ANALYZING THE INVESTMENT DECISION IN MODULAR MANUFACTURING SYSTEMS WITHIN A CRITICAL-THINKING FRAMEWORK

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ABSTRACT

The absence of the reasoning stage in the analysis of long-term investment decision creates a serious gap in this classic topic in management accounting literature. The purpose of this paper is to fill this gap. The traditional analysis focuses on the evaluation stage using capital budgeting tools to rank alternative investment proposals. It tacitly assumes that the decision is to be made, thereby bypassing the reasoning stage. However, the reasoning stage may reveal that there is no sufficient justification (reasoning) to consider searching for and evaluating alternative proposals for this decision. Focusing on the reasoning component, the paper combines Fritz's (1989, 1990) "creative tension" and Janis and Mann's (1977) "challenges" as the driving forces for the problem-finding step. To demonstrate the significance of filling the reasoning gap in the long-term investment decision, the paper selects the modular manufacturing system and the complex investment decision required for its adoption. Using hypothetical data, the paper employs the Dempster-Shafer

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Theory of Evidence and Omer, et al's (1995) algorithm to compute the belief and plausibility values of the three reasoned actions: (1) maintain the status quo, (2) adopt Level 2 (assembly) modularity or (3) adopt Level 2 (design) modularity.

The contributions of the paper include (1) highlighting a critical gap currently existing in one of the classical decisions in the management accounting literature; (2) developing a framework for filling this gap and (3) applying this framework to the intricate nature of the modular manufacturing system and its complex investment decision.

The traditional analysis of long-term investment decisions often begins with the evaluation stage, using financial criteria such as return on investment (ROI), net present value (NPV), internal rate of return (IRR) and payback period (in addition to some non-financial benefits) in ranking alternative investment proposals. This analysis bypasses a fundamental step, the reasoning stage of the decision-making process. Reasoning as a prelude to the evaluation stage is essential for developing the relevant framework for this decision; more importantly, this step ratifies the evaluation stage itself as it may prove that there is no need (i.e., no sufficient reason exists) to consider making the decision in the first place. The absence of the reasoning step in this classic topic in the management accounting literature creates a serious gap that needs to be filled.

To fill this gap, we construct the investment decision as a critical-thinking model. Finocchiaro's (1989, 1990) critical-thinking triad of reasoning, evaluating and self-reflecting is appropriate for this purpose. In addition, we employ Fritz's (1989, 1990) "creative tension" and Janis and Mann's (1977) "challenges" in order to develop the formal reasoning stage of the decision-making process. Thus, the major argument of this paper proceeds as follows: before an investor begins evaluating a set of alternative proposals, there is often a critical stage of "creative tension" and "challenges," driven by threats, uncertainty or substantial losses; upon the occurrence of a trigger event (e.g., a massive public recall of a defective product), the investor begins the process of problem finding (the reasoning stage) to justify the task of problem solving (the evaluation stage).

We demonstrate the importance of the reasoning stage as a prelude to the stage of evaluating alternative investment proposals by analyzing the decision of adopting a modular manufacturing system. This adoption entails a complex investment decision (Van Cauwenbergh, Durinck, Martens, Laveren, & Bogart, 1996; Abdel-Kader & Dugdale, 1998, 2001). The substantial investments needed to restructure the firm's operations around an intricate network of product platforms, product families, assembly processes and logistics can revolutionize the entire value chain (Meyer & Lehnerd, 1997); as Sanchez and Mahoney (1996) assert that modularity in the design of products should lead to modularity in the design of the organization itself that produces these products. Indeed, the platform approach has revolutionized the way products are designed, manufactured and marketed. Developing successful new lines of modular products hinges upon developing product-platform flexibility,[1] which requires a close examination of the firm's national and international supplier network at all tiers in order to establish a reliable source of modules, systems and interfaces at the prescribed quality on time and which are sufficiently flexible to cooperate rather than compete with other suppliers to serve the manufacturer. The first step in this complex decision is not to list and evaluate the alternative proposals regarding the type of plant and equipment for building the modular manufacturing system; rather, it is the development of sufficient reasoning to consider whether such a decision should be made.

This study, as we said above, analyzes the modularity investment decision using Finocchiaro's (1989, 1990) critical-thinking triad of reasoning, evaluating and self-reflecting.[2] Focusing on the reasoning part of the investment decision, this study applies Dempster-Shafer's Theory of Evidence to show how the investor justifies the importance of making this decision before it proceeds to the evaluating stage of the decision. We use hypothetical data to illustrate the mechanism of this application. The first section of the paper reviews the literature on long-term investment decisions to show its predominant emphasis on the evaluation stage. The second section introduces the critical-thinking triad in which the reasoning stage is an integral element of the decision-making process. The third section explains the complex decision of adopting a modular manufacturing system and the significance of the reasoning stage for analyzing this decision. The fourth section applies Dempster-Shafer's Theory of Evidence to justify the importance or urgency of considering this investment decision. Limitations of the study appear in the fifth section, and is followed by summary and conclusions section.

A LITERATURE REVIEW OF THE LONG-TERM INVESTMENT DECISION

The literature on long-term investment decision is vast and varied. We classify most of the studies on this topic into three groups. The *financial* *performance or capital budgeting group* usually includes surveys of practice studies (Van Cauwenbergh et al., 1996; Abdel-Kader & Dugdale, 1998). This group also includes field studies of practice that emphasize steps other than economic appraisal of this decision, e.g., creating investment proposals and investigating the interplay of financial and strategic information in the decision-making process (Nixon, 1995; Abdel-Kader & Dugdale, 1998). The *financial risk group* focuses on the relationship between risk and return. For example, Kaplan and Atkinson (1989) point to the deficiencies of the capital budgeting models, e.g., using excessively high discount rates and incorrect base-case forecasts as well as failing to recognize all of the benefits of the investment proposals under study. Several studies include risk analysis explicitly as a prime factor in making the investment decision (Kaplan, 1986; Slagmulder, Bruggeman, & Wassenhove, 1995). Finally, the *non-financial factors group* criticizes the studies in the first two groups for their over-emphasis on the financial aspect of the long-term investment decision, and surveys managers' perceived importance of intangible factors in making this decision (Slagmulder et al., 1995; Abdel-Kader & Dugdale, 1998, 2001). The arguments in these studies pivot primarily around the evaluation stage of the decision-making process. Therefore, we classify these three groups of studies under the evaluation component of the following critical-thinking model.

A CYCLICAL CRITICAL-THINKING MODEL OF LONG-TERM INVESTMENT DECISIONS

While currently there is no generally acceptable definition of critical thinking (Whitaker, 2002/2003, p. 51), many analysts would agree that important long-term investment decisions in modularity require critical thinking. The word "critical" is the key term necessary to understand the concept of critical thinking, which can be explained by a debate in philosophy between Siegel and Finocchiaro regarding the nature of critical thinking. Finocchiaro (1989) objects to Siegel's (1988) equation, critical thinking = good reasoning = rationality, in that "good" reasoning and rationality need not be critical, i.e., they need not involve negative criticism (Siegel, 1990, p. 453). Finocchiaro (1990, p. 462) argues that Siegel's equivocation ultimately is "reduced to questionable appeal to authority and to question begging." Instead, he defines critical thinking as "the special case of reasoning when explicit reasoned assessment is present." It suffices for this paper's purpose to mention that the debate may settle on the view that "critical thinking is thinking which is reasoned, evaluative and self-reflective" (Finocchiaro, 1990, p. 465). Johnson-Laird (1991, p. 454) explains self-reflection as a meta-cognition of a higher-order type of thinking that depends on having access to a model of a thought process that gives rise to self-awareness. As to the question "must thinking be critical to be critical thinking?" Finocchiaro (1990, p. 465) replies:

> I believe that it is probably true that all thinking which is reasoned *and* evaluative *and* self-reflective is critical thinking. Then insofar as reasoned, evaluative, and self-reflective are three senses of "critical," we may also say that critical thinking is, indeed, thinking which is critical.

We employ this triad of critical thinking (reasoning, evaluating and self-reflecting) as the key stages of the long-term investment decision cycle (Fig. 1). Reasoning represents the problem-framing stage, which is set into motion by threats, challenges and creative tension. The problem finding is a function of the intensity in Fritz's (1989, 1990) principle of creative tension, explained in the following section. The stronger the tension, the more urgent the search for problem finding. The problem-solving stage requires evaluating a set of alternatives, and then self-reflecting upon the completion of the decision process. Once the cycle is completed, experience learned from going through this process enriches organizational learning (Senge, 1995; Zebda, 1995), and in turn, this helps the reasoning, evaluating and self-reflecting stages, and so on ad infinitum (Bayou & Reinstein, 1999, 2000). Let us closely examine the reasoning stage since this is the focus of this paper and the Dempster-Shafer theory application.

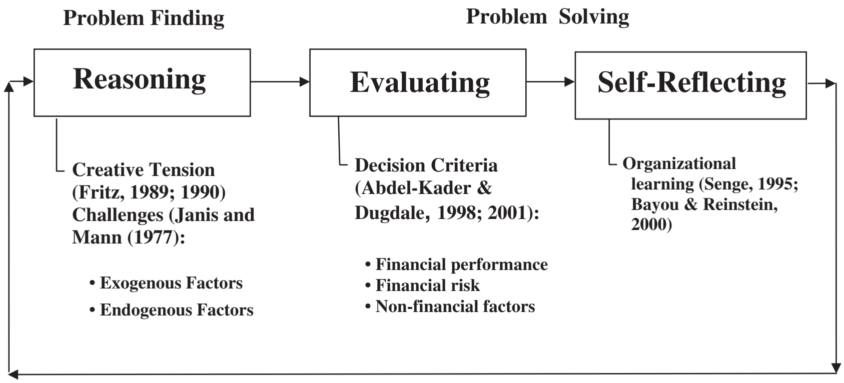

Fig. 1. The Cyclical Critical-Thinking-Based Investment Decision. *Source:* Adapted from Finocchiaro (1989, 1990).

Reasoning: Motivation (Cause) to Problem Finding (Effect)

Companies must be motivated before seeking to find and solve problems, a necessity that can be defined by Fritz's (1989, 1990) principle of "creative tension," which emanates from the distance (tension) between where one wants to be (vision) and is currently (current reality). Senge (1995, p. 79) recognizes this principle and stresses that "an accurate picture of current reality is just as important as a compelling picture of a desired future." Two sources can help form these "accurate pictures" of the present and the future: the employees and the organization.

Janis and Mann (1977) also explain the motivation needed for problem finding and solving by describing five stages in arriving at a lasting decision: appraising the challenge, surveying alternatives, weighing alternatives, deliberating about commitment and adhering despite negative feedback. We focus on the first stage, appraising the challenge, since it forms the basis for the reasoning stage of the modular investment decision. Janis and Mann's (1977, p. 172) challenge resembles Fritz's creative tension when they explain:

> Until a person is challenged by some disturbing information or event that calls his attention to a real loss soon to be expected, he will retain an attitude of complacency about whatever course of action (or inaction) he has been pursuing.

They (p. 172) classify the challenging information into two kinds. The first kind is a *trigger event*, as when a competitor has just suddenly designed its products using new modules and systems that threaten to disturb the industry's market share; this threat may escalate to a trigger point to begin serious consideration of investing in modularity. The second kind is new, impressive *communications*, e.g., a homebuilder announces to its suppliers that it will buy only whole modular sections of homes rather than individual components in building condominiums.

Modularity is currently a key production strategy that requires substantial investments. Therefore, the modularity investment decision is appropriate for explaining the importance of the reasoning stage, as presented in the next section.

THE NATURE OF THE MODULAR MANUFACTURING INVESTMENT DECISION

The management accounting literature often compares the mass production system (or Fordism, named after Henry Ford and his mass production of the Model T) and the Toyota Production System (Porter, 1985; Monden, 1993).[3] In mass production, a manufacturer seeks cost leadership through economies of scale by continuously producing and selling highly standardized products in large volumes. A cost leader can significantly reduce the sale price to strengthen its competitive position. But complex product markets of today demand the ability to quickly and globally deliver a high variety of customized products. In a mass-customization manufacturing system, the manufacturer seeks product differentiation to accomplish two objectives: to gain the perception of uniqueness that may ultimately lead to a monopolistic advantage, especially when the demand for the product is inelastic, and to increase product variety to respond to heterogeneous customer tastes and preferences. Product differentiation is costly to implement because as product variety increases, the risk of lower performance of a firm's internal operations increases due to higher direct manufacturing costs, manufacturing overhead, delivery times and inventory levels (Flynn & Flynn, 1999; Salvador, Forza, & Rungtusanatham, 2002). For example, component variety often increases when product variety increases, especially when vertical integration is low (Fisher, Ramdas, & Ulrich, 1999; Salvador et al., 2002) and suppliers experience dis-economics in responding to these developments (Krishnan & Gupta, 2001; McCutcheon, Raturi, & Meredith, 1994).

Accordingly, a manufacturer faces a difficult tradeoff decision: how to increase product variety to satisfy customers' heterogeneous needs while minimizing the cost of complexity arising from this product-variety strategy. The discussion of this tradeoff decision is not new. For decades, both research and practice have suggested modularity as a means for producing low-cost high-variety product architectures that provide final product configurations by mixing and matching sets of standard components with standard interfaces (Evans, 1963; Starr, 1965; Pine, 1993; Meyer & Lehnerd, 1997; Salvador et al., 2002). Langlois (2002) argues that the principles of modularity have an even longer pedigree that goes back to Adam Smith's proposal of "obvious and simple system of natural liberty" that shows how a complex modern society can become more productive through a modular design and economic institutions.

What is modularity? Modularity is an approach to design, develop and produce parts that can be combined in the maximum number of ways (Starr, 1965, p. 38). Evans (1963) treats modularity as a means to increase commonality across product varieties within a product family by incorporating the same components into these product variants. Kodama (2004, p. 634) elevates modularity to the level of strategy for "organizing complex products and processes efficiently. A modular system is composed of units (or modules) that are designed independently but still function as an integrated whole.''

There are two kinds of modularity. The first kind, assembly based modularity, focuses on manufacturing techniques and assembly operations associated with a product. It emphasizes geographical partitioning to optimize assembly interface, as in the production of a cockpit. The second kind, the function-based (design) modularity, focuses on the intrinsic functionality of the product and how these functions are distributed. It seeks functional partitioning to optimize functional interface. Examples of this kind for the design of an automobile include brakes, power supply, climate-control and entertainment system. Currently, many manufacturing entities use modularity as an approach to mass produce (or purchase) common modules that can be combined in different configurations to produce product variety.

Challenges facing the Modularity Investment Decision: Several exogenous and endogenous factors may drive a manufacturer to seriously consider implementing a modular manufacturing strategy or escalate an existing one. Exogenous factors include uncertainties of market acceptance of the new modular products, competitors' reaction to the manufacturer's switch to modularity, availability and reliability of suppliers who can supply the necessary modules and systems, and labor union's and other personnel's acceptance or resistance to the new mode of manufacturing. These factors are beyond the firm's control. Endogenous factors, developed internally, which can form serious challenges and dilemmas, include design risks, uncertainty of testing outcomes during modular developments, skills to use new technologies and the ability and speed of restructuring the organization to implement the modularity strategy.

Reasoned Actions for the Modularity Investment Decision

When intensified, the exogenous and endogenous challenges may move the manufacturer to take actions on the modularity issue. We consider three reasoned actions.

(1) *Maintain the status quo*. Although the challenges are severe, a manufacturer may opt to maintain the status quo if the exogenous and endogenous factors carry high degrees of uncertainty so that any change may endanger the very existence of the firm.
(2) *Adopt Level-1 (assembly) modularity strategy*. In this alternative, the suppliers' facilities produce and deliver the modules to the manufacturer's

plant, which then performs the necessary subassemblies. That is, the suppliers' facilities are separated from the manufacturer's plant (McAlinden, Smith, & Swiecki, 1999, p. 2).

(3) *Adopt Level-2 (design) modularity strategy*. In this strategy, modules are optimized at the final assembly level by independent suppliers. Design modularity is function based, which seeks functional partitioning to optimize functional interface (McAlinden et al., 1999, p. 2).

Level-1 modularity is one step beyond the status quo alternative. According to McAlinden et al. (1999, p. 2), Level-1 modularity merely represents another form of outsourcing as a means to reduce such costs as labor. Level-2 modularity has more aggressive purposes including ''a far greater range of system-wide improvements in design, material use, rates of product innovation, delivery time to market, and cost'' (McAlinden et al., 1999, p. 2). Accordingly, Level-2 modularity involves a high degree of exogenous and endogenous uncertainties. We assume that the selection of action 1 (maintain the status quo) implies that the decision maker's ''creative tension'' has not yet reached a trigger point. By selecting Level-1 modularity, the decision maker's creative tension has reached a trigger point, but the decision maker is cautious and willing to accept only some risk regarding market acceptance, design and test uncertainty. Selecting action 3 implies that the decision maker is willing to accept more risks than those of action 2. This attitude may result from the belief that a drastic change in manufacturing is long overdue, or that such a full-scale modularity as Level 2 with all of its risks is the best way to face competition, current and future.

These three alternative strategies form the basis for the application of the Dempster-Shafer Theory of Evidence, explained as follows.

APPLICATION OF THE DEMPSTER-SHAFER THEORY OF EVIDENCE

The Dempster-Shafer Theory of Evidence, introduced by Dempster (1967, 1968) and Shafer, 1976), has received wide attention from many researchers in several disciplines for decades (Omer, Shipley, & Korvin, 1995). It provides useful measures for evaluation of subjective uncertainties in a multi-attribute decision problem where the decision maker must consider a number of strategies. The decision is constrained by uncertainties inherent in the determination of the relative importance of each attribute and the classification of alternative strategies according to the level of each attribute of each strategy. Uncertainties also affect the decision maker's selection of the optimum strategy according to the perceived "ideal" levels of the specified attributes (Omer et al., 1995, p. 256). The "ideal" levels stem from the metrics provided by the decision maker that represent its preferred values for the given attributes of the alternative actions.

This theory is considered an alternative to the traditional Bayesian theory, that focuses on probabilities (Shafer, 1990; Beynon, 2004). However, some researchers argue that this theory alone is inadequate to address problems of ambiguity inherent in the subjective judgment of the three modularity strategies outlined above. As Shipley, de Korvin, and Omer (2001, p. 210) argue, methods that utilize classic logic or statistics are not equipped to account for uncertainty in these judgments where only limited information is available. In many instances, these uncertainties give rise to ambiguity, fuzzy notions and imprecision rather than randomness and probability of occurrence. For example, the very concept of "variety" in the term "product variety" is fuzzy because it ranges from very different to slightly different. Ford Motor Company's Crown Victoria and Grand Marquis models are only slightly different; Taurus and Mercury Sable models are different; and Taurus and Lincoln LS models are very different. These models may share many common, uncommon and modified modules. In brief, implementing modularity entails several problems of measurement, uncertainty and ambiguity which the Dempster-Shafer theory alone is ill-equipped to solve. But when fuzzy-set theory is combined with the Dempster-Shafer Theory of Evidence, a powerful methodology emerges to account for these uncertainties and ambiguities. Yager (1990), Yen (1990) and Zadeh (1986) have generalized this theory to fuzzy sets.

Data Source

We envision interviewing a group of managers of a manufacturing plant. The managers are seriously considering an improvement in their modularity production system. In particular, they are pondering whether the plant should switch from using individual components to build a transmission for a vehicle to buying a system composed of a few modules. They realize that the time, effort and funds needed for making this decision are substantial. After we explain the general characteristics of the fuzzy-Dempster-Shafer theory, they agree to cooperate with us to apply this theory to their plant. The data we use in this application are hypothetical.

Applying a Fuzzy-Dempster-Shafer Theory of Evidence Algorithm

Omer et al.'s (1995) algorithm is designed to address the uncertainty inherent in decision-making situations. By integrating the fuzzy-set theory and the Dempster-Shafer Theory of Evidence, the algorithm rank orders the given alternatives from the highest to the lowest value based on the decision maker's ideal levels of selected critical attributes. More specifically, the algorithm seeks to (Omer et al., 1995, p. 265)

- simplify complex systems;
- systematically incorporate subjective factors;
- combine evidence from independent sources of information; and
- recognize the uncertainties inherent in the complex decision-making process.

The algorithm has the following characteristics:

1. It ranks the given alternatives in the multi-attribute case.
2. The ranking results from measuring the belief and plausibility values of each alternative and its functions.

To apply this algorithm, we first define the following set of t alternative reasoned actions, h_i where $1 \leq i \leq t$ with a F_i ($i = 1, 2, 3$) set of attributes based on a hypothetical interview of the key personnel of a manufacturing plant:

$$h_1 = (.1/K1 + .8/K2 + .9/K3) + (.9/R1 + .5/R2 + .1/R3) + (.8/T1 + .1/T2 + .1/T3)$$

$$h_2 = (.1/K1 + .6/K2 + .8/K3) + (.1/R1 + .7/R2 + .2/R3) + (.3/T1 + .3/T2 + .2/T3)$$

$$h_3 = (.1/K1 + .6/K2 + .7/K3) + (.1/R1 + .8/R2 + .3/R3) + (.3/T1 + .4/T2 + .5/T3)$$

where

K = market acceptance = {Low, Average, High} = {$K1$, $K2$, $K3$}
R = design risk = {Low, Medium, High} = {$R1$, $R2$, $R3$}
T = testing uncertainty = {Low, Moderate, High} = {$T1$, $T2$, $T3$}
$K1$ = low-market acceptance of the modular products
$K2$ = average market acceptance of the modular products
$K3$ = high-market acceptance of the modular products

$R1$ = low-design risk of the modular products
$R2$ = medium design risk of the modular products
$R3$ = high-design risk of the modular products
$T1$ = low uncertainty of testing outcomes during development of the modular products
$T2$ = moderate uncertainty of testing outcomes during development of the modular products
$T3$ = high uncertainty of testing outcomes during development of the modular products.

The reasoned actions, h_1, h_2 and h_3, correspond to the three alternative strategies of maintaining the status quo, adopting Level-1 (assembly) modularity and adopting Level-2 (design) modularity, respectively. The first strategy, h_1, is the most conservative since it promotes no change. Management's preference of this strategy indicates weak or lack of Fritz's creative tension or the absence of a trigger event, as explained above. The second action, h_2, is a medium stand between h_1 and h_3, where h_3 is the most aggressive action because the Level-2 strategy represents a greater degree of modularity than that of Level 1.

The variables (market acceptance, design risk and testing uncertainty) are the set of attributes, F_i ($i = 1, 2, 3$), and the variables K_i's, R_i's and T_i's are the elements, $f_i^{k_i}$, of the attributes where $k_i = 1, 2, 3$. The focal elements, $F_i^{k_i}$, result from the reasoned actions, h_i's:

$$F_{Market}^{Low} = .1/h_1 + .1/h_2 + .1/h_3$$
$$F_{Market}^{Average} = .8/h_1 + .6/h_2 + .6/h_3$$
$$F_{Market}^{High} = .9/h_1 + .8/h_2 + .7/h_3$$
$$F_{Design}^{Low} = .9/h_1 + .1/h_2 + .1/h_3$$
$$F_{Design}^{Medium} = .5/h_1 + .7/h_2 + .8/h_3$$
$$F_{Design}^{High} = .1/h_1 + .2/h_2 + .3/h_3$$
$$F_{Test}^{Low} = .8/h_1 + .3/h_2 + .3/h_3$$
$$F_{Test}^{Moderate} = .1/h_1 + .3/h_2 + .4/h_3$$
$$F_{Test}^{High} = .1/h_1 + .2/h_2 + .5/h_3$$

To compute the mass functions for these attributes, we need to develop the "ideal" weights, which are defined as follows for n fuzzy sets. Associated with each alternative h_j, we have n fuzzy sets corresponding to the n different attributes:

$$\sum_{k_i=1}^{n_i} \alpha_{i_j}^{k_i} \Big/ f_i^{k_i} \qquad \text{where } 1 \le i \le n \quad \text{and} \quad 1 \le j \le t$$

where $\alpha_{i_j}^{k_i}$ represents the $f_i^{k_i}$ value present in action h_j.

We extract the α_{iji}^{a} amounts from pairwise comparisons of the attribute elements of market acceptance, design risk and testing uncertainty:

$$\text{Market acceptance} = \{\text{Low}, \text{Average}, \text{High}\} = \{K1, K2, K3\}$$
$$\text{Design risk} = \{\text{Low}, \text{Medium}, \text{High}\} = \{R1, R2, R3\}$$
$$\text{Testing uncertainity} = \{\text{Low}, \text{Moderate}, \text{High}\} = \{T1, T2, T3\}$$

To conduct the pairwise comparison, we asked the group of plant managers in our hypothetical scenario to allocate 100 "relative preference points" for one element over another, which resulted in the following data set for the market acceptance attribute:

Low	20	Average	30	High	90
Average	80	High	70	Low	10
	100		100		100

These assignments of points reveal that the average market acceptance is four times as important as the low-market acceptance; the high-market acceptance is 233% as important as the average market acceptance; and the high-market acceptance is nine times as important as the low-market acceptance. It is important to check the consistency of these relative preferences, which we calculate in Matrices A and B below following Omer et al. (1995) and Guilford's constant-sum method (Guilford, 1954; Cleland & Kocaogla, 1981).

Matrix A

	K1: *Low*	*K2*: *Average*	*K*3: High
K1: *Low*		80	*90*
K2: *Average*	20		*70*
*K*3: High	*10*	*30*	

We create Matrix B from the elements $a_{ij}$of Matrix A. Matrix B's elements are determined by $b_{ij} = a_{ij}/a_{ji}$.

Matrix B

	K1: *Low*	*K2*: *Average*	*K*3: High
K1: *Low*		4.00	*9.00*
K2: *Average*	0.25		*2.33*
*K*3: High	*0.11*	*0.43*	

Next, the elements of Matrix C are determined from elements of Matrix B as $c_{ij} = b_{ij}/b_{i(j+1)}$

Matrix C

	Low/Average	Average/High
K1: Low	*.25*	.44
K2: Average	*.25*	.43
K3: High	*.26*	.43
Mean	*.25*	.43
SD	.005	.009

We note that while some ratios in Matrix C's columns are equal, the underlying preferences need not be identical (Omer et al., 1995). These occurrences simply result from inconsistencies of human judgment. Bell (1980) explains that a standard deviation greater than 0.05 indicates a significant inconsistency of judgment. He suggests that a researcher should ask management to reevaluate its 100 point allocation among the attribute elements until consistency (i.e., $\sigma \leq 0.05$) is obtained.

The relative weights, d^a_{ii}, are computed from Matrix C by assigning first 1.00 to the "high" element, then normalizing the results and rounding to yield the relative preferences of .07, .28 and .65 for *K*1, *K*2 and *K*3, respectively, shown as follows:

	*K*1: Low	*K*2: Average	*K*3: High
Weighting	.11	.44	1.00
Relative preference	.07	.28	.65

Similarly, the relative weights for *R*1, *R*2 and *R*3 are .72, .25 and .03, respectively, and .78, .13 and .09, for *T*1, *T*2 and *T*3, respectively.

The decision maker's set of "most preferred" relative weights is called the "ideal." The ideal indicates the highest attainable degree of satisfaction of the decision maker after comparing and compromising between the elements of the critical attributes.

$$Ideal = Market\ acceptance \oplus Design\ risk \oplus Testing\ uncertainity$$

Where

$$\begin{aligned} \text{Market acceptance} &= (.07/K1, .28/K2, .65/K3) \\ \text{Design risk} &= (.72/R1, .25/R2, .03/R3) \\ \text{Testing uncertainity} &= (.78/T1, .13/T2, .09/T3) \end{aligned}$$

Based on the ideal, the mass functions for each focal element are determined as follows:

$$\begin{array}{lll} m_1(K1) = .071, & m_4(R1) = .718, & m_7(T1) = .779 \\ m_2(K2) = .248, & m_5(R2) = .254, & m_8(T2) = .133 \\ m_3(K3) = .645, & m_6(R3) = .029, & m_9(T3) = .088 \end{array}$$

Next, for the three attributes, we determine the mass function for each focal element, A_i. In this application, which has three attributes each with three elements, we have $3 \times 3 \times 3 = 27$ focal elements to account for. The first element is determined as follows:

$$S_\alpha = m(A_\alpha) = \sum_{B \wedge C \wedge D = A_\alpha} m_1(B)m_2(C)m_3(D) / \sum_{B \wedge C \wedge D \neq 0} m_1(B)m_2(C)m_3(D)$$

where B, C and D represent focal elements of m_1, m_2 and m_3, and A_i is the ith focal element of m. Therefore, A_1 is computed as follows:

$$\begin{aligned} A_1 &= K1 \Lambda R1 \Lambda T1 \\ S_1 &= m(A_1) = m_1(F_{Market}^{Low})m_2(F_{Design}^{Low})m_3(F_{Test}^{Low}) \\ &= (.071)(.718)(.779) = .0398 \end{aligned}$$

The Theory of Evidence allows easy combination of independent sources of evidence (de Korvin, 1995). In this theory, "evidence" consists of two functions called *belief* and *plausibility*, i.e., lower and upper probability, respectively. For example, if X is the set of all potential answers of which A is a subset, the belief function, Bel (A), is the degree of support for the answer to be in A. Plausibility, Pls (A), is the degree to which the answer is in A cannot be refuted. Similarly, Pls (not A) is the degree to which the decision maker can refute that the answer is not in A (de Korvin, 1995). As Zadeh (1986) explains, the belief and plausibility measures in the Dempster-Shafer theory are the certainty (or necessity) and possibility, respectively, and both are probability distributions.

We use the following functions to compute the belief functions for the three alternative reasoned actions, h_1, h_2 and h_3:

$$\mathrm{Bel}(h_j) = \sum_{\alpha x} \inf \neq h_j[1 - \mu_{A\alpha}(X)m(A_\alpha)]$$

Applying this function produces the following results:

$$\mathrm{Bel}(h_1) = .23$$

$$\mathrm{Bel}(h_2) = .19$$

$$\mathrm{Bel}(h_3) = .18$$

These results show that action h_1 is better than the other alternatives since it is closest to management's ideal. The other two beliefs of h_2 and h_3, .19 and .18, respectively, are lower than that of alternative h_1 whose belief is .23. That is, management holds a strong belief in maintaining the status quo rather than switching to Level-1 or Level-2 modularity and take their market, design and testing risks. However, the ultimate ranking must also include the plausibility values of the three alternatives, which are measured by the following equation:

$$\mathrm{Pls}(h_j) = \sum_{\alpha} A_\alpha(h_j)m(A_\alpha)$$

Application of this equation provides the following results:

$$\mathrm{Pls}(h_1) = .54$$

$$\mathrm{Pls}(h_2) = .22$$

$$\mathrm{Pls}(h_3) = .23$$

Combining the belief and plausibility values provides the support for each alternative action as follows:

$$\mathrm{Evidence}(h_j) = \mathrm{Bel}(h_j) \oplus \mathrm{Pls}(h_j)$$
$$\mathrm{Evidence}(h_1) = .23 \oplus .54 = .77$$
$$\mathrm{Evidence}(h_2) = .19 \oplus .22 = .41$$
$$\mathrm{Evidence}(h_3) = .18 \oplus .23 = .41$$

Combining the belief and plausibility functions provides results closer to management's ideal: h_1, h_2 and h_3. That is, currently management prefers to maintain the status quo rather than switch to a modularity strategy and take the market, design and testing risks that accompany the modularity actions. Management's belief in the status quo alternative of .23 is stronger than its belief in Level-1 (assembly) modularity of .19 and in Level-2 (design) modularity of .18. Although management's belief in adopting Level 1 (.19) is slightly stronger than in Level-2 (.18), these two strategies have equal evidence (.41). The status quo alternative has a much stronger evidence of .77. When management does not accept the switch to modularity, the investment decision does not proceed to the second stage, evaluation, in the cyclical critical-thinking decision model (Fig. 1). Our process has shown that *evidently* an investment decision is not worth making.

LIMITATIONS OF THE STUDY

This study has some limitations, summarized as follows:

(1) Finocchiaro's (1990) concept of critical thinking adapted in this paper is not universally accepted. Moreover, some authors argue that the term "critical thinking" is an empty concept, devoid of any substance (Whitaker, 2002/03).
(2) The application of the Dempster-Shafer Theory of Evidence accounts for only three alternative actions and three attributes, each with only three elements. There are several other actions, attributes and elements that may play critical roles in the investment decision. However, incorporating more alternative actions and attributes and elements into the algorithm increases the complexity of the methodology and calculations, which runs counter to the algorithm's primary goal of simplifying complex systems, as mentioned above.
(3) Managers' perceptions are subjective, reducing the reliability of results. However, repeating the process with more and different personnel may increase the credibility of the algorithm's results.
(4) The theories of Dempster-Shafer and fuzzy sets have many critics. This paper inherits the weaknesses of these theories.

SUMMARY AND CONCLUSIONS

The traditional long-term investment decision, as presented in the management accounting literature, often begins with listing and evaluating a number of alternative investment proposals, using such criteria as NPV, IRR, and payback period in addition to non-financial measures. This approach tacitly assumes that the decision is to be made; therefore, it bypasses an essential step, the reasoning stage that precedes the evaluation stage. Finding sufficient reasons for such strategic decisions as the adoption of a modular manufacturing system is one of the important functions of the controller (Lee, 1999, p. 4). The absence of the reasoning step as a prelude to the evaluation step in the traditional long-term investment decision creates a gap in this approach. Filling this gap is necessary in order to (1) provide sufficient reasoning for considering this decision or dropping it from consideration, and (2) help the decision maker frame the decision according to its compelling reasons revealed by the reasoning step.

The purpose of this paper is to fill this gap by presenting the long-term investment decision as a critical thinking structure. Using Finocchiaro's (1989, 1990) critical-thinking triad, namely reasoning, evaluating and self-reflecting, and Fritz's (1989, 1990) "creative tension" model, the paper focuses on a combination of the first element of the triad, reasoning, and Fritz's model. Thus, the main argument of the paper states that *without a compelling reason and a trigger event, a decision maker would not seriously consider making the long-term investment decision and begin collecting and evaluating alternative courses of action for making this decision.*

To demonstrate the application of this reasoning stage, the paper explains the intricate nature of the investment decision in a modular manufacturing system. This decision is critical to many manufacturers because it revolutionizes the entire value chain (Sanchez & Mahoney, 1996). A manufacturer may consider applying (1) Level-1 (assembly) modularity strategy, (2) Level-2 (design) modularity strategy or (3) refrain from making the decision by maintaining the status quo. The Dempster-Shafer Theory of Evidence is instrumental for this reasoning stage. Using hypothetical data and Omer et al.'s (1995) algorithm, which operationalizes the evidence theory, the paper shows how a decision maker can justify with sufficient reason his or her consideration of the long-term investment decision.

The contribution of the paper includes (1) highlighting a critical gap currently existing in one of the classical decisions in the management accounting literature; (2) developing a framework for filling this gap and (3) applying this framework to the intricate nature of the modular manufacturing system and its complex investment decision.

NOTES

1. A platform is a set of elements and interfaces that are common to a family of products. Within a product family, the set of common elements, interfaces and/or processes is generally called the "product platform," while the individual product instances derived from the platform are called the "variants." That is, product-family designs share platform architecture, i.e., common elements and structures.

2. The investment decision triad of reasoning, evaluating, and self-reflecting is Finocchiaro's (1990) definition of critical thinking. This definition results from a long debate between Siegel (1988; 1990) and Finocchiaro (1989, 1990) as explained in this paper.

3. It is important to note that the Toyota Production System (TPS) and lean manufacturing are not synonymous. As Hall (2004) explains: "Differences between the Toyota Production System, as practiced by Toyota, and lean manufacturing are significant. Two of those are that TPS emphasizes worker development for problem solving and spends much more time creating standardized work, which lean seldom incorporates."

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