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Justification and Classification of Issues for the Selection and Implementation of Advanced Manufacturing Technologies

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Abstract**—**It has often been said that the strength of any country resides in the strength of its industrial sector, and Progress in industrial society has been accomplished by the creation of new technologies. Developments have been facilitated by the increasing availability of advanced manufacturing technology (AMT), in addition the implementation of advanced manufacturing technology (AMT) requires careful planning at all levels of the organization to ensure that the implementation will achieve the intended goals. Justification and implementation of advanced manufacturing technology (AMT) involves decisions that are crucial for the practitioners regarding the survival of business in the present days of uncertain manufacturing world. This paper assists the industrial managers to consider all the important criteria for success AMT implementation, when purchasing new technology. Concurrently, this paper classifies the tangible benefits of a technology that are evaluated by addressing both cost and time dimensions, and the intangible benefits are evaluated by addressing technological, strategic, social and human issues to identify and create awareness of the essential elements in the AMT implementation process and identify the necessary actions before implementing AMT.

Keywords**—**Advanced Manufacturing Technology (AMT), Justification and Classification.

I. Introduction

MANY companies are currently strengthening their competitive positions by updating the technologies used in the manufacturing process. The 1990s has created an environment where manufacturing organisations must become increasingly more sophisticated in their manufacturing techniques if they are intending to achieve a competitive advantage. These changes have largely been in response to the increasing need for companies to become competitive not only in terms of cost, but also with regard to quality and responsiveness to customers. Developments have been facilitated by the increasing availability of advanced manufacturing technologies (AMTs).

Despite the significant role of AMTs in Global Market and it's competitive advantages ,many applications of advanced manufacturing technologies (AMTs) have not yielded their potential benefits frequently because the selections and implementations has not been carried out in relation to strategic objectives. Maximum benefit will be accrued if there is a fit between the capabilities of the technologies and the firm's business and manufacturing priorities. Many firms that implemented AMT achieved technical success (the technology is running) but not business (increased competitiveness, quality) success. Decentralized decision making with a high level of inter-functional coordination can increase the potential for the flexible use of AMT.

Investment evaluation methods play an important role in today's competitive manufacturing environment. Both economic evaluation criterion and strategic criteria such as flexibility, quality improvement, which are not quantitative in nature, are considered for evaluation. ,(Selection and using proper manufacturing technology can enhance the production process, provide effective utilization of resources, increase productivity and improve system flexibility, repeatability and reliability. Strategic decision making, like technology selection, is very complex because the decision involves uncertain environment, lengthy time horizon, inadequate information and subjective factors, which cannot be easily quantified. Usually, in the selection of the best technology, objective factors such as cost, profit, revenue, time saving, time of completion, etc. are considered but subjective factors such as flexibility, learning, capacity increment, etc. are overlooked. This results in advanced technology not winning the confidence of top management.

In this study, an attempt is made to discuss the various issues of a learning organization which have helped to evaluate manufacturing strategies and select advanced manufacturing technology, based on strategic, tactical and monetary factors.

II. AMTs Adoption and Justification

Adoption of advanced manufacturing technology (AMT) involves major investment and a high degree of uncertainty and, hence, warrants considerable attention within a manufacturing firm at the strategic level as discussed by Meredith [33]. Works cited earlier by Sambasivarao and Deshmukh [51], Small and Chen [55], Chan *et al*. [9], Sohal *et al*. [5] have identified several barriers that may encounter manufacturing companies to adopt AMT successfully. As a result, issues involving selection and justification procedures assume greater importance.

Studies conducted in the past two decades have shown that the benefits of AMTs are both tangible and intangible and

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hinged on the type of AMTs and its applications (Voss, [64]; Sohal, [4]; Sohal *et al*., [5]).In addition according to the Sambasivarao and Deshmukh [51], advanced manufacturing technologies involve a set of quantifiable and non-quantifiable attributes. So there is a need to evolve an integrated framework for comprehensive appraisal of AMTs using these attributes. There is little doubt that significant tangible and intangible benefits can be gained from implementing AMT, and that failure to quantify all benefits is detrimental to the decision-making process, whether the project is accepted or not (Small and Chen [55]).

The literature about AMT justification shows that the idea of a strategic, non-monetary decision process is already consolidated (Mohanty and Deshmukh [37]; Sambasivarao and Deshmukh [52]; Denis *et al*, [15]). Over the last ten years, many authors have suggested that in the AMT performance measurement systems, financial and cost indicators should be complemented by non-financial measurement tests related to qualifying , delivery and flexibility, with the integration of the different business areas being encouraged and the management's strategic objectives being reflected (Macarena *et al*, [32]).Furthermore when monitoring the results of investments is made in advanced manufacturing technologies (AMT) it is dangerous to focus solely on costs, as it is possible that the system used to assess performance might lead managers to ignore other strategic objectives (Karsak and Tolga [29]). According to Michael [34], while the costs (hardware, software, planning, training, operations, etc.) and many of the operational benefits are generally easily quantifiable, on the other hand, some of the major strategic benefits are very difficult to estimate. To overcome this limitation some have promoted the use of strategic justification approaches that consider criteria such as the comparison with competitors, the retention, attainment or perception of industry leadership, and expected future developments in the industry. There is a growing consensus that hybrid investment approaches which include both strategic and economic justification criteria are needed to evaluate these complex systems. Abdel-Kader and Dugdale [1] supposed a model for the evaluation of investments in advanced manufacturing technology. Considering the importance to an integration of financial and non-financial factors in AMT implementation evaluations he demonstrates that it is conceptually possible to do this using the mathematics of the analytic hierarchy process and fuzzy set theory. New justification methods, such as the Analytical Hierarchy Process (AHP), real options pricing, and simulation began to be used to provide a more thorough evaluation of investments in AMT. These new justification tools addressed the traditional tools' inability to include the qualitative benefits of AMTs such as increased flexibility (Dessureault [16]). In brief, both economic evaluation criterion and strategic criteria such as flexibility, quality improvement, which are not quantitative in nature, should be considered for evaluation.

III. Classification of AMTs selection Methods

Several approaches for justifying investment in AMT have been advanced. The literature that informs this topic can be grouped into three categories (Suresh and Meredith [33]; Raafat [43]; Michael [34]).

- The economic approach. Involving the classical financial justification techniques of payback period (PP), return on investment (ROI), internal rate of return (IRR), and net present value (NPV).
- The strategic approach. Involving analysis of competitive advantage, business objectives, research and development objectives and technical importance.
- The analytic approach. Involving value analysis, portfolio analysis and risk analysis (RA).

These methods deviate from each other due to the non-monetary factors. Economic justification methods of manufacturing investments are discussed by Proctor and Canada [42]. Economic analysis methods are the basic discounted cash flow techniques such as present worth, annual worth, internal rate of return and other techniques such as payback period and Return on Investment (ROI) which ignore the time value of money.

The economic approach has long been quite popular in investment justification. Fotsch [18] reported that the PP technique was the most popular method of AMT appraisal in his study of the machine tool industry. Lefley *et al*. [30] found that PP techniques continue to be popular in the USA, the UK and the Czech Republic. However, those payback methods, because they favour a short-term perspective on investments, can be deleterious for AMT projects. It is interesting to note that it has been suggested that while the Japanese also used the payback method most frequently, it serves more as a performance measurement tool than as a rigid financial criterion (Huang and Sakurai [25]). ROI was the second most popular technique being used for AMT appraisal according to Fotsch [18]. However, it has been suggested that this method has more disadvantages than the payback method because it does not measure the economic value of the project (Primrose [41]).

The discounted cash flow (DCF) techniques, NPV and IRR are considered to be more effective than ROI and payback. Kaplan [28] argued that DCF approaches should always be applied for the justification of AMT but, for most firms, the discount rate should be lower than that required for conventional projects. Other researchers also support the use of DCF, but warn that there is a need to quantify the intangible benefits prior to the application of DCF in order to ensure a realistic appraisal (Primrose [41]; Kakati and Dhar [27]; Park and Son [40]).

Cost/benefit analysis is also utilized for AMT project appraisals. Researchers have sought to identify costs and benefits of AMT through the use of case studies. For firms where the level of risk and uncertainty make up the most critical elements of the justification process, it is felt that risk sensitivity analysis is the most appropriate evaluation technique (Primrose [41]; Swamidass and Waller [58]). Lefley et al. [30] indicate that firms can use the PP, probability analysis, and sensitivity analysis and computer simulation to assess the level of risk. Hodder and Riggs [24] suggested that there was also a need to vary the discount rate to reflect the changes in the risk premium over the life of the project. Differences in risk related to different types of AMT must also be recognized. Generally, more complex AMT that offer a wide range of benefits are expected to have lower risks than less complex technologies with a narrow range of benefits.

A pervasive issue in justifying investment in AMT has been the inappropriateness of the economic approaches using only financial and accounting techniques (i.e. PP, NPV, ROI, IRR, etc.) for determining the intangible benefits of AMT such as improvements in flexibility, quality, time-to-market, and other synergistic effects (Attaran [2]; Roth *et al*. [47]; Swann and O'Keefe[59]). The lack of faith in these techniques has led some researchers to advocate the justification of AMT using strategic arguments.

Vrakking [65] suggested that AMT projects might have to be justified on the basis of strategic arguments. Criteria such as comparison with competitors, the retention, attainment or perception of industry leadership, and expected future developments in the industry might serve as alternative factors for decision makers to approve AMT projects. Support for this strategic view is also provided by Huang and Sakurai [25], who found that, in Japanese firms, installation of AMT is seen as a natural step that must be taken to retain manufacturing credibility as well as market share. Primrose [41] indicated that if strategic benefits are not quantified in the appraisal, they will appear as unexplained variances not attributable to the project in the accounting report. Another approach is to regard the benefits from the new technology as essential and calculate the cost of meeting these with conventional technology. However, there is a fear that such an approach might militate against the adoption of useful conventional projects.

To alleviate the problems inherent in using purely financial or purely strategic appraisal approaches, recent studies have promoted hybrid economic and strategic appraisal approaches (Raafat [43]). Kakati and Dhar [27] suggest that AMT projects should be evaluated using two basic criteria: first, through economic justification, and then a strategic assessment if the project fails to meet the investment criteria. An earlier variation of this approach called for the use of DCF techniques, and if the project is not feasible, the difference needed to make it feasible is determined (Kaplan [28]). The adoption decision is then based on the ability of the strategic benefits to make the project acceptable. There is also a school of thought that considers all AMT costs and benefits to be quantifiable (Primrose [41]). These authors suggest that all projects should be appraised through a single evaluation technique which uses sensitivity analysis on the intangible benefits to compensate for the risk associated with evaluating these parameters. However, there is evidence that suggests that manufacturers are still having great difficulty quantifying intangible benefits and that conventional appraisal techniques are partly to blame for missing some potential benefits (Lefley *et al*., [30]).

The move towards merging economic and strategic approaches has also seen the evolution of several weighted scoring models (WSM) which allow management to assign weights to each tangible and intangible factor under consideration (Slagmulder and Bruggeman [54]; Soni *et al*., [56]). Scoring models possess multiple criteria capabilities, are simple to use, and can take management policies and the impact of flexibility into consideration (Suresh and Meredith [57]). While these techniques represent the importance of each strategic factor by weights determined by management, these weights are generally not measured for consistency. Furthermore, the assumption of linear additivity of the weighted scores may not be accurate. Wabalickis [66] proposed the use of more sophisticated scoring models such as the analytic hierarchy process which can correct for managerial inconsistencies. There are some other recent approaches to hybrid justification that utilize decision support tools, the analytic hierarchical process and fuzzy logic (Abdel-Kader and Dugdale [1]; Chiadamrong and O'Brien [11]; Luong [31]). When flexibility, risk and non-monetary benefits are expected, and particularly if the probability distributions can be subjectively estimated, analytical procedures may be used.

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TABLE I JUSTIFICATION METHOD FOR ADVANCED MANUFACTURING TECHNOLOGIES [29]

	Techniques	*Advantages*	*Disadvantages*
Economic	Payback method Return on investment Discounted cash flow techniques	Ease of data collection Intuitive appeal	Do not take into account strategic and non-economic benefits Consider a single objective of cash flows, and ignore other benefit such as quality and flexibility
Strategic	Technical importance Business objectives Competitive advantage Research and development	Require less technical data Use the general objectives of the firm	Necessity to use these techniques with economic or analytic ones since they consider only long-term intangible benefits
Analytic	Scoring models(Analytic Hierarchy Process AHP) Mathematical programming Integer programming Goal programming Data Envelopment Analysis (DEA) Stochastic methods Fuzzy set theory	Uncertainty of the future and multi-objectivity can be incorporated Subjective criteria can be introduced in the modelling phase	Require more data Usually more complex than the economic analysis

Strategic justification methods are qualitative in nature and are concerned with issues such as a technical importance, business objectives and competitive advantage (Meredith and Suresh [33]). When strategic approaches are employed, the justification is made by considering long-term intangible benefits. Hence, using these techniques with economic or analytical methods would be more appropriate. Table I, which is an updated version of the classification initially proposed by Meredith and Suresh [33], evaluates the different justification methods for AMT.

Wabalickis [66] developed justification procedure based on the Analytic Hierarchy Process (AHP) to evaluate the numerous tangible and intangible benefits of an FMS investment. Chakravarty and Naik [8] pointed out the need for integrating the non-financial and strategic benefits of AMT with the financial benefits and proposed a hierarchical evaluation procedure involving strategic evaluation, operational evaluation and financial evaluation. Shang and Sueyoshi [53] proposed a selection procedure for an FMS employing the AHP, simulation and Data Envelopment Analysis (DEA).

Small and Chen [55] discussed the results of a survey conducted in the US that investigated the use of justification approaches for AMS. According to their findings, manufacturing firms using hybrid strategies, which employ both economic and strategic justification techniques, attain significantly higher levels of success from advanced technology projects. Sambasivarao and Deshmukh [51] presented a decision support system integrating multi-attribute analysis, economic analysis and risk evaluation analysis. They suggested AHP, TOPSIS and linear additive utility model as alternative multi-attribute analysis methods. Methods include game theoretical models, multiattribute utility models, fuzzy linguistic methods and expert systems.

In summary, investment justification of AMT should include consideration of the operational costs and strategic and operational benefits of these systems together with consideration of the costs and benefits of the infrastructural adjustments (e.g. information technology adjustments, employee training and development costs) that are required to successfully implement these systems. The choice of AMT should reflect both the benefits that the organization expects to achieve and the quality of organizational preparation and support for the adoption of the chosen system. In addition, measurement of AMT performance must be focused on assessing progress towards the original strategic, business and organizational objectives for implementing the systems.

IV. Classification of AMTs issues

The decision to implement useful advanced manufacturing technology (AMT) is a major decision for many organizations. Selection of the appropriate technology that achieves or matches with the organization objective, and maximum benefits of technology, which is made based on a sound decision-making process. Selection and ranking of advanced manufacturing technologies (AMTs) which are defined as the strategic decision-making process for successful implementation of AMT would be the goal of the hierarchy. Numerous issues are addressed by researchers in studies involving the selection and justifications of AMT. A researcher has given attributes the different names but the concepts behind the terminology are the same.

Mohanty R.P. [35] has classified implementation issues into six categories: direct cost factors, preproduction cost factors, human issues, social issues, strategic issues, and technological issues. Selection issues are classified primarily based on accountability for analysing AMT benefits. Tangible factors are quantifiable dimensions. These factors are classified into two categories, namely Cost and Time.

Economic issues: Economic issues involve cost-borne analysis of AMT. They include cost-benefit analysis and economic analysis strictly in monetary terms. The economic factors are either estimated, based on certain assumptions, or are actual cost-borne figures. It is evident to the literature that economic attributes play a major decisive role for selection and justification of AMT. However, analysis based on economic factors may not be adequate, because AMT offers a large number of intangible benefits.

TABLE II ECONOMIC ISSUES

Researchers	1	2	3	4	5	6	7
Sambasivarao and Deshmukh[51]	x	x	x	x	x	x	x
Crookall[12]	x					x	
Ferdows *et al*.[17]	x	x	x		x	x	x
Young and Murray[68]						x	
Park and Son[40]			x	x			
Wabalickis[66]	x						x
Fry and Smith[20]		x	x				
Troxler and Blank[63]	x	x				x	
Huang and Sakurail[25]		x	x	x		x	
Ghosh and Wabalickis[21]			x		x		x
Primrose[41]	x					x	
Datta *et al*.[13]		x				x	x
Demmel and Askin[14]	x	x	x	x	x		
Afzulpurkar *et al*.[3]		x					x
Chang and Tsou[10]		x	x				
Hin *et al*.[23]	x	x				x	
Mohanty[36]	x	x	x		x	x	x
Sambasivarao and Deshmukh[52]		x			x	x	
Mohanty and Deshmukh[37]	x						x
Kevin Low Lock[60]			x				
Chan, H. Lau[9]		x	x	x			x
Crowe and Noble[61]				x	x	x	
Godwin and Ehie[22]		x	x			x	x
Borenstein and Becker[15]		x				x	x
Rosnah Mohd and Chek[46]			x				
Hulya Julie Yazici[26]			x				
Sohal and Burcher[4]			x				
Sacrista´n Dı´az and lvarez Gil[32]		x					x
DeRuntz and Turner[6]							x

Key:
1. Investment 3. Labour 5. Modification 7. Throughput
2. Inventory 4. Maintenance 6. Quality

Time issues: Time issues would be one of the essential components of competition environment. All steps of production cycles from production lines until market position can perform effectively and would reflect all their potential benefits if they were scheduled well.

Selection of advanced manufacturing technologies involves a large number of intangible attributes. Intangible attributes are the indirect/direct factors which are generally not quantifiable. However, their relative importance may be analyzed using multi attribute decision-making approaches. These issues include Human, Social, Strategic and Technological issues. Thus, manufacturing firms will face large-scale issues when selecting and implementing AMT.

TABLE III TIME ISSUES

Researchers	1	2	3	4
Sambasivarao and Deshmukh[51]	x	x		
Mohanty and Deshmukh[37]	x	x		
Kevin Low Lock[60]		x	x	
Chan, H. Lau[9]	x			
Crowe and Noble[61]		x		
Godwin and Ehie[22]	x		x	
Borenstein and Becker[15]	x	x	x	
Hulya Julie Yazici[26]				x
Sohal and Burcher[4]	x		x	
Sacrista´n Dı´az and lvarez Gil[32]		x		x
DeRuntz and Turner[6]	x		x	x
Sohal and Schroder[5]		x	x	
Salaheldin Ismail[50]			x	x
Bolden and Waterson[44]				x
Rosnah and Megat Ahmad[45]				x

Key:
1. Shortening product life-cycles
2. Reduced lead time
3. Reduced change over/set up times
4. Improving speed of delivery

Human issues: Employees play a most vital role in selecting AMT. It may be evident that one of the objectives behind the innovation of AMT is to reduce human intervention. In developed countries like the UK, Germany, France and the USA, more efforts are put in order to reduce human intervention in manufacturing as the industry appears to be capital-intensive. Human factors play a very significant role, especially in many developing countries where AMTs are at the critical early stages of implementation AMTs.

Social issues: Automation technologies have far-reaching social impacts. Social issues are essential to consider as they involve cost borne and benefits received by those associated with the organization.

Strategic issues: The strategic impacts have long-term implications for the organization as a whole. It is necessary to consider the effects of AMT on other functional departments of an organization. Many researchers have discussed the effects of AMT on manufacturing strategy. These effects are reflected in decisions like replacement with improved technology, expansion of entire plant and plant modernization projects. Strategic issues can be viewed as having significant repercussions of AMT on different functional areas of the organization. These repercussions are reflected in costs borne and benefits received by each of the functional departments. These are the key factors for setting the management objectives and can be viewed as indicators to assist in making strategic decisions.

TABLE IV HUMAN ISSUES

Researchers	1	2	3	4
Sambasivarao and Deshmukh[51]		x	x	x
Ferdows *et al.*[17]		x		
Voss[64]			x	x
Weatherall[67]		x	x	
Troxler and Blank[63]			x	
Datta *et al.*[13]		x	x	
Demmel and Askin[14]		x	x	
Hin *et al.*[23]				x
Mohanty[35]		x	x	x
Sambasivarao and Deshmukh[52]		x		x
Mohanty and S.G. Deshmukh[37]	x			
Chan, H. Lau[9]		x		x
Crowe and Noble[61]		x		
Rosnah Mohd and Chek[46]	x			
Sohal and Burcher[4]	x		x	
Abdel-Kader and Dugdale[1]		x		
Salaheldin Ismail[50]	x		x	
Sohal and Schroder[5]	x		x	
Rosnah and Megat Ahmad[45]	x			

Key:
1. Level of skill
2. Employee moral/motivation
3. Employee and working relationships
4. Manpower planning

TABLE V SOCIAL ISSUES

Researchers	1	2	3	4	5
Sambasivarao and Deshmukh[51]	x	x		x	x
Frazelle[19]		x			
Ferdows *et al.*[17]	x				
Park and Son[40]	x				
Weatherall[67]	x			x	
Troxler and Blank[63]	x				
Ghosh and Wabalickis[21]		x			
Mohanty[35]	x	x		x	x
Mohanty and Deshmukh[37]	x		x		
Kevin Low Lock[60]			x		
Abdel-Kader and Dugdale[1]			x		
Godwin and Ehie[22]	x				
Orlando and Aguilo[39]					x
Rosnah Mohd and Chek[46]					x
Hulya Julie Yazici[26]			x		
Sohal and Burcher[4]		x			
Sacrista´n Dı´az and lvarez Gil[32]	x				
DeRuntz and Turner[6]	x				
Sohal and Schroder[5]	x				
Bolden and Waterson[44]			x		
Rosnah and Megat Ahmad[45]	x				

Key:
1. Customer satisfaction
2. Working environment
3. Responsiveness
4. Community development
5. Ecology

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TABLE VI STRATEGIC ISSUES

Researchers	1	2	3	4	5	6
Sambasivarao and Deshmukh[51]	x	x	x	x	x	x
Ferdows *et al*.[17]		x		x		
Voss[64]		x	x		x	
Wabalickis[66]				x		
Weatherall[67]	x			x		x
Troxler and Blank[63]	x			x		x
Huang and Sakurail[25]	x	x	x	x		
Primrose[41]				x		x
Datta *et al*.[13]	x			x		x
Demmel and Askin[14]			x	x		x
Mohanty[36]	x					x
Mohanty[35]	x		x	x	x	x
Sambasivarao and Deshmukh[52]	x	x	x	x	x	x
Mohanty and Deshmukh[37]	x	x		x	x	x
Kevin Low Lock[60]				x		x
Chan, H. Lau[9]				x		x
Crowe and Noble[61]				x		
Godwin and Ehie[22]						x
Sohal and Burcher[4]			x	x		x
Sacrista´n Dı´az and lvarez Gil[32]				x		x
DeRuntz and Turner[6]				x	x	x
Sohal and Schroder[5]			x			x
Salaheldin Ismail[50]			x	x		x
Bolden and Waterson[44]				x		x
Rosnah and Megat Ahmad[45]						x
Monge and Rao[7]				x	x	x

Key:

1. Finance position	3. Management development	5. R&D activities
2. Government policy	4. Market position	6. Competition

Technological issues: These issues are limited to the capabilities of the AMT to improve manufacturing performances. The following issues describe the compliance of manufacturing systems. Pervious studies have reported that changed markets require flexible manufacturing. The researchers have described procedure and methodological aids such as technological performance, and economic evaluation used for planning and realization of a CAM system. Henceforth, Cost, Time, Technological, Strategic, Social and Human issues would be the success factors for selecting AMT and criteria of the hierarchy.

V. Conclusion

One of the main objectives of this paper is to identify the important criteria affecting advanced manufacturing technology selection. These factors would affect the overall organization through new technology selection and implementation, which are identified as main criteria and sub-criteria of the AMT selection. From the literature, it may be observed that a large number of issues are involved in advanced manufacturing technology implementation procedures.

Various attributes are addressed and used in this paper for procedures involving selection and justification of AMT. In this paper, a comprehensive list of attributes has been identified and classified under two categories – tangible and intangible attributes. The literature observes common difficulties in implementing AMT such as lack of technical skills, managerial problems, and lack of the systematic evaluation methods. Economic issues alone are inadequate for justify new manufacturing systems because traditional evaluation methods are inadequate for the purpose.

The present paper suggested has brought several elements to the fore. Advanced manufacturing technologies involve a set of quantifiable and non-quantifiable attributes. There is a need to evolve an integrated framework for comprehensive appraisal of AMTs using these attributes.

TABLE VII TECHNOLOGICAL ISSUES

Researchers	1	2	3	4	5	6	7
Sambasivarao and Deshmukh[51]	x	x	x	x		x	x
Frazelle[19]		x					
Crookal[12]					x		
Ferdows *et al*.[17]		x	x		x		
Young and Murray[68]		x		x	x		
Voss[64]			x				x
Park and Son[40]							x
Weatherall[67]		x			x	x	
Fry and Smith[20]	x	x					
Troxler and Blank[63]	x	x			x		
Huang and Sakurail[25]	x	x	x		x		x
Ghosh and Wabalickis[21]	x			x			
Primrose[41]		x		x			
Datta *et al*.[13]	x			x		x	x
Demmel and Askin[14]		x	x	x			
Mohanty[36]			x				
Afzulpurkar *et al*.[3]	x						
Chang and Tsou[10]			x				x
Hin *et al*.[23]			x	x			x
Mohanty[35]	x	x	x	x	x	x	x
Sambasivarao and Deshmukh[52]	x						
Mohanty and Deshmukh[37]		x			x	x	
Crowe and Noble[61]					x		
Godwin and Ehie[22]		x	x	x			
Borenstein and Becker[15]	x	x			x	x	
Rosnah Mohd and Chek[46]		x			x		
Hulya Julie Yazici[26]	x	x					
Sohal and Burcher[4]		x		x			
DeRuntz and Turner[6]		x			x		
Sohal and Schroder[5]		x		x	x		
Monge and Rao[7]		x			x		
Salaheldin Ismail[50]	x	x			x	x	
Bolden and Waterson[44]		x				x	
Rosnah and Megat Ahmad[45]		x			x		
Orlando and Aguilo[39]		x			x	x	
Houseman and Tiwari[38]	x	x					
Abdel-Kader and Dugdale[1]		x					
Dessureault[16]		x	x				
Tilak Rajand Shankar[62]		x			x		

Key:

1. Capacity utilization	3. Hardware	5. Productivity	7. Software
2. Flexibility	4. Management information	6. Reliability	

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