	0,85	0,62	0,92	0,73
39	290	1	1	2	2	2	1	2	1	2	1	1	2	1	0,69	0,85	0,54	0,92	0,75
40	289	1	1	2	2	2	2	1	2	1	2	1	1	1	0,69	0,92	0,62	0,92	0,79
41	288	1	1	2	2	1	2	2	1	2	2	1	1	1	0,69	0,85	0,54	0,92	0,75
42	288	1	1	2	2	1	2	1	1	2	2	1	1	1	0,62	0,85	0,46	0,92	0,71
43	288	1	1	2	1	1	2	1	1	2	2	1	1	1	0,62	0,85	0,46	1,00	0,73
44	288	1	1	2	1	1	2	2	1	2	2	1	1	1	0,69	0,85	0,54	1,00	0,77
45	287	1	1	2	2	1	2	1	1	2	2	1	2	1	0,54	0,85	0,38	0,92	0,67
46	286	2	2	1	1	2	2	1	2	2	2	1	1	2	0,46	0,77	0,46	0,92	0,65
47	286	2	2	2	1	2	2	2	2	2	2	1	1	2	0,54	0,77	0,62	0,92	0,71
48	286	2	2	2	1	2	2	1	2	2	2	1	2	2	0,38	0,77	0,46	0,92	0,63
49	286	2	2	2	1	2	2	1	2	2	2	1	1	2	0,46	0,77	0,54	0,92	0,67
50	286	2	2	1	1	2	2	1	2	2	2	1	2	2	0,38	0,77	0,38	0,92	0,62
						S_h									*0,61*	*0,88*	*0,54*	*0,95*	

Note: The values 1 and 2 indicate the first and the second module instance respectively.

4.6 Consistency analysis

To identify a manageable number of future product architectures capable of satisfying the broadest possible range of identified future needs, and to eliminate technically inconsistent combinations of module variations, a consistency analysis was carried out. In this example, 13 module types with two variations each can configure 2^{13} (= 8192) alternative future product variations, which may be too much product variety to realise and support in the market. A consistency matrix was therefore constructed to analyse consistency between the 26 identified module variations, which generate 312 (=(26*26–13*4)/2)) pairs of component variations. We then determined the 50 product variations that have the highest level of consistency among their pairs of component variations and that have no pairs of inconsistent components. These 50 product variations with the highest consistency ratings are shown in Table 5. The second column in Table 5 ranks the 50 product variations by the overall consistency (c^*) of each future product variation.

4.7 The product-scenario matrix

Finally, we constructed a product-scenario matrix to determine the most robust future product variations and to assess the extent to which they would meet the future market needs identified by the scenarios. Average satisfaction levels were calculated for each product variation (z_{th}) for all scenarios, and an overall satisfaction index was computed for each scenario (S_h), as shown in Table 5. None of the proposed future product variations were found to perfectly satisfy all the scenarios, but several product variations were found to have satisfaction levels greater than 80%, as highlighted by bold type in the last column in Table 5. Thus, the future product variations that will most likely be successful in the future were identified as having the following component compositions:

- $P^*_1 = (y_1^1, y_2^1, y_3^2, y_4^1, y_5^2, y_6^2, y_7^2, y_8^1, y_9^2, y_{10}^2, y_{11}^1, y_{12}^1, y_{13}^1)$
- $P^*_5 = (y_1^1, y_2^1, y_3^2, y_4^1, y_5^2, y_6^2, y_7^2, y_8^2, y_9^2, y_{10}^2, y_{11}^1, y_{12}^1, y_{13}^1)$
- $P^*_{20} = (y_1^1, y_2^1, y_3^2, y_4^1, y_5^2, y_6^1, y_7^2, y_8^1, y_9^2, y_{10}^1, y_{11}^1, y_{12}^1, y_{13}^1)$
- $P^*_{24} = (y_1^1, y_2^1, y_3^2, y_4^1, y_5^2, y_6^2, y_7^2, y_8^1, y_9^2, y_{10}^1, y_{11}^1, y_{12}^1, y_{13}^1)$
- $P^*_{26} = (y_1^1, y_2^1, y_3^2, y_4^2, y_5^2, y_6^2, y_7^2, y_8^1, y_9^2, y_{10}^1, y_{11}^1, y_{12}^1, y_{13}^1)$
- $P^*_{32} = (y_1^1, y_2^1, y_3^2, y_4^2, y_5^2, y_6^2, y_7^2, y_8^1, y_9^1, y_{10}^2, y_{11}^1, y_{12}^1, y_{13}^1)$
- $P^*_{34} = (y_1^1, y_2^1, y_3^2, y_4^1, y_5^2, y_6^2, y_7^2, y_8^1, y_9^1, y_{10}^2, y_{11}^1, y_{12}^1, y_{13}^1)$
- $P^*_{37} = (y_1^1, y_2^1, y_3^2, y_4^1, y_5^2, y_6^2, y_7^1, y_8^1, y_9^1, y_{10}^2, y_{11}^1, y_{12}^1, y_{13}^1)$.

We note here that the module variations identified in the product variations judged to be the most robust $(y_1^1, y_2^1, y_3^2, y_5^2, y_{11}^1, y_{12}^1, y_{13}^1)$ are not necessarily the same module variations used in the product variations identified as most robust in the module-scenario matrix $(y_1^1, y_3^2, y_4^1, y_5^2, y_9^1)$. This is the result of the differing selection criterion used in the two matrices.

The last step in the application of our methodology was assessing the overall average satisfaction level of each scenario. Scenarios 2 and 4 were found to have high satisfaction indices of 0,88 and 0,95, whereas scenarios 1 and 3 had average satisfaction indices of 0,61 and 0,54. To increase the satisfaction levels for Scenarios 1 and 3, it may be possible that a different product variation with a lower (technical) consistency value would yield a higher overall satisfaction index for these scenarios, pointing to possible trade-offs between satisfaction levels and consistency values.

Finally, the results summarised in Table 5 suggest that the proposed set of future product variations has the ability to meet a large part of identified future market needs as determined from future scenarios. Through the ability of a common modular architecture to configure this set of product variations, the identified modular product architecture enables a rapid and flexible response to a range of imagined market needs in the future.

5 Conclusion

"Generally what we suffer in the future is the result of past actions. Similarly what we want in the future explains present action" (Godet, 2001, p.8). The goal of management is to help firms gain or sustain advantages in a dynamic competitive environment. In this paper, we have suggested how a modular design capability can help firms prepare today for an uncertain future, and we have proposed a methodology for implementing a modular design that integrates scenarios about future market needs into the modular design process. In effect, the methodology of SDMD explained in this paper shows how product innovations that could serve future market needs can be identified, evaluated and translated into future product designs. Applying our SDMD methodology should help any firm to improve its product development capability, and to launch and sustain a continuous cycle of future competence identification, competence building and competence leveraging in creating modular product architectures.

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Notes

1 For example, in a modular product structure with ten component types, each of which are available in ten variations, 10 000 000 000 product variations can be configured (Sanchez, 1999).

2 www.interguvenlik.com/cctv1.htm (accessed June 2004).