Journal of Engg. Research **Vol. 4 No. (4) December 2016** pp. 130-150

نظام لدعم قرار اختيار تقنيات التصنيع المتقدمة

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الخلاصة

تتطلب تقنيات التصنيع المتقدمة استثمارات رأسمالية ضخمة وتعمل على توفر عدد كبير من الفوائد غير الملموسة مثل المرونة، والجودة، والقدرة التنافسية، ورضا العملاء، إلخ....، والتي تكون في الغالب صعبة التقييم. يكمن هذا التحدي في إدراج الاعتراف الكامل بفوائد تقنيات التصنيع المتقدمة وإدراجها بشكل منطقي ودقيق في النماذج. في هذه الورقة، تم اقتراح منهجية نظام دعم قرار شامل لمساعدة منظمات التصنيع في اختيار تقنية التصنيع المراد الاستثمار فيها، والتي تكون أكثر ملاءمة للأهداف الاستراتيجية. في النموذج المقترح يمكن تحديد قيمة أكثر واقعية للفوائد والفوائد الفرعية المرتبطة ببدائل الاستثمار المتاحة. نظام دعم القرار المقترح يستند إلى منطق ضبابي ويساعد صناع القرار في شركات التصنيع على إجراء تحليلات كاملة لبدائل تقنيات التصنيع المتقدمة. تقارن هذه الطريقة بين فوائد المستويات والمستويات الفرعية القابلة وغير القابلة للقياس لتقنيات التصنيع المتقدمة. تم اقتراح استخدام طريقة التقييم اللغوي الضبابي لتقييم المستويات غير القابلة للقياس. وتعرض الورقة حالة دراسية لاختبار وعرض نظام دعم القرار المقترح.

Decision support system for the selection of advanced manufacturing technologies

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ABSTRACT

Advanced manufacturing technologies require huge capital investments and offer large number of intangible benefits such as flexibility, quality, competitiveness, customer satisfaction etc., which are ill-structured in nature and very difficult to quantify. The challenge is to incorporate full recognition of advanced benefits of manufacturing technologies logically and accurately in justification model. In this paper, comprehensive decision support system approach is proposed to help manufacturing organizations in selecting advanced manufacturing technology for investment, which is most suitable to their strategic objectives. In the proposed model, one can define more realistic value for benefits and sub benefits associated with a particular investment alternative. Proposed decision support system is based on fuzzy logic and assists decision makers of manufacturing firms in making more informed and complete analyses of alternative advanced manufacturing technologies. It opts both quantifiable and non-quantifiable benefit levels and sublevels for advanced manufacturing technologies. For non-quantifiable levels, fuzzy linguistic approach is suggested. A case study is presented to test and demonstrate proposed decision support system.

Keywords: Advanced manufacturing technology; decision support system; fuzzy logics; multiple criteria.

INTRODUCTION

The global manufacturing sector is becoming very competitive day by day. It needs to develop diverse, complex, sophisticated, productive, and high quality products faster to cater for market demand with shorter lead time and cost. In such situation, advanced manufacturing technology (AMT) governs and determines an option intended for survival. AMT is a collective approach to monitor and control design and development of products, equipment and tools, to satisfy global market requirements (Small & Yasin 1997). AMT can be combined with microelectronic, information technology, and or new organizational practices to achieve improvement, integration, flexibility and competence in manufacturing systems (Rafaat, 2002). Meredith & Suresh (1986) categorized AMT systems as 'stand-alone systems', 'partly integrated systems' and 'fully integrated systems'. For a manufacturer, there is a choice from automation of individual process to fully automated manufacturing system. But implementation of fully integrated AMT is not affordable to any manufacturing organization. So, they choose an appropriate implementation of AMT to satisfy their dynamic requirement. For example, an implementation of material resource planning may be suitable for one manufacturer while computer aided design & manufacturing may be the most suitable choice for another one, or enterprise requirement planning is more beneficial to another. Benefits of these AMTs are well identified by researchers and practitioners (Kumar *et al.*, 1996; Hofmann & Orr, 2005; Sohal *et al.,* 2006; Singh & Khamba, 2013).

Economic justification of investment of AMT has been discussed and presented in literature, since 1984. AMT systems have multiple attributes that result in complex evaluation process. It needs enormous capital investment in all stages of implementation, starting from planning and purchase, till its installation and operation. It should also have a minimum rate of depreciation and maintenance cost, over the long run. However, traditional appraisal method does not take into account such flexibility. Since there is synergy among AMT components, lack of experience in handling and implementation of AMT systems can be a risky decision. The existing traditional investment models fail to quantify all benefits of the AMT. For example (Naik & Chakravarty, 1992; Chen & Small, 1996; Kaplan, 1986), in traditional models major focus is only on the maximization of net cost savings, minimization of energy and labor costs, which are easily quantifiable. But, they ignore system flexibility, product quality, demand mix, and short lead times. These shortcomings associated with these traditional economic models leads to improper investment justification of AMTs (Ordoobadi & Mulvaney, 2001). Similarly, many of the existing investment justification models estimate the value of benefits, without determining any real level of benefits to manufacturing organization. Hence, the challenge is to incorporate full recognition of AMT benefits logically and accurately in a justification model. In addition, manufacturers need justification models to be easy to use, understand, consume minimum business time and satisfy organizational objectives.

It is apparent that most of these manufacturing companies do the investment in advanced manufacturing technologies, when they find out that current processes, procedures and or technologies are inadequate to meet their current or future demand.

Evidently, everyone is interested in improving their performance to meet the ever-increasing market demand. As a result, it was realized to have an interactive model for assessment and ranking of advanced manufacturing technologies. In this paper, an attempt is made in this direction. The proposed model was set to determine the investment decisions within organization is own comprehensive set of criteria. Also, a report generated by the model cross compare and highlight which beneficial criteria and alternatives are to be selected. If one feels a readjustment in assessment criteria and alternatives, the proposed model has the flexibility to change it at any stage.

This paper is organized into six sections. An introduction is followed by literature review. Details of proposed decision support system (DSS) are presented in section 3. An application of the model is verified and presented in section 4. Section 5 highlights comparative aspects of the proposed DSS and section 6 concludes the paper.

LITERATURE REVIEW

Till date, researchers reviewed and practitioners adopted numerous approaches to justify investment in AMT. They classified these justification approaches into four main approaches (Meredith & Suresh, 1986; Badiru *et al.* 1991; Naik & Chakravarty, 1992): economic, analytical, strategic, and integrated approaches. Whereas, Mohanty & Venkataraman (1993) classify justification models as qualitative, semi-qualitative, quantitative and mathematical programming models. Based on existing literature, common evaluation techniques / approaches for advanced manufacturing technologie's investment decisions are categorized in Table 1.

Table 1. Common evaluation techniques / approaches for AMT investments decisions

Approaches	Evaluation based on
Economic approaches	Net present value (NPV), Payback, Internal rate of return (IRR), Other discounted cash flow (DCF) methods, Non DCF methods or Sensitivity analysis
Strategic approaches	Business advantage, Future expansion / R & D efforts, Technical Benefits or Competitive Factors
Analytic approaches	Value analysis using: Weighted evaluation methods, Utility models, AHP models, Simulation or fuzzy set theory
	Mathematical analysis using: Integer programming, Goal programming or Linear programming
	Risk analysis: Stochastic methods or Monte Carlo simulation
Decision support system	Combinations of two or more of the evaluation methods

In the case of traditional engineering *economic approaches*, Fotsch (1984) reported the comparative difference between payback period and return on investment (ROI) technique. While, Small & Chen (1997) emphasized on DCF, NPV and IRR. Some representative models for selection of AMT have arisen (Chen & Small, 1994; Efstathiades *et al.,* 2002; Lin & Nagalingam, 2000; Meredith & Suresh, 1986; Sambasivarao & Deshmukh, 1997; Small & Yasin, 1997).

Strategic approaches are focused more on qualitative attributes of manufacturing systems. Researchers (Meredith & Suresh, 1986; Ramasesh & Jayakumar, 1993) reviewed and described a strategic approach based on criteria as a business strategy, competitive market advantage, operational importance, research & development. Mital & Vinayaganoorthy (1987) examined the economic feasibility of robotization of the workplace in a metal industry. They emphasized economically desirable solution from the viewpoint of unemployment due to AMTs. Nagalingam & Lin (1998) proposed an approach to identify suitable AMTs, which fulfill the strategic objectives of an enterprise. MacDougall & Pike (2003) raised concern that organizational strategic benefits can be captured to some degree, and there is a need to consider changes in strategic value as organization adapts to setbacks that arise during AMTs investment projects.

Analytic approaches take into account economic and non-economic benefits. Kuei *et al.* (1994) initiated a framework for the ranking of machine technology. Subsequently, Mohanty & Deshmukh (1998) proposed and validated an integrated model for evaluating and analyzing an Indian manufacturing firm's AMT investment justification. Chandran *et al.* 2005 presented an analytical model based on linear programming (LP). In analytic approaches, there is a need to code measurable and available information in crisp (real) numbers. In case information is unquantifiable and incomplete, fuzzy set numbers are preferred into the decision model. Perego & Rangone (1998) proposed a fuzzy analytic approach to AMT selection. Chiadamrong (1999) proposed an integrated approach based on fuzzy logic and taking in to account the strategic quantifiable aspects of the investment. Successively, a fuzzy logic algorithm was proposed by Karsak & Tolga (2001) to justify the selection of AMT from a set of alternatives. In parallel, Ordoobadi & Mulvaney (2001) has developed a decision approach using a fuzzy discounted cash flow analysis, taking into account both qualitative and quantitative evaluation criteria. A systematic integrated fuzzy multi-criteria approach has been proposed by Chan *et al.* (2003) for the AMT selection and investment justification problems. Whereas, Abdelkader & David (2001) reviewed and developed a model for evaluating AMT investment projects, based on empirical research survey and utilizing the concept of fuzzy numbers and linguistic variables. Karsak (2002) and Bozda *et al.* (2003) presented the fuzzy multi-criteria decision-making approach, to select the best manufacturing system from a set of alternatives manufacturing systems. Kulak & Kahraman (2005) are the first, who developed the fuzzy axiomatic design approach to rank alternative manufacturing systems. Researchers (Talluri & Yoon, 2000; Amin *et al.,* 2006; Karsak & Sebnem, 2008; Wang & Chin, 2009) also proposed the use of data envelopment analysis (DEA) for selection of AMT. While few others (Ordoobadi, 2009; Chuu, 2009) presented an evaluation tool for decision makers to assist investments in AMT. Based on this, researchers developed a model using fuzzy decision trees (Evans *et al.,* 2011) and fuzzy graph theoretic approach (Goyal & Grover, 2013) for the evaluation of AMT investment. Similarly, Yusuf *et al.* (2013) also presented a theoretical model to allow decision makers to foresee the results of AMT implementation based on definite criteria. Maldonado *et al.* (2013) evaluated AMTs compatibility based on human factors and ergonomic characteristics. Subsequently, Maldonado *et al.* (2014) also presented a fuzzy technique for order of preference by similarity to ideal solution (TOPSIS) decision-making model under an intuitionistic fuzzy environment that is used for the evaluation of AMT, regarding ergonomic compatibility attributes.

A *decision-support system* (DSS) is a special kind of computer-aided automated tool for decision-making processes. In DSS a decision process consists of four stages: problem input, analysis, solving and output of results. Situation assessment, information fusion, and alternatives generation are the three important functions in any decision support system. Researchers (Sambasivarao & Deshmukh, 1997; Nagalingam & Lin, 1998; Luong, 1998) make use of DSS for the selection and justification of automation technologies based on only risk and economic analysis. Chiadamrong & O'Brien (1999) presented DSS model which focus on only economic and strategic values. DSS model by Rouse (1988) involves characterizing anticipated demand and obstacle in manufacturing systems. Kumar *et al.* (1996) reviewed decision process of twenty-two manufacturing firms, who adopted AMTs, revealed a consistency in decision-making patterns; their views led to the development of an AMT investment decision models. Raafat (2002) provides a comprehensive note on the techniques and their rationale in the planning, purchase and investment justification of AMTs. As a case study, for a German manufacturing firm, Hofmann & Orr (2005) surveyed the benefits provided by AMTs. While Sohal *et al.* (2006) proposed general selection model based on the experience of 224 Australian manufacturing companies that have invested in AMTs and succeeded in using AMTs. Similarly, Zhou *et al.* (2009) compare the sample of firms in Singapore and Sweden based on AMT investment strategies. Sweden manufacturing firms exhibit a positive impact on firm profit and growth compared to Singapore manufacturing firms. Singh & Khamba (2013) done a study, which was aimed to evaluate and understand AMTs in a leading tractor manufacturing organization. From the published literature, it is evident that economic justification of AMTs investment is a complex multi-criteria problem. Methods developed to take into account many intangible and tangible decision attributes but fall short in a comprehensive analysis. Manufacturers need justification models to be easy to use, understand, consume minimum business time and satisfy their objectives.

THE PROPOSED DSS PROCESS

The process of DSS includes six steps, each of which is further explained below.

Step 1: (*Narrow down objectives*): Any well-managed manufacturing organization always desire for multiple strategic and operational benefits, after any change in their investment strategy. In view of this, the user of the proposed DSS model is provided with a list of benefits, and if he/she wishes, can narrow down these benefits. As presented in Table 2, increased flexibility is a benefit and has sub benefit as product flexibility. In this case benefit indicators are 'number of product types manufactured', 'level of cycle times' and 'setup times'.

Step 2: (*Pairwise comparison matrix of linguistic variable*): Decision makers in any manufacturing organization need to do a pairwise comparison of alternatives in pairs, to judge which of each alternative is to be preferred. These alternatives have a greater amount of some quantitative property, and sometimes the two alternatives are identical. In such cases, there is need to have a scientific method of pairwise comparison. In the proposed model, user has an option to either adopt an existing fuzzy linguistic scale, which has been provided as default in the model, or he/she can develop one using pairwise comparisons. Here in the model, fuzzy linguistic scale proposed by Abdelkader & David (2001) is used to evaluate fuzzy importance. The model provides an option to assign fuzzy ratings to alternative AMT for each benefit. A pair-wise comparison between linguistic values is done to generate a linguistic scale and its values. A sample pairwise comparison matrix of the linguistic variable is presented in Table 3.

Step 3: (*Completing the fuzzy inputs*): There are a number of manufacturing organization objectives, which are defined qualitatively. Linguistic fuzzy inputs are used in order to rank or prioritise these desired manufacturing organization objectives.

For example, a sample objective question is: How much importance manufacturing organization gives 'to reduce the cycle time of product'? (Select any one choice)

○ Very important (VI) ○ Important (I) ○ More-or-less important (MI)

○ More-or-less unimportant (MU) ○ Unimportant (U) ○ None

Table 2. Classification of objectives/benefits desired from AMTs

Benefits	Sub benefit's	Benefit indicators
Increased Flexibility	Product flexibility	Volume of parts
		Shorter cycle time
		Decreasing machine setup time
	Process flexibility	Decreasing waiting time for parts
		Decreasing work in process (WIP)
	Demand flexibility	Reduce lead times
		Reductions in inventory
		Decreasing time to market
	Equipment flexibility	Increase machine utilization
		Reduction in idle time and cost
	Manufacturing flexibility	Reduce material handling time
		Increase automatic tool change capability
		Reduce setup time
		Lower exchangeability and movements
		Reduce transportation time between workstation
Increased Productivity	Single/ Multiple and or Total productivity	Decreased labor cost
		Decreased material cost
		Decreased service cost of using capital
		Decreased floor space requirement
		Decreased production time per unit

Table 3. Pairwise comparison linguistic variables and their triangular fuzzy numbers (x_{ij}, y_{ij}, z_{ij})

i ↓ j→	VH	H	M	L	VL
VH#	(1,1,1): (x_{11}, y_{11}, z_{11})	(2,3,4)	(4,5,6)	(6,7,8)	(8,8,9)
H	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(4,5,6)	(6,7,8)
M	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(4,5,6)
L	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
VL	(1/9,1/8,1/8)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)

Note: # Very High (VH), High (H), Medium (M), Low (L) and Very Low (VL)

Step 4: (*Assignment of fuzzy rating scale*): The ratings assigned using linguistic membership functions need to be converted into their corresponding numerical value. Most of the fuzzy linguistic rating scales do not take into account weights of confidence of decision maker's opinion into account. Therefore, to take into account weights assigned to fuzzy numbers preferred to use weighted geometric mean (Wang *et al.* 2009). Let us say, A_{ij}: (x_{ij},y_{ij},z_{ij}) is triangular fuzzy number, then geometric mean for linguistic values 'Q_i' is as

$$Q_i=(u_i, v_i, w_i): \left(\left[\prod_{j=1}^{n} x_{ij}\right]^{1/n}, \left[\prod_{j=1}^{n} y_{ij}\right]^{1/n}, \left[\prod_{j=1}^{n} z_{ij}\right]^{1/n}\right) \quad (1)$$

While weights of linguistic value 'W_i' expressed as:

$$W_i=(b_i, c_i, d_i): \left(\frac{u_i}{\sum_{i=1}^{n} w_i}, \frac{v_i}{\sum_{i=1}^{n} v_i}, \frac{w_i}{\sum_{i=1}^{n} u_i}\right) \quad (2)$$

Using Table 3 pair-wise comparison triangular fuzzy values (x_{ij}, y_{ij}, z_{ij}), geometric mean (Q_i) and weights (W_i) calculated for each linguistic value. And these values are represented in Tables 4 and 5 respectively.

Table 4. The geometric mean for linguistic values (Q_i)

Q_i	u_i	v_i	w_i
Q_1	$(1*2*4*6*8)^{1/5}$ u_1= 3.29	$(1*3*5*7*8)^{1/5}$ v_1= 3.84	$(1*4*6*8*9)^{1/5}$ w_1= 4.44
Q_2	$(1/4*1*2*4*6)^{1/5}$ = 1.64	$(1/3*1*3*5*7)^{1/5}$ = 2.04	$(1/2*1*4*6*8)^{1/5}$ = 2.49
Q_3	$(1/6*1/4*1*3*6)^{1/5}$ = 0.94	$(1/5*1/3*1*4*6)^{1/5}$ = 1.10	$(1/4*1/2*1*5*8)^{1/5}$ = 1.38
Q_4	$(1/8*1/6*1/5*1*2)^{1/5}$ = 0.38	$(1/7*1/5*1/4*1*5)^{1/5}$ = 0.51	$(1/6*1/4*1/3*1*9)^{1/5}$ = 0.66
Q_5	$(1/9*1/8*1/8*1/9*1)^{1/5}$ = 0.18	$(1/8*1/7*1/6*1/5*1)^{1/5}$ = 0.23	$(1/8*1/6*1/6*1/2*1)^{1/5}$ = 0.28
Total	$\sum u_i$ = 6.44	$\sum v_i$ = 7.72	$\sum w_i$ = 9.25

Table 5. Weights of linguistic values (W_i)

W_i	$b_i = u_i / \sum w_i$,	$c_i = v_i / \sum v_i$	$d_i = w_i / \sum u_i$
W_1	$b_1 = u_1$/9.25= 0.36	0.50	0.69
W_2	0.18	0.26	0.39
W_3	0.10	0.14	0.21
W_4	0.04	0.07	0.10
W_5	0.02	0.03	0.04

However, it is preferred to transfer these weights into a rating scale. Weights (W_i) computed in Table 5 are used to define fuzzy rating for linguistic values as:

VL = W_5 = (0.02, 0.03, 0.04),

L = VL + W_4 = (0.02, 0.03, 0.04) + (0.04, 0.07, 0.10) = (0.06, 0.10, 0.15),

M = L+ W_3 = (0.06, 0.10, 0.15) + (0.10, 0.14, 0.21) = (0.16, 0.24, 0.36),

H = M + W_2 = (0.16, 0.24, 0.36) + (0.18, 0.26, 0.39) = (0.34, 0.50, 0.75),

VH = H + W_1 = (0.34, 0.50, 0.75) + (0.36, 0.50, 0.69) = (0.70, 1.00, 1.00^+) '+' means that if the value is greater than 1, it will be consider as 1.

Similarly, the concentration and dilation operations of equation were used to derive new linguistic values of fairly low and fairly high, as:

Fairly High (FH) = $(\text{High})^{0.5}$ = $(H)^{0.5}$ $\{(0.34,0.50,0.75)^{0.5}\}$= {0.58, 0.71, 0.86}

Fairly Low (FL) = $(\text{Medium})^2$ = $(M)^2$ $\{(0.16,0.24,0.36)^2\}$ = {0.03, 0.06, 0.13}

Excellent fixed value = {0.90, 1.00, 1.00} and None fixed value = {0.00, 0.00, 0.00}.

Graphically, each linguistic membership functions values are as presented in Figure 1.

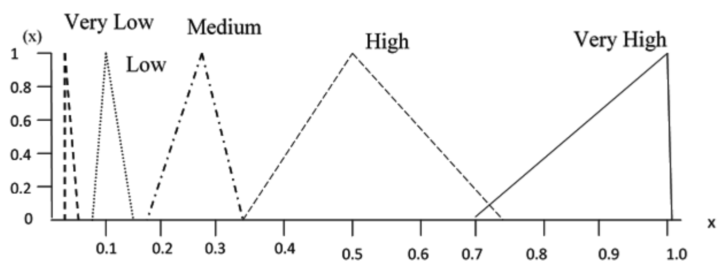

Fig. 1. Membership function of the linguistic scale

If there are several decision makers, then all of the decision makers' fuzzy ratings are to be combined by taking the arithmetic mean. Sample fuzzy rating for AMT alternatives 1 and 2 are presented in Table 6.

Step 5: (*Assigning normalized ratings to alternative AMTs*): The normalization procedure has the advantage of converting multiple attributes into dimensionless measurement unit. In the proposed model the normalized ranked value for each alternative AMT is obtained as presented here in the following para.

If there are 'm' numbers of AMTs, and 'n' numbers of benefit indicators, then for given 'j^{th}' AMT alternative and its benefit indicator 'b', the fuzzy linguistic rating is 'LR_{jb}: (G_{jb}, H_{jb}, I_{jb})'. Similarly, if 'IC_b: (W_{bl}, W_{b2}, W_{b3})' is importance weight assigned to benefit indicator 'b', then considering all benefit indicators, a fuzzy measure in terms of fuzzy triangular number 'FC_j : (W_{jl}, W_{j2}, W_{j3})' for AMT_j is computed using Equation (3). 'FC_j: (W_{jl}, W_{j2}, W_{j3})' for two alternatives is as presented in Table 7.

$$FC_j = \left(\left[\frac{1}{n}\left(\sum_{b=1}^{n}\left(W_{b1} * LR_{jb}\right)\right)\right], \left[\frac{1}{n}\left(\sum_{b=1}^{n}\left(W_{b2} * LR_{jb}\right)\right)\right], \left[\frac{1}{n}\left(\sum_{b=1}^{n}\left(W_{b3} * LR_{jb}\right)\right)\right]\right) \quad (3)$$

Table 6. Mean fuzzy rating (LR_{jb}) for each benefit indicator for respective AMT

Objective↓	Alternatives 'j'→	AMT Alternative 1				AMT Alternative 2			
	AMT Benefit Indicator 'b'↓	LS#	Triangular fuzzy numbers TFM			LS#	Triangular fuzzy numbers TFM		
Product Flexibility	Volume of parts	FL	0.03	0.06	0.13	M	0.16	0.24	0.36
	Shorter cycle time	M	0.16	0.24	0.36	FH	0.58	0.71	0.86
	Decreasing machine setup time	VL	0.02	0.03	0.04	FH	0.58	0.71	0.86
Process Flexibility	Decreasing waiting time for parts	L	0.06	0.10	0.15	H	0.34	0.50	0.75
	Decreasing work in process	L	0.06	0.10	0.15	H	0.34	0.50	0.75
Demand Flexibility	Reduce overall lead times	FL	0.03	0.06	0.13	M	0.16	0.24	0.36
	Reductions in inventory	VL	0.02	0.03	0.04	FL	0.03	0.06	0.13
	Decreasing time to market	L	0.06	0.10	0.15	VH	0.70	1.00	1.00

Note: # Linguistic Scale (LS), Very High (VH), High (H), Medium (M), Low (L), Very Low (VL), Fairly High (FH), Fairly Low (FL)

Table 7. The equivalent fuzzy numbers (FC_j) for each AMT overall benefits criteria

	AMT Alternative 1 Triangular fuzzy numbers			AMT Alternative 2 Triangular fuzzy numbers		
FC_j	0.0834	0.190	0.293	0.03076	0.1885	0.39

These weighted triangular fuzzy numbers are converted into an equivalent crisp value using a method proposed by Abdelkader & David (2001). Let 'TFM_j: (TFM_{j1}, TFM_{j2}, TFM_{j3})' be a triangular fuzzy measure for 'j^{th}' AMT alternative (AMT_j). The ranked value for 'AMT_j' is 'RV_j' and computed using Equation (4).

$$RV_j = TFM_{j2} * \left\{ (I) \frac{TFM_{j2} - X_{min}}{X_{max} - X_{min} + TFM_{j3} - TFM_{j2}} + (1 - I) \frac{1 - X_{max} + TFM_{j1}}{X_{max} - X_{min} + TFM_{j2} - TFM_{j1}} \right\} \quad (4)$$

In Equation (4), X_{min} = Minimum of $\{TFM_{j1}, TFM_{j2}, TFM_{j3} \mid \forall\, j = 1, 2, 3, ...m\}$ and X_{max} = Maximum of $\{TFM_{j1}, TFM_{j2}, TFM_{j3} \mid \forall\, j = 1, 2, 3, ...m\}$ and 'I' is an index of optimism in the closed interval {0, 1}. Subsequently, the normalized ranked value 'NRV_j' for each 'AMT_j' is obtained. Sample 'NRV_j' are as shown in the following Table 8.

Table 8. The ranked values (RV_j) and normalized rank values (NRV_j) for each alternative AMT

	Advanced manufacturing technology alternative (AMT_j)							
'j'→	1	2	3	4	5	6	7	8
RV_j	0.0605	0.264	0.1322	0.2491	0.2425	0.11333	0.1041	0.07829
NRV_j	0.0487	0.2122	0.1063	0.20023	0.1949	0.09108	0.0837	0.0929
Rank	8	1	4	2	3	6	7	5

The normalized ranked values 'NRV_j' of all alternatives were sorted in increasing order and the one with the maximum normalized value is ranked '1' and preferred to be carefully chosen. In a practical scenario, due to economic constraints, manufacturing organization and or decision makers prefer to evaluate future actions based on economic analysis of chosen alternative.

Step 6: (*Economic analysis of selected AMT alternative*): Commonly all manufacturing organizations prefer to do an economic analysis before adopting any change. In presented model, an option has been provided to do an economic analysis of selected AMT alternatives. The model user has to provide appropriate information as an input for the economic justification. A summary report will be generated, which includes internal rate of return 'IRR' and net present value 'NPV', minimum attractive rate of return 'MARR' and planning period 'k' in years. NPV value is obtained using Equation (5). And equality of Equation (6) is also tested.

$$NPV = \sum_{k=1}^{m} \frac{(R_k - E_k)}{(1+MARR)^k} \quad (5)$$

$$\sum_{k=0}^{m} \frac{R_k}{\left(1+i^*\right)^k} = \sum_{k=0}^{m} \frac{E_k}{\left(1+i^*\right)^k} \quad (6)$$

In the above Equations (5 and 6), E_k = Net expenditures including investments for the k^{th} year, R_k = Net revenues or savings for the k^{th} year, i = Effective interest rate per interest period and i^* = IRR of the investment. When Equation (5) yields a positive value and Equation (6) satisfies, the proposal is considered economically viable. The presented model needs to provide appropriate information as an input for the economic analysis of selected AMT alternatives. These input variables in the case of the realistic situation might have randomness, the proposed DSS model has scope to handle such type situations. In order to demonstrate an application of the proposed DSS model, a case study has been considered. The details of the case study are presented in the succeeding section.

CASE STUDY

The manufacturing organization in the case study has an annual total operating cost of five million dollars. They decide to invest eight hundred thousand dollars in AMTs in order to compete with others in the market and wish to accomplish strategic goals. There was a need to propose DSS model to justify their investment based on their certain strategic goals. The model starts by selecting organization objectives, which are to be achieved or improved through the implementation of new AMT. Subsequently model prompts to define objectives using the linguistic rating for each benefit indicator. For the case, as presented in the following Table 9, there are sixteen AMT alternatives to be incorporated in evaluation analysis. Subsequently, model asks to input contribution of each AMT alternative toward each objective. Numerical input '1'means very low contribution in achieving the objective and input '10' means very high contribution in achieving the objective. Step by step flow in the form of computer screen shot is presented in Figure 2.

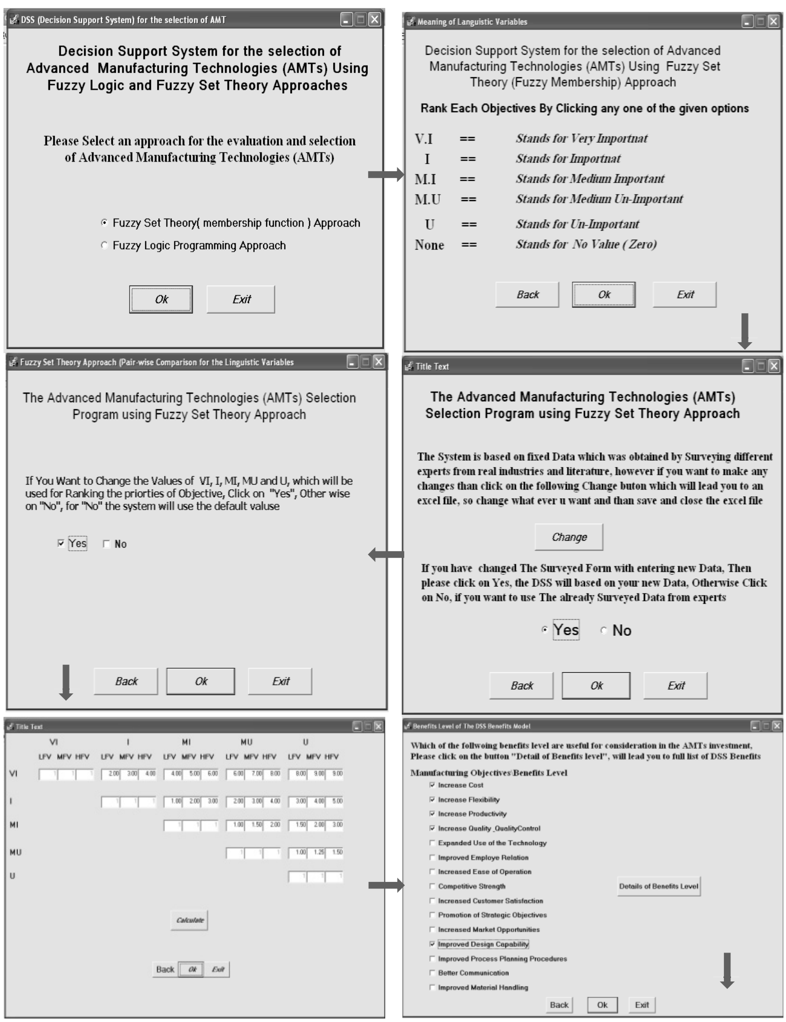

Fig. 2. DSS model screen shots

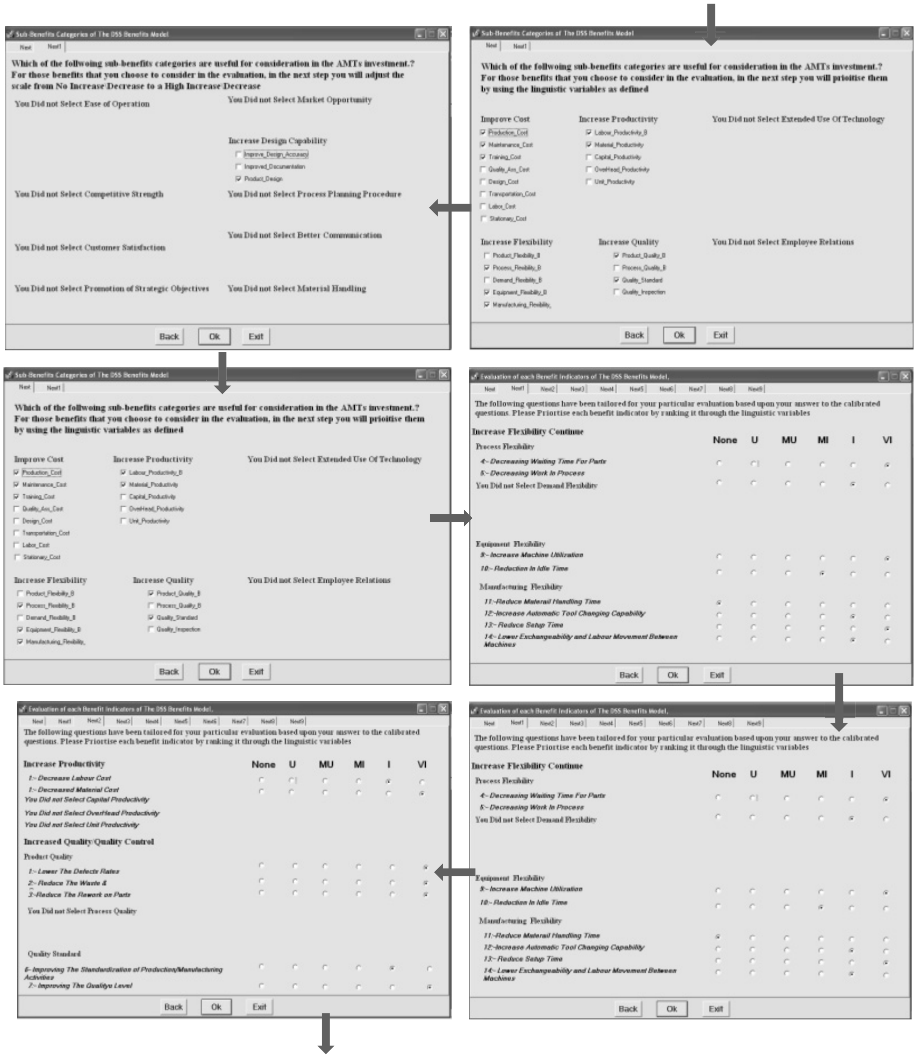

Fig. 2. (Continue) DSS model screen shots.

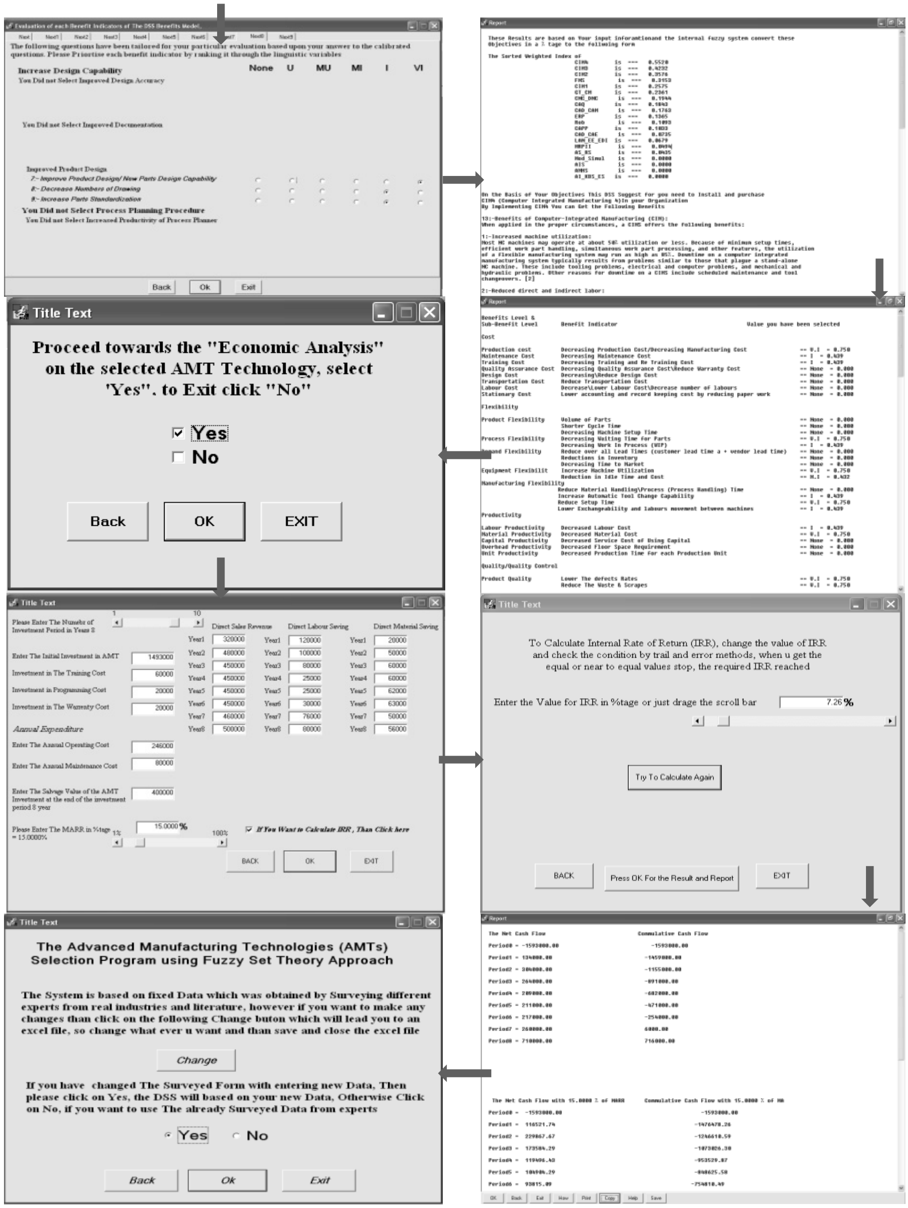

Fig. 2. (Continue) DSS model screen shots.

As presented in the above screen shot, CIM4 (fully automated system) is the best alternative selected for the case on hand. Also, a report generated by the model highlight, which benefits category\sub benefits indicators were selected and how they are cross compared. If one feels a readjustment in objectives and benefit indicators, the model has flexibility and it can be done at any stage.

Table 9. The list of AMT alternatives and their codes.

j	AMT alternative and Codes
1	Computer Aided Design and Engineering (CAD/CAE)
2	Computer Aided Design and Manufacturing (CAD/CAM)
3	Manufacturing Cell (MC)
4	Flexible Manufacturing System (FMS)
5	Computer Numerical Control (CNC)
6	Robotics (ROB)
7	Automated Storage and Retrieval System (AS/RS)
8	Manufacturing Resource Planning (MRP-II)
9	Enterprise Resource Planning (ERP)
10	Computer Aided Process Planning (CAPP)
11	Computer Aided Quality (CAQ)
12	Local Area Network (LAN)
13	Computer Integrated Manufacturing1 : (CIM1) : (CAD + CAM + CAPP)
14	Computer Integrated Manufacturing2 : (CIM2) : (CAD + CAM + CAPP + CAQ)
15	Computer Integrated Manufacturing3: (CIM3) : (CAD + CAM + CAPP + CAQ + MRP II + AS/RS)
16	Computer Integrated Manufacturing4 : (CIM4) : Fully automated system: (CAD + CAM + CAPP + CAQ + ERP)

Similarly, based on the cost and benefit information, economic analysis is performed independently. Apart from analytical data analysis, the manufacturing organization wants to make an initial investment of four hundred thousand Saudi Riyals (fifty percent of budgeted cost), which incurs an annual expenditure of ninety thousand Saudi Riyals in the form of maintenance, overhead and operation costs. The initial period for the new AMT investment is set as 8 years, and it produces annual revenue for each year as shown in Table 10. This revenue is in the form of direct sales, direct labor saving and direct material saving. Salvage values of the investment at the end of the eighth year is four hundred thousand Saudi Riyals. The values for such variables be left entirely up to individual organization and decision makers performing the analysis. This entire data of is entered into economic analysis dialog box as shown in the screenshots (refer Figure 2). The proposed DSS model calculate 'IRR' to benchmark the return of the investment against 'MARR', which can be regarded as a minimum standard for the manufacturing organization. Therefore, to equate the two values, each time, change the value of IRR and click on the "Try to Calculate Again" and look for the equality reaches, stop and click on the "Ok" button to get the report. The report details are as presented in Table 11. As the difference between 'IRR' and 'MARR' is negative (refer Table 11) it means that 'IRR' is less than the 'MARR', the selected AMT alternative

(CIM4) investment is financially not viable. Thus, by examining these results, CIM4 option is not economically justified. This indicates that re-adjustment is required either in the objectives to be met or readjustment of some economic variables.

Table 10. Cost information by investment period for a selected CIM4.

Cost categories↓	Investments (in thousand Saudi Riyals)								
Period (in years) →	0	1	2	3	4	5	6	7	8
Initial investment	1493	-	-	-	-	-	-	-	-
Annual operating	-	246	246	246	246	246	246	246	246
Annual maintenance	-	80	80	80	80	80	80	80	80
Training	60	-	-	-	-	-	-	-	-
Programming	20	-	-	-	-	-	-	-	-
Warranty	20	-	-	-	-	-	-	-	-
Total investment cost	1593	326	326	326	326	326	326	326	326
Benefit categories↓	Benefits (in thousand Saudi Riyals)								
Direct sales revenues	0.00	320	480	450	450	450	450	460	500
Direct labor savings	0.00	120	100	80	25	25	30	76	80
Direct material savings	0.00	20	50	60	60	62	63	50	56
Total benefit cost	0.00	460	630	590	535	537	543	586	1036

Table 11. The economic analysis report.

Simple payback period = 6.98 years	Internal rate of return = 7.26%
Discounted payback period = 10.00 years	MARR = 15.00%
Net present value = -424, 966.60 Saudi Riyals	Difference = IRR – MARR= -7.74

COMPARATIVE DISCUSSION

Proposed DSS model takes into account multiple AMT benefits and allow to define a level of each benefit and need to consider cost factors involved with AMT. With this model, managers can determine their investment decisions within organization's own comprehensive set of criteria. The existing expert choice AHP software (http://expertchoice.com/), which is based on a hierarchical structure, needs consistency checks and takes a good amount of computational time. In the existing models, computational time involved escalates, as the numbers of criteria and alternatives increases. The proposed DSS model is based on a framework of analytic hierarchy process, but uses fuzzy numbers along with fuzzy linguistic variables. Proposed DSS model requires both analytical and economic information (for example details of alternatives, benefits level, sub benefits categories, linguistic variables, the contribution of each alternative against each benefits indicator, investment details, the life span of alternative AMTs, and cash flow of the AMT investment project for the expected life). Salient features of proposed model compared to other currently available multi-attributes analysis methodologies are: it is simple and guiding approach for manufacturing managers/ decision makers with interactive dialogue frames, it provides a facility in realizing the benefits of AMTs, and it allows refinement in construction of fuzzy linguistic scales. It has the flexibility of simplifying analysis by having a number of user-driven options. One can use both fuzzy numbers along with the linguistic variables. It facilitates user to validate their input data. It also provides an option to perform an economic analysis to evaluate the proposed decision and quantifying intangibles and indirect costs.

CONCLUSION

A comprehensive approach in the form of DSS is proposed to help manufacturing organizations in selecting an AMT, which is most suitable to their strategic objectives. It allows to define a more realistic value for benefits associated with a particular investment alternative, also allow decision makers to set or modify benefit or sub benefit values. The model attempts to guide through a series of input questions. These questions are to set the level of benefits that can be obtained from each alternative AMT. A fuzzy set theory approach is used to convert each benefits level into membership functions and which in turn convert it into crisp output values for each benefits category. There are non-financial benefit levels and sub level benefit indicators for the AMTs, those cannot be translated into cash flows. For such case, the fuzzy linguistic approach is suggested. The linguistic scale is generated by using pair-wise comparisons. An option for economic analysis has been provided to see, if the investment is economically justifiable. Proposed DSS model has been validated through a manufacturing organization interested in AMT investment decision-making. Another aspect to be considered in future is to examine dependencies between the input variables, and even some interactions may in fact exist with advanced manufacturing technologies.

ACKNOWLEDGEMENTS

This project was financially supported by the Vice Deanship of Research Chairs of King Saud University.

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Submitted: 24/10/2015
Revised: 19/06/2016
Accepted: 14/07/2016