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ORIGINAL ARTICLE

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An expository note on an economic justification of investments in advanced manufacturing systems

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Abstract This is not an overview paper. This paper is concerned with simply making an expository note on three issues that should be taken into account when making an economic justification of investments in advanced manufacturing systems. They are the product of cost information, uncertainty, and intangible benefits available from the investment, which have been widely discussed in isolation for the last 20 years. The main purpose of this paper is primarily to provide practitioners with a synopsis of leading edge research in the area of justifying investment in advanced manufacturing systems and to stimulate a desire for better understanding and application of knowledge and techniques that will enhance professional practice.

Once companies replace their existing manufacturing systems with advanced manufacturing systems, the characteristics of the manufacturing environment are greatly changed in general. Such different characteristics usually entail three problems in justifying investment in the advanced manufacturing systems: (1) Calculating an accurate product cost, (2) Dealing with uncertainty inherent therein and (3) Intangible benefits available from the investment project. Each of these problems has been greatly discussed, mostly independently, in the academic world for the last two decades. In this paper we will revisit and discuss each of them on a general, but relatively informal, level using simple examples to illustrate the main points. The paper is intended to be expository and aimed primarily to hopefully provide practitioners with a synopsis of leading edge research in the area of justifying investment in advanced manufacturing systems and to stimulate a desire for better understanding and application of knowledge and techniques that will enhance professional practice.

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1 Introduction

Companies today have gradually steered their market competition strategy away from being price-oriented to the diversified exploitation of attributes, such as product quality, dependability, flexibility, price, and so on. They have tried to effectively attain their objectives through the changed strategy context by replacing the existing traditional manufacturing systems (TMS) with advanced manufacturing systems (AMS). In other words, they have been led toward a renewed commitment to excellence in manufacturing to be viable.

Once companies switch their manufacturing system from the TMS to the AMS, they are generally faced with a completely new manufacturing environment. Such a changed mode of manufacturing environment usually entails the following three problems when conducting an economic evaluation of investments in the AMS. Firstly, if a company replaces the TMS with the AMS, a cost behavior under the AMS becomes greatly different from the TMS. Abandoning traditional cost accounting (TCA) systems, the company is then forced to select a new cost accounting system properly designed for the AMS so that it is possible to derive accurate product cost information. Cooper [1] proposed activity-based cost (ABC) systems as the alternative to the TCA systems in the middle of 1980s, which has been considered to adequately reflect the cost behavior occurring under the AMS. Many researchers [2–5] assert that when managers use different cost information to make an investment decision, they are led to different conclusion about the decision. In this paper, we will revisit the problem and explore how TCA systems distort an investment justification of AMS and ABC systems and lead to a correct investment decision.

Secondly, as the manufacturing environment is becoming increasingly complex to analyze, a related decision environment is getting more uncertain accordingly. What managers of a company are concerned about under such a decision environment is to figure out a more desirable way to deal with the uncertainty inherent in the specific investment project. They can thereby improve the possibility of accomplishing their targeted goals. In this paper, we will present two ways to handle uncertainty for the purpose of comparison: traditional discounted cash flow (DCF) techniques and real options pricing theory. Since a decision tree analysis (DTA) technique was proposed to deal with uncertainty at the beginning of 1960s [6, 7], it has been widely adopted as a way to manage uncertainty inherent in a strategic investment project [8–12]. With the same purpose of the DTA techniques, Myers [13] proposed a real option pricing theory as another way to handle uncertainty of the strategic investment project in 1977. It has currently been receiving much attention from academics and practitioners [14–16]. In this paper, we will show how these two techniques work for the investment justification and why the real option pricing theory is superior to the DTA technique. And we will explore what is composed of the real option value using the opportunity cost concept familiar to most investment practitioners.

Lastly, the primary motivation for which many companies today implement an AMS is to take advantage of such intangible benefits as improved quality and enhanced flexibility to stay in business. Nevertheless, many companies have been negligent in incorporating the intangible benefits into the investment appraisal process. The negligence usually happens when the investment justification is performed with traditional DCF techniques [17]. Multiple attribute decision-making (MADM) techniques such as simple additive weighting (SAW), the technique for order preference by similarity to ideal solution (TOPSIS), the analytic hierarchy process (AHP), and the like were proposed to be those which are capable of effectively coping with intangible (strategic) benefits when economically justifying investments in the AMS. The MADM techniques are credited for the capability, but they also hold deficiencies. We will provide some notes on the deficiencies of the MADM techniques from the investment justification point of view.

The main purpose of this paper is to provide practitioners with a synopsis of leading edge research in the area of justifying investment in AMS and to stimulate a desire for better understanding and application of knowledge and techniques that will enhance professional practice. This paper is organized in the same order as described above: product cost information, uncertainty, and intangible benefit. In the final section, we will provide our concluding thoughts on potential future research.

2 Product cost information

Once companies change their manufacturing systems to effectively respond to the changing market competition factors of today, they need to take a close look at the existing costing systems and consider replacing them with new costing systems adequate for a new manufacturing environment. Johnson and Kaplan [18] point that if companies do not take proper action for the replacement at the right time, there exists a high possibility that they would be led to make a wrong decision on the strategic decision-making problems critical to their future survival. As required, several new costing systems such as ABC and throughput costing systems have been proposed to determine product cost more accurately than TCA systems.

Over the last decade, ABC systems have been widely accepted as an alternative to TCA systems for correctly calculating product cost and in general for support of the strategic decision-making. Narayanan and Sarkar [5] cite that 15%–20% of companies have installed ABC systems and an equal number are considering adopting them for the next 10 years or so. Cooper and Kaplan [19] insist that when a company implements the ABC systems, it has a chance to closely examine its entire operation and performance and enables to exploit ABC product cost information to change the mix of products produced and customers served, causing to pay attention to making profitable products. Boyd and Cox III [20] insist on their survey result that managers of manufacturing companies make strategic decisions related to product pricing, offering new products/discontinuing products, make versus buy, plant expansion/contraction, and equipment purchase.

Gupta and Galloway [2] discussed a general managerial implication of ABC systems to support effective operation decision-making processes. Degraeve and Roodhooft [21] used ABC product cost information to assess vendor relationships and develop a decision support system to determine procurement strategies. Ioannou and Sullivan [3] developed a two-stage method for justification of investments in material modern material handling systems employing cost information derived by ABC systems with emphasis on the opportunity costs such as waiting and idle costs. Prior to Ioannou and SullivanŠs work, Park and Kim [5] proposed an investment decision model that was developed based on a linear programming approach with ABC cost information provided. The bottom line behind this research is that ABC systems provide a company's managers with accurate cost information to make correct strategic decisions, while TCA systems produce distorted cost information leading the company's managers to make a wrong decision.

In this paper, we will use a short numerical example to show how distorted product cost information leads the managers of a company to make wrong decisions on investments in the AMS. Suppose that a company manufacturing a variety of products plans to replace its TMS with the AMS. Table 1 shows a summary of the general characteristics of the TMS and AMS. Compared with the TMS, the AMS usually asks for a huge amount of initial investment before any production begins. Most of the initial investment is then spent on purchasing computers, software, automatic equipment controlled by the computer, and so on, to sustain a competitive edge in the product marketplace.

This spending pattern on the initial investment ultimately leads a company to shift their process method from simply labor-intensive production workers to knowledge-intensive workers like computer programmers, process schedulers, and system analysts. Due to such a changed spending pattern, the proportion of overhead costs in total product cost sharply increases, whereas that of direct costs, except for material and utility costs consumed to operate equipment, greatly decreases. It is frequently

Table 1. General characteristics of two manufacturing systems

	TMS	AMS
Product diversity	Low	High
Production volume	Mass	Small/Medium
Operating leverage	Low	High
Process method	Labor-intensive	Capital-intensive
Technology	Unconnected	Integrated by computer network
Initial investment	Small	Large

Table 2. The relevant data

Model	No. of cars produced	No. of the inspecting points	Direct labor consumption
Small	3000	30	60%
Midsize	2500	44 (22*)	40%

*Number of inspecting points after investment

Table 3. Cost-savings calculated based on a TCA system

Model	Before investment	After investment	Cost-savings
Small	$ 1.8M	$ 1.32M	$ 0.48M
Midsize	$ 1.2M	$ 0.88M	$ 0.32M
Total	$ 3.0M	$ 2.20M	$ 0.80M

Table 4. Cost-savings calculated based on an ABC system

Model	Before investment	After investment	Cost-savings
Small	$ 1.35M	$ 1.35M	$ 0.00M
Midsize	$ 1.65M	$ 0.85M	$ 0.80M
Total	$ 3.0M	$ 2.20M	$ 0.80M

reported [22] that overhead costs take up more than 50% of total manufacturing costs and direct labor cost around 10% under the advanced manufacturing environment. TCA systems mainly developed for a direct cost-based manufacturing environment do not properly capture the changed cost behavior occurring under the AMS. New costing systems like ABC thus need to be developed or introduced to capture the true cost behavior occurring under an advanced manufacturing environment.

Let's see how a different product cost information affects the appraisal of an investment project by taking a simple numerical example. The main idea of the example is rooted on Smith and Leksan's [23]. Suppose that an automobile company manufacturing small and midsize cars is considering purchasing an automatic inspection system and installing it on the production line for a midsize car. The system costs $ 2.0 million and its salvage value is estimated to be $ 350 000 at the end of its expected useful life of 5 years. For the analysis, it is assumed that the annual amount of the overhead costs incurred to operate and maintain the inspection system is $ 3 million and the company expects to save $ 800 000 with the purchase of the new inspection system each year over 5 years. All cost savings result from the reduction in the number of inspection points of a midsize car by one-half of the original number of inspection points (see Table 2).

The minimum attractive rate of return (MARR) for the investment and the company's marginal tax rate are assumed to be 15% and 35%, respectively. For simplicity, it is also assumed that a straight-line depreciation method is used to depreciate the system over its useful life. Then, a production manager in charge of producing a midsize car expects the profitability of the production line to increase with the hope that he/she can take the full amount of cost-saving attainable from the investment.

An economic evaluation of the investment project may be done using product cost information derived under either the TCA or ABC systems. Under the TCA systems, the relevant overhead costs are allocated to each car based on the amount of direct labor that it consumed. This allocation practice, however, causes the small car production line to take a partial benefit of the investment even if it never spends even a single penny on the proposed inspection system (see Table 3). As shown in Table 3, the small car production line takes the cost-savings of $ 0.48 million, which is equivalent to 60 percent of the total amount of the cost-savings. As a consequence of this allocation practice, the proposed investment project should be turned down because its net present value (NPV) turns out to be the negative value of $ 0.38 million (see Table 5).

However, if the overhead costs are assigned to each car under the ABC systems, more accurate product costs can be obtained because this practice is attributed to the amount of a cost driver that is conceived to have a direct relationship with the cost causes. In this example, a number of the inspecting points are selected as a cost driver used to assign the overhead costs to each car. Table 4 shows that the full cost-savings of $ 0.8 million are absorbed by the production line of the midsize car that proposes and executes the investment. This causes the NPV of the invest-

Table 5. Investment analysis by TCA and ABC systems

Item	TCA system	ABC system
Cost savings	\$ 0.32M $(P/A, 15\%, 5)$ = \$ 1.07M	\$ 0.8M $(P/A, 15\%, 5)$ = \$ 2.68M
Tax savings by depreciation	{(0.35)(\$ 2M − \$ 0.35M)/5} $(P/A, 15\%, 5)$ = \$ 0.38M	
Salvage value	\$ 0.35M $(P/F, 15\%, 5)$ = \$ 0.17M	
Investment	\$ 2M	
Net present value @15%	−\$ 0.38M	\$ 1.23M

ment to be a positive number of $ 1.23 million. Therefore, with the ABC systems, the company can now undertake the investment project that was rejected with the TCA system.

At the MARR = 15%, both TCA and ABC systems generate the completely opposite results about the same investment project. These striking results are absolutely subject to how the manufacturing overhead of a product is distributed. Therefore, it should be noted that the choice of a cost accounting system appropriate for a manufacturing environment plays a critical role in the investment appraisal [3, 5, 18].

3 Uncertainty inherent in the AMS investment project

As the technology has advanced and the manufacturing environment has become more dynamic, manufacturing systems have become more complex and the consequences have become more difficult to quantify, analyze, and predict. It is partly due to the fact that a company needs a relatively long period of time to realize the expected intangible benefits available from the AMS investments. The future payoffs of the AMS investments thus become more uncertain to achieve. Also, since the AMS is highly specialized instead of general, connected with a network at which information and knowledge associated with product and process design technology flow, and so on, it is extremely difficult to recover, either partially or fully, once the AMS investments are made. Therefore, when making an investment decision in the AMS, the question arises about "how to achieve a targeted (expected) profit, while effectively dealing with the uncertainty inherent in the AMS investment project?".

Traditionally, uncertainty has been handled with such techniques as DTA, simulation analysis, or sensitivity analysis. All of these are basically performed with the aid of DCF techniques like NPV and IRR. The basic concept of the DCF techniques is that an investment decision maker first makes an investment decision and then waits to see what will happen in the future. Based on the understanding of the concept, it can be inferred that an investment decision maker must make a decision on the acceptance of the underlying investment project "now" and thus loses an opportunity to actively deal with the changes in the risk profile of the project that arises. Amram and Kulatilaka, Copeland and Antikarov et al. [14–16] criticize the DCF techniques for this deficiency. When it comes to the DTA techniques, there is some confusion about the role of the DTA and real options pricing theory explained in the following. However, they clearly state that that DTA techniques possess the ability to structure a decision problem by considering all feasible options contingent on the possible chance events, they are not so effective as the real options pricing theory because they do not allow a proper discount rate to be determined at the different stages of the investment project, each of which involves a different degree of uncertainty. A critical review on the shortfalls on the DCF techniques can be found in the related references [14–16, 24–26].

Recently a real options pricing theory has emerged as an approach that accounts for the shortfalls of the DCF techniques. The origins of the real options pricing theory derive from the seminal work of Black and Scholes [27] and Merton [28] in pricing financial options. Myers [13] first noticed in 1977 that a financial options pricing theory could be applied to evaluating the value of real investment projects and used the term "real options". What really makes the real options pricing theory such an attractive investment valuation tool in the business environment of today lies in its ability to clearly recognize that an investment decision maker can incorporate new information obtained over the planning horizon of the investment project so as to change the decision already made at the start.

Such benefits of the real options pricing theory have been exploited to evaluate and justify investment in AMS for the place of the DCF techniques. For example, Kumar [29] considers investment decisions related to expansion-flexible manufacturing systems and evaluates its value using a valuation model for option proposed by Margrabe [30]. And Bengtsson [31] investigates manufacturing flexibility in terms of real options. However, MacDougall and Pike [32] suggest that care should be exercised when employing the real options pricing theory to evaluate investment projects for the AMS. They argue for the reason that the strategic value of the investment projects varies during the critical and complicated implementation phase, and thus it is difficult to incorporate such varying value into the real options pricing theory at the early stage. The overall recognition of the real options pricing theory is that it is more effective investment valuation tool than the DCF techniques.

Below, we will show why the DCF techniques are incomplete, often misleading, and sometimes dead wrong in comparison with the real options pricing theory and also look at how real options value is reconstructed in terms of the opportunity cost concept, drawing on a simple example for illustrative purpose only. Readers who are interested in the option pricing theory can refer to the related references [14–16, 33, 34].

Let us consider the following numerical example to understand the difference between the traditional approach and the real option approach in valuing the investment projects in which a real option to defer is embedded. Suppose that a company plans to launch an investment project requiring an initial investment of $ 1.5 million. This project will then generate an expected net cash flow of $ 2.2 million with a probability of 60% if the economic situation turns out to be favorable one year later and $ 0.95 million with a probability of 40% if otherwise (see Fig. 1). The risk-free discount rate for this project is assumed to be 15% that is assumed to be constant over the project's useful life.

If the company evaluates the investment project using the traditional NPV method, the NPV is then calculated as follows:

$$\mathrm{NPV}(15\%) = -1.5 + \frac{(2.2 \times 0.6) + (0.95 \times 0.4)}{(1 + 0.15)} = -0.0217\,. \tag{1}$$

Since the NPV is negative, it is better to reject the investment project under consideration. Figure 1 shows a decision tree of this investment problem for a "what-if scenario" concept.

However, looking back at the process of calculating the $\mathrm{NPV}(15\%) = -\$\,0.0217$ million, we can recognize that the $\mathrm{NPV}(15\%)$ is just averaged-out, but not actual. The recognition

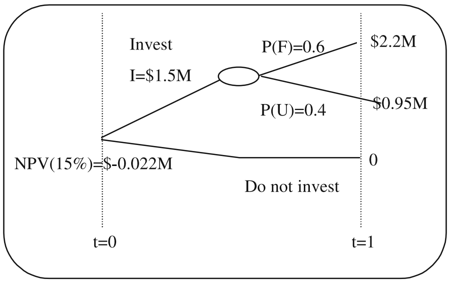

Fig. 1. The traditional DTA approach

leads us to believe that there exits, to some extent, likelihood that the underlying investment project can attain its positive NPV. Suppose that a company wants to delay implementing the investment project by one year to see what will happen collecting additional information on the economic outcome of the next year. If the economic outcome of the next year is judged to be favorable, the company will then definitely make a decision to invest in the investment project. Otherwise, it will give up investing in it. It implies that the company is going to make the investment decision based on the actual value happening one year later rather than the hypothetical value of the averaged-out value. Evaluating the investment project in such a way is called "a real options approach" and its corresponding decision tree, called "a binomial lattice model", is depicted in Fig. 2.

In this example, if the economic situation turns out to be favorable one year later, the company will make the initial investment of \$ 1.5 million at the end of the first year. But, if the economic situation becomes unfavorable, it will abandon the initial investment of \$ 1.5 million at the time. Thus the NPV of the investment project can be calculated as follows:

$$\mathrm{NPV}(15\%) = \frac{\left\{-1.5 + \frac{2.2}{(1+0.15)}\right\} \times 0.6}{(1+0.15)} = 0.215\,. \tag{2}$$

The company now obtains the positive NPV by delaying investing one year and thus can launch the investment project, which is completely opposite to the NPV under the traditional approach case. The value of \$ 0.215 million is specifically called a "strategic net present value (SNPV)" [31, 32]. By waiting one year, the company earns \$ 0.237 million more money than when the company makes an investment decision immediately. The value of \$ 0.237 million is the incremental amount of profit obtained by putting off investing by one year and is called a "value of flexibility" or "real option premium (ROP)" [15, 16, 33, 34]. In general, the ROP is expressed as follows:

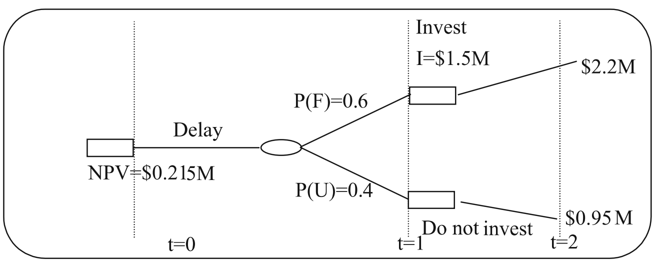

Fig. 2. A real option approach

$$\mathrm{ROP} = \mathrm{SNPV} - \mathrm{NPV} = \$\,0.215 - (-\$\,0.022) = \$\,0.237\mathrm{M}\,. \tag{3}$$

We will present in the following how the ROP can be reconstructed using the opportunity cost concept. In this paper, we identified three different opportunity costs as the components of the ROP: the capital gain, the opportunity loss, and the opportunity gain. All of these three opportunity costs occur when the investment is delayed by one year.

The capital gain is the amount of interest obtained by making a deposit of the initial investment for one year at the risk-free discount rate of 15%. The opportunity loss is the forgone operating profit by having to wait. Once the company decides to delay the investment decision, it may lose a chance to make profit by selling the product during the first year. Finally, the opportunity gain is the amount of money earned by not making the investment in a case for which the economic situation turns out to be unfavorable one year later.

Care should be exercised when calculating the opportunity loss. The opportunity loss must be an average value of the annualized equivalent cash flows. To calculate it, we need to use the following two steps. First, the lump-sum styles of \$ 2.2 and \$ 0.95 million are relaxed to the equal amount of the net cash flows of \$ 0.33 (\$ 2.2M × 0.15) and \$ 0.1425 (\$ 0.95 × 0.15) million, respectively. Second, the expected net cash flow can be calculated with these two cash flows (\$ 0.33 and \$ 0.1425). Refer to Fig. 1 rather than Fig. 2 to understand this relaxation. ROP is then summed over the three opportunity costs as follows:

$$\begin{aligned}\mathrm{ROP} &= \text{Capital Gain} + \text{Opportunity Loss} + \text{Opportunity Gain}\\ &= (1.5 \times 0.15)/1.15\\ &\quad - \left\{(0.33 \times 0.6 + 0.1425 \times 0.4)/(1.15)^2\right\}\\ &\quad + \left\{(1.5 - 0.95/1.15)(0.4)\right\}/(1.15)\\ &= 0.19565 - 0.19282 + 0.2344\\ &= 0.23723\,.\end{aligned} \tag{4}$$

Decomposing the ROP as described above allows us to better understand the implication of the real options value. Since the detail discussion of the implication of the ROP components is beyond the scope of this paper, we will omit its explanation. Instead, we will present Fig. 3 showing the relationship between the present values of each SNPV component and the varying risk-free discount rate. The rough investigation of Fig. 3 says that as the risk-free discount rate increases, the SNPV rapidly decreases. The fact is that the present value of the opportunity gain expected to positively contribute to the SNPV does not increase as the risk-free discount rate increases, while others behave as expected. Another fact is that most of ROP comes from the opportunity gain up to a risk-free discount rate of 15% and the former begins to be greater than the latter.

With this short example, we experienced that a real option valuation approach provides us with the investment timing flexi-

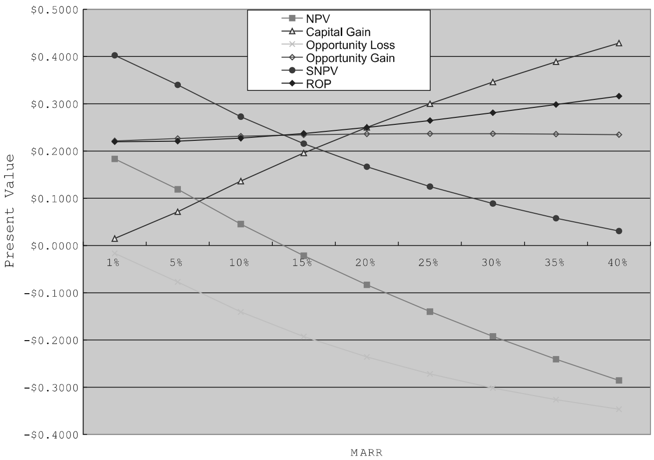

Fig. 3. The relationship between ROP components to the varying risk-free discount rate

bility, which traditional DCF techniques do not. However, many researchers [14, 15, 24, 25, 33, 34] insist that the real option pricing theory is not an absolute alternative for the traditional DCF techniques because the former does not exit without input provided by the latter [14, 15, 24, 25, 33, 34].

4 Intangible benefits

Many companies install an AMS with the expectation of gaining intangible benefits rather than tangible benefits. The intangible benefits include greater manufacturing flexibility, better quality, enhanced company image, and so on. Many attempts to quantify flexibility in a monetary value have been carried out [35–37], but this area of research is still in the process of development. In addition, it takes a long time for the companies to obtain those intangible benefits. On the other hand, tangible benefits include reduced inventory level, less required space floor, less direct labor, reduced scrap and rework rate, and so on. These tangible benefits are conceived to be easy to quantify in a monetary value and to be attained in a short period of time. An investment decision maker needs to incorporate information about the tangible and intangible benefits into the investment appraisal process.

The DCF techniques like NPV and IRR have been widely employed to evaluate AMS projects including such a mix of benefits. However, the DCF techniques only work with the monetary values that are usually associated with the tangible benefits. When performing the investment justification, an investment decision maker has to put zeros for the intangible benefits in the investment justification process. As a consequence of this negligence, the investment project for the AMS frequently appears economically infeasible. This is the main reason why traditional investment justification techniques have been severely criticized [38–40].

As required, many researchers have proposed alternative techniques to the DCF. Among them, Kaplan proposed a way to economically justify the investment project for the AMS. According to his proposed way, what the investment evaluator first performs is the investment justification process with the tangible benefits only [41]. If the net present value with these benefits turns out to be good enough, it is then worthwhile to accept the investment project. Otherwise (i.e., if there is a shortfall in a net present value), it is required to assess whether or not anticipated intangible benefits outweigh the shortfall. Kaplan warns of not putting zeros in for them, but to put in any other value. He maintains that if the intangible benefits are valued as zeros, it severely hurts investments in AMS. This process is one route to follow, but it also inherently involves a shortcoming of asking an investment decision maker to depend on his/her own guess-work at the final stage.

Another way to simultaneously cope with the tangible and intangible benefits in the justification process is to use MADM techniques. Falkner [39], Wabalickis [40], and Yoon and Hwang [41] assert that since the MADM techniques allow us to simultaneously incorporate the various kinds of benefits (monetary and nonmonetary) into the justification process, the shortcoming of the DCF techniques can be easily overcome. However, the MADM techniques also have their own shortcomings that we will expound in the following.

The MADM techniques ultimately provide us with the comparable evaluation value of the alternatives to determine the preference order of the alternatives. To this end, we must undergo the normalization process. The main purpose of normalization is to obtain a comparable scale from the various units of measurement that each benefit factor possesses. However, different normalization equations have appeared without the proper logic required to make the right choice of the normalization equation. If we define the normalized rating as the ratio between individual and combined distance from the origin $\mathbf{0} = (0, 0, \ldots, 0)$, then the comparable rating of x_{ij} is given as

$$r_{ij}(p) = \frac{x_{ij}}{\left\{\sum_{i=1}^{m} \left|x_{ij}\right|^{p}\right\}^{1/p}}, \quad p = 1, 2 \tag{5}$$

$$r_{ij}(\infty) = \frac{x_{ij}}{\max_{i} \left\{\left|x_{ij}\right|, \quad i = 1, 2, \ldots, m\right\}} \quad p = \infty \tag{6}$$

where x_{ij} is the rating of alternative A_i with respect to the jth benefit [42, 43].

Using the Minkowski lp metrics, the above normalization equations are developed. Yoon [42] asserts that regarding the choice of the value for p, there is no firm logic background. He implies that the order preference of the alternatives may depend on the value chosen for p. Also, MADM techniques such as SAW and TOPSIS do not yield results that are consistent with each other.

Let's take a simple numerical example. A company is now considering four different manufacturing systems to select the most favorable one for their own sake, each of which is evaluated with five benefits considered. Those benefits are the initial investment, quality, flexibility, serviceability, and cost savings. Table 6 is a decision matrix showing the relevant data for this example.

Table 6. The relevant data

	Initial investment	Quality	Flexibility	Serviceability	Cost savings
Alternative 1	1.5	75	0.7	50	8
Alternative 2	2.0	90	0.5	38	6
Alternative 3	2.5	80	0.3	35	5
Alternative 4	2.5	85	0.9	30	6
Weight	0.3	0.25	0.15	0.1	0.2

Table 7. The results of SAW and TOPSIS

	SAW	TOPSIS
Alternative 1	0.923	0.758
Alternative 2	0.785	0.438
Alternative 3	0.647	0.078
Alternative 4	0.775	0.478

If we apply the SAW and TOPSIS techniques to the example, we get the order preference as shown in Table 7.

The order preference in descending order by the SAW technique is as follows: alternative 1, 2, 4, and 3. However, that by the TOPSIS is as follows: alternative 1, 4, 2, and 3. Although the order preference of the best alternative is not changed in this example, there is a high likelihood that inconsistency in the order preference may exist among MADM techniques. Then, the question is which technique to take for the investment justification.

The second shortcoming of the MADM techniques that will be discussed in this paper is that since the MADM techniques are used to provide a ranking among alternatives, its cardinal value has no meaning. All that matters is how it ranks alternatives when an evaluation value of the alternatives is computed. What managers of a company in a real world need is information with which they can effectively manage the investment project to achieve the expected profitability after it is actually implemented. This process is called post-auditing activity. However, the MADM techniques do not provide any valuable information for such a purpose.

The post-audit activity is one of the most significant aspects of the capital budgeting process, which involves (1) Comparing actual results with those predicted by the investment evaluator and (2) Explaining why any differences occurred. From the post-audit point of view, it can be said that dependence on the MADM techniques solely to economically evaluate the investment project for an AMS is so much harmful as on the DCF techniques.

5 Concluding remarks

This paper presented a brief discussion of the three major issues in economically justifying AMS investment projects: product cost information, uncertainty, and intangible benefits. Much research has been done on each issue, mostly in isolation during the past decades even though the compounding effect of these issues plays a more critical role in economically evaluating investments in the AMS. Without carefully considering the compounding effect of these issues at the same time, a company may fail to obtain the true value of the underlying investment project, causing it not to gain a foothold for an enhanced competitive advantage. Therefore, as for the future research, we recommend that a case study taken from an industry field should be performed and analyzed from the systematically integrated investment justification viewpoint (i.e., concurrently taking all three issues into considering when developing an investment decision framework). Finally, we hope that there will be much research focusing on overcoming the shortcomings of the MADM techniques when they are applied to the evaluation of investment projects.

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