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ORIGINAL ARTICLE

Advanced manufacturing techniques and information technology adoption in India: A current perspective and some comparisons

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Abstract This paper explores the issues of measurement and comparison of the current state of advanced manufacturing technology (AMT) adoption in India, including important information technology (IT) factors, and, surprisingly, this appears to be the first such attempt. For a worldwide perspective, comparison is made between Indian firms, firms in a developed country (Canada), and in a developing country (China). Contrary to expectation, the average score of AMT adoption degree of Indian companies in our survey is higher than that of all Canadian companies (when unadjusted for size) and of Chinese companies in one of the highly industrialized regions of China as measured in other surveys. While this suggests considerable strength of the Indian manufacturing sector, there should be further evaluation by other studies in this area to refine and develop these results. This study finds the top six AMTs currently adopted in India are plant certification, computer aided design, local area network, quality circle, MRP/ERP, and wide area network. Clearly four of these top six are directly in the IT area (CAD, LAN, WAN) or directly dependent on it (MRP/ERP systems), indicating a strong IT adoption rate as well as its underlying supportive role in the overall AMT adoption in India. The comparison between Indian firms and Canadian firms indicates that Indian firms adopted computer networks less and MRP/ERP and rapid prototyping systems more. Tests in our survey also reinforce the hypothesis that larger companies are more likely to adopt AMT than the smaller ones.

Keywords Advanced manufacturing technology · Manufacturing technology adoption · Manufacturing technology implementation · Manufacturing technology management · Manufacturing technology comparison · Manufacturing technology in India

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1 Introduction

India, a large developing country with a population of more than 1 billion, has experienced fast and stable economic growth in the past decade. Besides the much-recognized software exporting industry and an offshore service industry for developed countries, India has a large set of products in its full range of industrial categories, along with a large domestic market. Despite the visibility of Indian IT and its global significance in various other ways, measured as a percentage of gross national product (GDP), its direct contribution to the total national output is very small. However, significance of IT ought to be valued in its supporting role in the overall Indian economy and in AMT adoption in particular. For example, Kotha and Swamidass [14] stress the “information processing capability inherent in AMTs”, and also Frohlich and Dixon [8] find that commensurate information systems adaptation was most important in the successful implementation of AMTs. This paper focuses on the adoption of advanced manufacturing technology (AMT) in the Indian manufacturing industrial sector, including its important IT components. Even though we discuss the overall AMT adoption to provide a fuller perspective on AMT, of the 25 AMT techniques in the study at least ten directly require or closely relate to IT. The relatively greater significance of industrial sector in developing economies and increasingly strengthening economic ties between United States and developing Asian countries, especially with China and India, make such AMT adoption enquiries quite important. The work presented here is in response to this global context.

What is the level of use of different manufacturing technologies in India, ranging on a scale from the traditional technologies to newer technologies such as robotics and communications networks? Which AMTs are most attractive to Indian firms resulting in higher adoption rates? Which characteristics of the AMTs might be responsible for their greater adoptability in India? What is the way AMT adoption pattern differs from others? It is clear that exposition and discussion relating to such questions are important aspects in the framework of attracting foreign investment in India, which is certainly a crucial factor in the growth of emerging economies worldwide.

In order to answer some of these questions, we surveyed selected firms in India on their level of AMT implementation. Constrained by considerable difficulty of obtaining field data in India, it is based on a small-scale survey; however, it covers many widely dispersed and important parts of industrial India and is comparable in size to many studies on Indian manufacturing as discussed in Sect. 3.1. Here we discuss their current status and their relationship with the overall organizational business strategies. For an initial worldwide perspective, comparison is made between Indian firms, firms in a developed country (Canada), and in a developing country (China), even though our sample size is not very large. Our classification of the 25 AM technologies in three levels (simple - level I, moderate - level II, and sophisticated - level III) facilitates the discussion of the reasons of higher and lower adoptability rates of the different level AMTs in India.

The organization of the remainder of the paper is as follows. Section 2 presents the related literature; Sect. 3 presents the development of the questionnaire, the data collection process, and the profile of surveyed companies. The classification of AMTs in three levels is done in Sect. 4. Section 5 discusses the relationship of overall business strategies of the organization and the level of AMT adoption in that organization, Sect. 6 presents the findings on the levels of adoption for the 25 AM technologies surveyed in India, and then Sect. 7 compares these with Canadian and Chinese firms. Section 8 explores the effect of company size and product categories on AMT adoption, and Sect. 9 discusses the basic conclusions along with the suggested directions for future research in this area.

2 Related literature

The main objective of this survey is to give a first basic view of the level of use of advanced manufacturing technologies in Indian manufacturing industries, including its important IT components. To see how such studies have been done previously, we examine some important surveys conducted in other countries. For immediate relevance and brevity of our exposition, we will only cite the most directly related literature, selected from a wide range of available works.

One of the most, if not the most, comprehensive survey on the adoption of AMT was carried out by Sabourin and Beckstead [16] in Canada. Statistics Canada is a Canadian central statistical agency and has the legislative responsibility for providing indicators of science and technology activity in Canada. This survey is quite extensive both in the size of its sample and the coverage of its questions. A total of 4,200 companies were sampled and, being done by an official government organization, 3,702 companies completed survey questions. The questionnaire used in the survey has nine main sections, covering import factors of business strategy, including current status of AMT implementation, shortage of various types of skilled personnel, result of AMT adoption, and obstacles to AMT adoption.

Related to China, Pyke, Farley, and Robb [15] surveyed 120 manufacturing firms in the Shanghai area of China. They reported on the adoption of manufacturing technologies by firms of different types of ownership (e.g., state-owned, privately-owned, joint-venture, and wholly-owned foreign subsidiaries). They discovered that the differences among the ownership types are often insignificant. Their work provides a very good measure of the overall level of AMT adoption in Shanghai, one of the best developed regions in China.

A complementary survey in a less developed region of China was conducted by Sun, Tian, and Cui [17]. They surveyed 30 state-owned enterprises (SOEs) in northeast China, where heavy industries are located. They found that the level of AMT used in these Chinese SOEs is much lower than expected and reported. One reasonable explanation was that the northeast region in China lags far behind China's southeast coast region during China's ongoing economic reform.

Other related literature is as follows. Zhao and Henry [19] examined 27 "success factors" important to the adoption of AMT in Singapore's manufacturing industry. Responses from 110 companies were used in their study. They found that firms with larger financial resources are likely to be more successful, but larger number of employees is not necessarily conducive to AMT implementation.

Kotha and Swamidass [13] compared the use of 18 advanced manufacturing technologies in the US and Japan in an exploratory study using data from 160 US firms and 125 Japanese firms. Survey shows that AMT use is significantly different in the two countries. US manufacturers use more scheduling and control technologies, while their Japanese counterparts use more factory floor technologies.

Swamidass and Winch [18] compared the use of 17 different technologies in similar industries in the US (sample size 1025) and UK (sample size 166) using a common questionnaire. Largely, there are remarkable similarities between the two countries. US manufacturers are ahead of the UK firms in computerized integration; more UK manufacturers reported the use of soft technologies such as just-in-time, total quality manufacturing, and manufacturing cells.

More generally, superior performance is a top goal of most organizations, as such, AMT adoption and its relationships with overall business strategy, investment firms make in AMTs, adaptations that enhance successful AMT adoption, specially IT integration, and resulting performance due to AMTs have been treated in many research studies. From this larger research area, we refer and discuss the following works in relevant sections below: on AMT investment- Diaz et al. [7], and Boyer [1]; on AMT and resulting performance - Kotha and Swamidass [14], Brandyberry, Rai, and White [3], and Boyer [1]; on AMT and overall business strategy - Cagliano and Spina [4], Boyer et al. [2], Frohlich and Dixon [8], Hewitt-Dundas [9], Dangayach and Deshmukh [5], and Das and Jayaram [6].

3 Development of questionnaire, data collection, and company profiles

The questionnaire used in Sabourin and Beckstead [16] is the most comprehensive one we have found. To facilitate comparison, we adopt most major components of this questionnaire. The questionnaire gives a list of 25 advanced technologies with brief descriptions (Exhibit 1 -Appendix). Since success factors used in Zhao and Henry [19] would be useful in providing insight in the AMT adoption process in further analysis, we complemented our questionnaire by most of the success factors on their list.

Our questionnaire consists of nine main sections (A to I) with a total of 154 questions relating to general firm and establishment characteristics, current status of AMT implementation for all the 25 technologies (see Table 3. Current AMT adoption status in India for the list of the technologies and Exhibit 1: Brief advanced manufacturing technologies description for clarification), general organizational strategies used by the companies, and various other aspects related to AMT implementation. Here we concentrate on the current status measurement and its comparison with others; namely, Canadian and Chinese firms.

3.1 Data collection

In our survey, the sample of the firms is drawn from the listing of the companies in the government agencies and other sources. Despite the maintenance of confidentiality of all the individually identifiable company information on manufacturing practices and techniques, the difficulty of getting data on an a comprehensive 154-question instrument on manufacturing is not hard to imagine, especially in a developing country where global competition in that sector seems significantly strong. Witness to this are the small sample sizes used in doctoral dissertations and other works published in various journals relating to Indian manufacturing: Jharkharia and Shankar [10–12], where sample sizes between 30 and 35 have been used. Also in the study on China by Sun, Tian, and Cui [17], only 30 state-owned enterprises (SOEs) in northeast China have been surveyed. A survey of 20 plants was used in the study of AMT investment patterns in Diaz, Machuca, and Alvarez-Gil [7]. In our case, different industry categories are sampled based on such criteria as the type of products they manufacture, size of the firm, and their locations. We visited more than 30 companies in various widely dispersed cities including Delhi, Bangalore, Bombay, Bhopal, Allahabad, Lucknow, Hyderabad, Chennai, and Kanpur. A few more (fewer than 5–10) questionnaires were presented to companies in proximity to those that we visited and where we had a contact person. The responses from 32 companies were complete and usable.

As in other studies, most items on our questionnaire are closed-ended with definitive responses. All the questions in the questionnaire require only appropriate check marks or circles except for six at the very end of the questionnaire which ask for very brief text content, such as the title of the respondent and number of years employed. Most questions are designed to use a seven point scale, for instance, 1 represents strongly disagree and 7 strongly agree, paralleling the scales used in other similar surveys [15, 16, 19]. This helps us obtain comparable statistics in the data analysis stage.

3.2 Profiles of companies surveyed

Among 32 companies, seven have fewer than 250 employees, 7 between 250 and 999, 11 between 1,000 and 5,000, and 7 more than 5,000. Based on number of employees, we classify companies as small (44%, <1000 employees), or large (56%, >=1000 employees). Comparisons and differences between small companies and large companies are reported in Sect. 8.1.

All plants produce goods for the domestic market, i.e., India. In addition, most plants also sell products in foreign countries. In terms of markets, 25% of plants produce items sold in Asia, 19% in Europe, 6% in US, and 28% in other countries. Since US is a major market in the world, it is somewhat surprising that so few companies in India are able to sell products in the US market. This perhaps reflects that global quality and competitive pricing levels are harder to achieve in the manufacturing sector, especially for complex industrial products.

In terms of the type of goods produced by these companies, 34% of companies produce manufacturing equipment, 31% parts or components for assembling, 6% durable consumer goods, 6% supplies and other consumption goods, 3% non-durable consumer goods, 3% raw materials, and 38% companies produce other type of goods (due to overlapping of products, percentages do not sum to 100).

4 AMT Technologies in three levels

Based on our discussion with the companies and perusal of general related literature, we reach the likely conclusion that not all 25 AMTs in our list have the same set of characteristics, such as how much capital investment is required for the technology, and how long it has been in use in the industry, and so on. Thus, we have classified AMTs into three increasingly complex levels based on their four basic characteristics in Table 1: Classification of AMTs in three levels. At the highest level, level III technologies are newly emerged, sophisticated, require large capital investment, and may demand several technologies to work together synchronously; thus, only developed countries may be expected to have a high degree of adoption of such technologies. Level I technologies, on the other hand, are well established, simple, require small/medium capital investment, and can work standing alone, therefore they may have high potential of being adopted in developed countries as well as in developing countries. Lastly, the middle level, level II technologies have characteristics between level I and level III technologies; they could be expected to be undergoing rapid adoption in developing countries currently. Note that following their capital, history, complexity, and independence criteria, IT related AMT techniques appear in all the three levels. As mentioned earlier, Kotha and Swamidass [14] also stresses this IT information processing capabilities inherent in AMT adoption. For a discussion of 'stand alone AMTs' and levels of its integration within the organization see Cagliano and Spina [4], and for a technology scale ranging from 'stand-alone AMTs' to 'functionally oriented AMTs', and then to integrative CIM level AMTs see Brandyberry, Rai, and White [3]. In the following sections, we will investigate whether the three-level classification we just discussed here is supported by the data obtained by our survey responses. It is expected that such a classification is only approximate and subjective to some extent, since there may not be a clear line of separation between the levels. Some AMTs may be at the boundaries of the levels and may therefore overlap. However, assuming some underlying flexibility, the classification does seem reasonable, and facilitates the discussion of the different degrees of AMT implementation of different levels (which is supported by the statistical testing that we carry out in Sect. 6 and Sect. 8.1).

5 Organizational business strategies and AMT adoption

The major policies and decisions, including technology adoption, made by companies are deeply influenced by the overall general business strategies used by them to direct and lead the entire organization. A general discussion of

Table 1 Classification of AMTs in three levels

Criteria	Level I	Level II	Level III
1. Capital investment	Small or medium investment	Medium investment	Large investment
2. History	Well established history	Middle range history	Newly emerged history
3. Complexity	Simple	Moderate complexity	Sophisticated
4. Interdependence	Stand alone	Stand alone, or based on another technology	May demand several technologies to work together
Technologies belonging to the group	1. Computer aided design	2. Computer aided manufacturing	3. Quality function deployment
	12. Quality circle	8. Rapid prototyping systems	4. Computer-driven material handling
	14. Local area networks	9. High speed machining	5. Flexible manufacturing systems
	15. Company-wide computer networks	11. Optimization techniques software	6. Lasers for materials processing
	16. Inter-company computer networks	13. Automated systems used for testing	7. Robots
	17. MRP/ERP	20. Multi-departmental design teams	10. Uniform machine loading
	22. Plant certification	21. Benchmarking	18. Computer integrated manufacturing
		23. Just-in-time inventory control	19. Automatic guided vehicles
		25. Statistical process control	24. Group technology

manufacturing strategy, including the use of AMTs in Indian process companies, is given in Dangayach and Deshmukh [5]. On the other hand AMTs also have influence on overall business strategy in turn [9]. Also it is natural to expect that a consistency between business strategy and AMT dimensions will encourage superior performance [14], thus encouraging suitable AMT adoption in the long run (though there may be a 'lag' between initial investment in AMTs and the resulting performance Boyer [1]). To access the impact of these strategies on AMT adoption, our questionnaire lists seven business strategies and asks respondents to select a degree of importance that they assign to it (on a seven-point scale, 1 - not important at all, 7 - extremely important). The result is shown in Table 2: Business strategies used by surveyed firms. Reducing manufacturing cost is the most important business strategy with a mean score of 5.78, followed by using teams (5.66), developing new products (5.58), and ongoing technical training (5.47). The next two strategies are entering new market (5.26) and developing new manufacturing technology (4.91). Using new materials is the least important business strategy with a mean score of 4.19.

In comparing AMT use in Japanese and US companies Kotha and Swamidass [13] found many differences, while there were remarkable similarities in UK and US companies (Swamidass and Winch [18]). When comparing our findings to those in Sabourin and Beckstead [16] for Canadian firms, there are both similarities and differences. Reducing manufacturing cost is the most important business strategy both in our and their survey, while using new materials is the least important business strategy in both surveys. Ongoing technical training is also ranked 4th in both the surveys. On the other hand, the importance of the other four business strategies is viewed differently by Indian firms and Canadian firms. As in other studies, we use ranks here to represent relative importance of a business strategy. However, when two ranks are close, mean scores should also be examined to get a sense of how much difference there is. Indian firms put more emphasis on using teams and developing new products. Using teams is ranked 2nd in our survey, but 6th in Sabourin and Beckstead [16], possibly because India has more extended family, social, and interactive structures, or that good work cooperation is a more often automatically assumed professional standard in Canada. Developing new products is ranked 3rd in our survey, but 5th in Statistics Canada; the reason may be that Canadian firms are likely to already have a broader range of products. Conversely, Canadian firms put more value on entering new markets and developing new manufacturing technology. Entering new markets is ranked 5th in our survey, but 2nd in Sabourin and Beckstead [16]; here, due to geographical proximity Canadian firms have strong desire to enter US market while Indian firms are more likely to stay in the domestic market, at least initially. Developing new manufacturing technology is ranked 6th in our survey, but 3rd in Sabourin and Beckstead [16], apparently Canadian firms have more power, experience and resources to develop new technologies.

6 Status of AMT implementation in India: the grand average score of 2.0

We asked firms the current status of their implementation on each of 25 AMTs on a three point scale (1 - not implemented, 2 - implementation in progress, 3 - fully im-

Table 2 Business strategies used by surveyed firms

Firm's business strategy	Importance										
	Not imp.		Moderately imp.			Extrem. imp.					
	1	2	3	4	5	6	7	Mean	Adj. Can.[a] Mean(rank)	Std. dev.	Rank
	(Percentage of establishment)										
Products and marketing											
a) Developing new products	9.38	0.00	9.38	3.12	12.50	18.75	50.00	5.58	4.45 (5)	1.94	3
b) Entering new markets	6.25	3.12	0.00	12.50	25.00	28.12	21.88	5.26	4.77 (2)	1.63	5
Technology											
c) Reducing new manufacturing tech.	0.00	6.25	3.12	9.38	15.62	18.75	46.88	5.78	5.69 (1)	1.52	1
d) Developing new manufacturing tech.	0.00	15.62	6.25	9.38	31.25	15.62	21.88	4.91	4.60 (3)	1.69	6
e) Using new materials	12.50	9.38	6.25	25.00	25.00	9.38	12.50	4.19	4.01 (7)	1.84	7
Human resources											
f) Using teams (e.g., cross functional)	0.00	3.12	6.25	15.62	9.38	28.12	37.50	5.66	4.34 (6)	1.45	2
g) Ongoing technical training	3.12	3.12	0.00	12.50	15.62	50.00	15.62	5.47	4.50 (4)	1.37	4

[a] Adjusted mean scores (=1.5[a] original score−0.5) of Canadian firms, original scores are based on five point scale: 1 to 5.

plemented). The mean score of all companies is used to indicate the overall degree of implementation of a technology in Indian firms. The highest mean score 3 means all companies have fully implemented a technology. The lowest mean score 1 means all companies have not implemented a technology. A middle range mean score can represent numerous combinations of possibilities; for example, a score of 2 could imply that all companies have a technology implementation in progress, or that half the companies have fully implemented a technology while the other half have not; or many other similar equivalent combinations. In general, a higher mean score indicates a higher degree of overall implementation of a technology. It should also be mentioned here that certain technologies may be of somewhat continuous nature and it may be hard to say when they are fully implemented, in such a case, full implementation is interpreted as company's full preparedness to apply the technology to emerging opportunities or to adopt improved versions of the technology. See Table 3: AMT adoption status in India for details.

Plant certification has the highest degree of implementation with a mean score 2.93. Other technologies that have a high degree of implementation are computer aided design (2.72), local area network (2.65), quality circle (2.65), manufacturing resource planning/enterprise resource planning (2.40), and wide area network (2.39). Note that all the three direct IT techniques are included in this list, reflecting the IT adoption rate and the importance of IT in AMT adoption in India.

Table 3 Current AMT adoption status in India

AMTs	Current status						
	Not implm. 1	Imp. in progress 2	Fully implm. 3	Ans. rate	Mean	Std. dev.	Rank
Design and engineering			(Percentage of establishment)				
1. CAD	3.13	21.88	75	100.0	[ab]2.72	0.52	2
2. CAM	21.88	34.38	37.5	93.8	[ab]2.17	0.79	9
3. QFP	21.88	37.5	34.38	93.8	2.13	0.78	10
Materials & production							
4. Computer - driven material handling	59.38	15.62	9.38	84.4	[ab]1.41	0.69	23
5. FCM/FMS	53.12	18.75	15.62	87.5	[ab]1.57	0.79	19
6. Lasers used in materials processing	75	3.12	12.5	90.6	[a]1.31	0.71	24
7. Robotics	62.5	15.62	18.75	96.9	[ab]1.55	0.81	20
8. Rapid Prototyping Systems(RPS)	65.62	15.62	12.5	93.7	[a]1.43	0.73	22
9. High speed machining	25	34.38	28.12	87.5	[a]2.04	0.79	12
10. Uniform machine/ assembly line loading	34.38	31.25	31.25	96.9	1.97	0.84	15
11. Optimization techniques software	50	28.12	9.38	87.5	1.54	0.69	21
Quality control and inspection							
12. Quality circle	9.38	15.62	71.88	96.9	[b]2.65	0.66	3
13. Automated systems used for inspection /testing	28.12	31.25	31.25	90.6	[a]2.03	0.82	13
Network communications							
14. LAN	12.5	9.38	75	96.9	[a]2.65	0.71	3
15. WAN	21.88	9.38	56.25	87.5	[a]2.39	0.88	6
16. Inter-company network	31.25	15.62	40.62	87.5	[a]2.11	0.92	11
Integration & control							
17. MRP II / ERP	9.38	37.5	46.88	93.8	[a]2.40	0.67	5
18. CIM	40.62	28.12	9.38	78.1	[ab]1.60	0.71	18
19. AGV & robotics-automated guided vehicles	75	6.25	3.12	84.4	1.15	0.46	25
Business practice							
20. Concurrent & Multi-departmental design teams	15.62	34.38	37.5	87.5	2.25	0.75	7
21. Benchmarking	18.75	46.88	18.75	84.4	2.00	0.68	14
22. Plant certification	0	6.25	87.5	93.8	[b]2.93	0.25	1
23. Just-in-time inventory control	34.38	34.38	25	93.8	[b]1.90	0.80	16
24. Group technology	34.38	25	21.88	81.3	[b]1.85	0.83	17
25. Statistical process control	15.62	40.62	34.38	90.6	[b]2.21	0.73	8
Grand average	32.75	23.87	33.75	90.38	2.00	0.72	–

[a] Mean score comparison of 14 technologies with Canadian firms can be found at Fig. 1. Mean score comparison with Canadian manufacturing firms.

[b] Mean score comparison of 11 technologies with Chinese firms can be found at Fig. 3. Mean score comparison with China Shanghai firms

Globalization is forcing every aspiring country to compete in the world market. Companies in developing countries may see plant certification as a prerequisite of entering foreign market as well as a tool to improve product quality. Of course, for several large markets specified certifications are mandatory. Computer aided design (CAD) is a stand-alone technology that is easy to implement because only design engineers are involved, and it has been shown to be highly cost effective in relation to manual design process that is very lengthy and expensive. Computer hardware and network hardware are getting cheaper, while in the meantime their capability and capacity are getting larger, which helps to explain the high adoption degree of local area network (LAN) and wide area network (WAN). MRP/ERP, besides having been available for a considerable time, is basically a software technology, and India is the largest software exporting country. Quality circle generally does not require capital investment, instead it requires a lot of human inter-activities. Previously we mentioned India having relatively more social and interactive structures to explain why using teams is highly valued by Indian firms; the same factor helps to explain high degree adoption of Quality circles among Indian firms.

Considering the underlying factors of embedded complexity, continuity, investment, and dependence on other technologies, it is expected from our three level classification of AMTs in Sect. 4 that, at least approximately, level I technologies should have the highest degree of implementation, level II technologies a modest degree, and level III technologies the lowest degree of implementation in India. Our survey data are very consistent with our expectations. Level I technologies has a grand average score 2.55 in our survey, suggesting a very high degree of implementation of these technologies in India. Indeed level I technologies should have a high degree of implementation in all countries including developing countries due to its relative ease of adoption. Level II technologies has a grand average score 1.95, suggesting a modest degree of implementation. In developing countries such as India, level II technologies are deemed to have a good but not high degree of adoption. Lastly, level III has a grand average score 1.61, indicating a low degree of implementation in India. The low adoption degree of level III technologies in developing countries can be considered consistent with various factors, such as lower labor cost, less-trained workforce, difficulty of obtaining hard currency capital, and lack of technical know-how of upper echelon advanced technologies.

The value of the ‘percentage of firms’ who answered “1 - not implemented”, instead of a ‘mean’ score value, may give a more direct illustration of those technologies that have low degree of implementation. Seventy-five percent of establishments have not implemented automated guided vehicles, also 75% of establishments have not implemented lasers used in materials processing, followed by rapid prototyping systems (66%), robotics (63%), computer driven material handing (60%), flexible manufacturing cells or systems (53%), optimization techniques software (50%), and computer integrated manufacturing (41%).

Some respondents did not answer current status question of some technologies. It might be omitted mistakenly, since there happen to be many rows of text close to each other in this section of the questionnaire. It could also be omitted purposefully. To consider some skipped responses, it is reasonable to assume that a respondent could purposefully not answer a specific question if he did not know that specific technology, or he did not understand (and did not bother to ask us for a clarification) the terminology used in our questionnaire to describe that technology (despite the brief descriptions given in the Exhibit 1- Appendix). If we assume that all omitted answers are “1 - not Implemented”, then the adjusted grand average score of current status is 1.91, in comparison to the current value of 2.00, but the difference is small. Also, this adjustment does not materially change the rankings of the 25 technologies.

In general, a low answer rate corresponds to a low degree of implementation. Four technologies have answer rates lower than 85%; they are computer integrated manufacturing, group technology, benchmarking, and automated guided vehicles. Correspondingly, they are ranked 18th, 17th, 14th, and 25th among the 25 advanced technologies.

7 Two comparisons

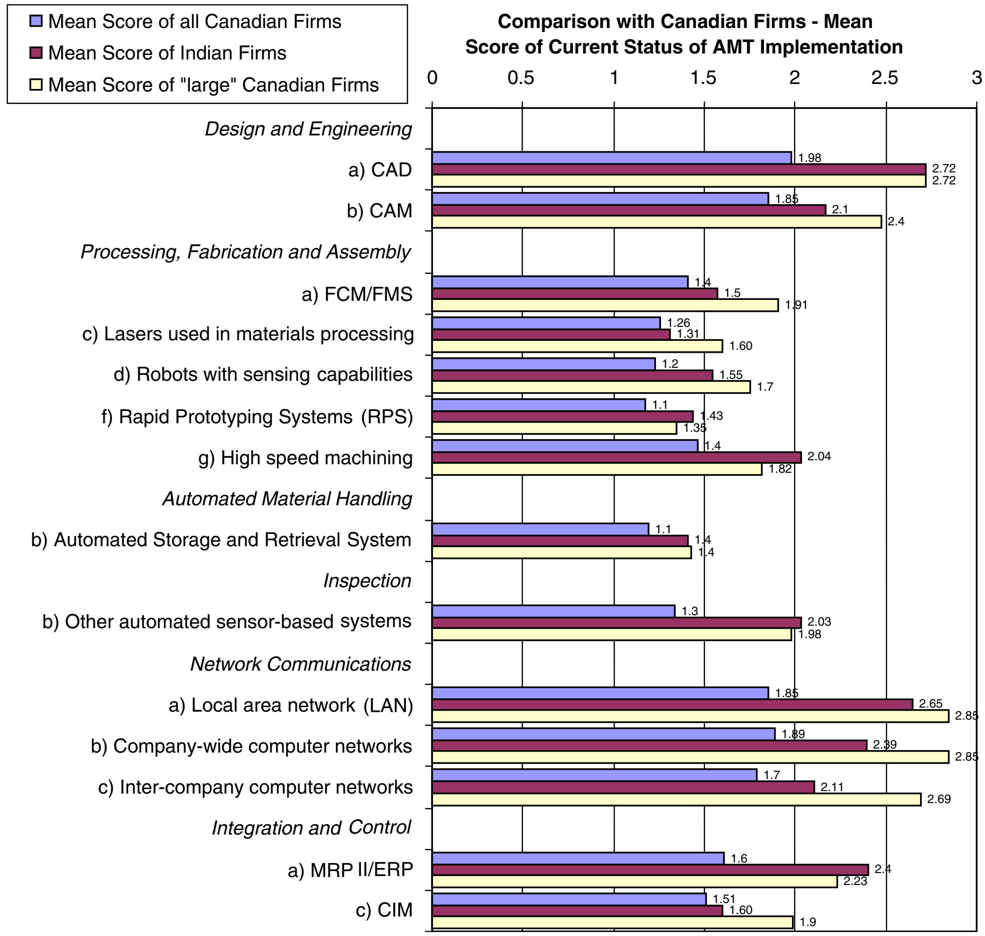
7.1 Comparison with Canadian manufacturing firms

Comparing our findings to findings in Sabourin and Beckstead [16], we see many similarities in the results here. A technology which has a high degree of implementation in Canada also has a high degree of implementation in India. We use a list of 25 technologies and Sabourin and Beckstead [16] uses a list of 26 technologies. Fourteen technologies are presented in both the lists. Furthermore, both surveys use three point scales for answer selection. We use 1 - not implemented, 2 - implementation in progress, and 3 - fully implemented. Sabourin and Beckstead [16] uses 1 - no plans, 2 - plan to use, and 3 - in use. Therefore comparison of these fourteen technologies between two surveys is feasible.

7.1.1 The Canadian grand average score 1.52

The grand average of AMT implementation of all the technologies in our survey is higher than that in Sabourin

Fig. 1 Mean score comparison with Canadian manufacturing firms



and Beckstead [16]; 2.00 vs. 1.52 (computed but not shown in Fig. 1). However, it is expected, a priori, that the degree of AMT use in India would be lower than that in a developed country like Canada. This would indicate some significant strength of Indian manufacturing. However, to evaluate differences in the sample sizes and time frames of the studies further investigation should be carried out to refine and develop these initial findings. Also, there is a large difference between the size of companies in our survey and that in Sabourin and Beckstead [16]. Fifty-six percent of companies in our survey have more than 1,000 employees; while only 6% companies in Statistics Canada have more than 250 employees, and 68% companies have fewer than 50 employees. We consider this below.

7.1.2 The Canadian grand average score- considering large companies 2.11

Economies of scale suggest that technology use increases as company size increases. The company sizes in our survey are most comparable to the top 6% of the largest Canadian companies surveyed in Sabourin and Beckstead [16]. Without surprise, the grand average degree of AMT use in these 6% of "large" Canadian companies is 2.11, a number that is a bit higher than 2.00 of Indian companies. In terms of specific technologies, Fig. 1. Mean score comparison with Canadian manufacturing firms gives detailed comparison among three mean scores for each of the 14 common technologies.

7.1.3 Technology rank comparison

Furthermore, we compared ranks of those 14 technologies in the two surveys in order to see relative importance of technologies in the two countries, since the difference between the sizes of the two lists of AMTs is minimal (25 and 26). Figure 2. Rank comparison with Canadian manufacturing firms presents the rank comparison between our findings and findings in Sabourin and Beckstead [16]. As discussed below, we found differences in our case as Kotha and Swamidass [13] found differences in AMT use in Japanese and US companies.

Computer aided manufacturing, lasers used in materials processing, and computer integrated manufacturing have significantly lower rank in Indian firms than in Canadian firms. One possible explanation is that more sophisticated

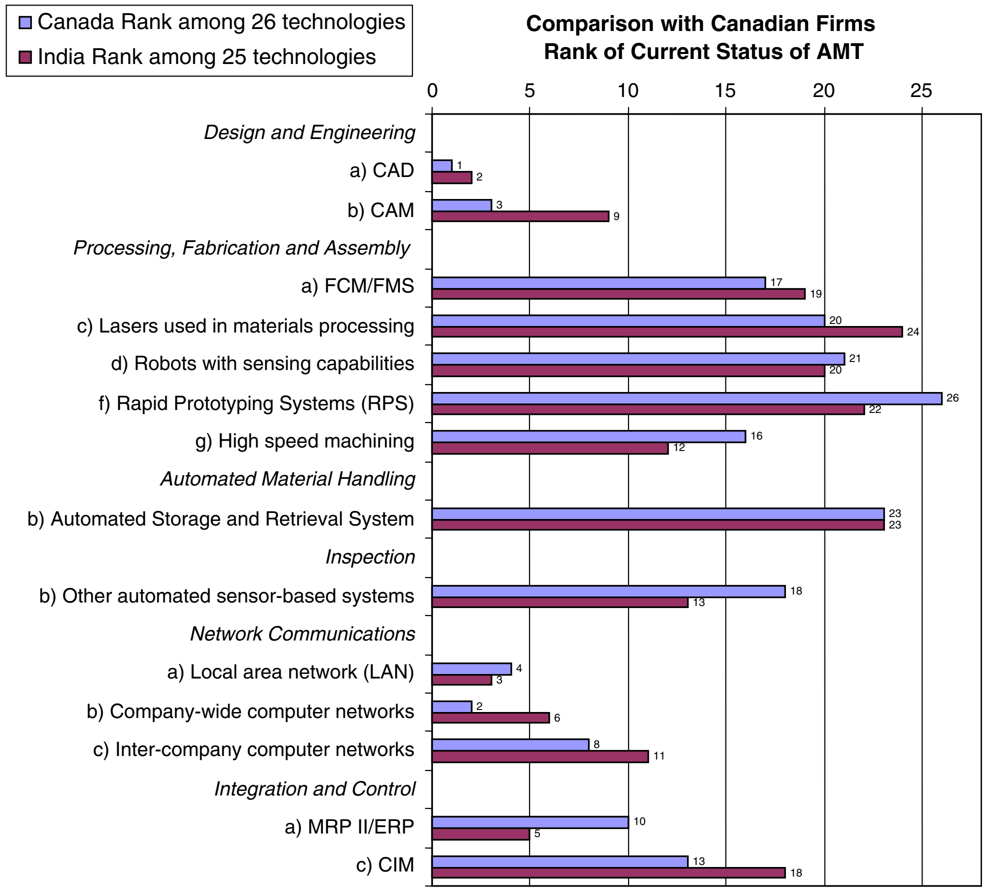


Fig. 2 Rank comparison with Canadian manufacturing firms

and capital intensive technologies are less likely to be adopted in developing countries than in developed countries at a given point of time.

Indian firms in comparison to Canadian firms also rank company-wide computer network and inter-company computer networks lower. A good reason may be that the cost of prevailing telecommunication services in India is high. For instance, the price of IP phone is about 2 cents per minute from US to China, 4 cents to UK, and 20 cents to India.

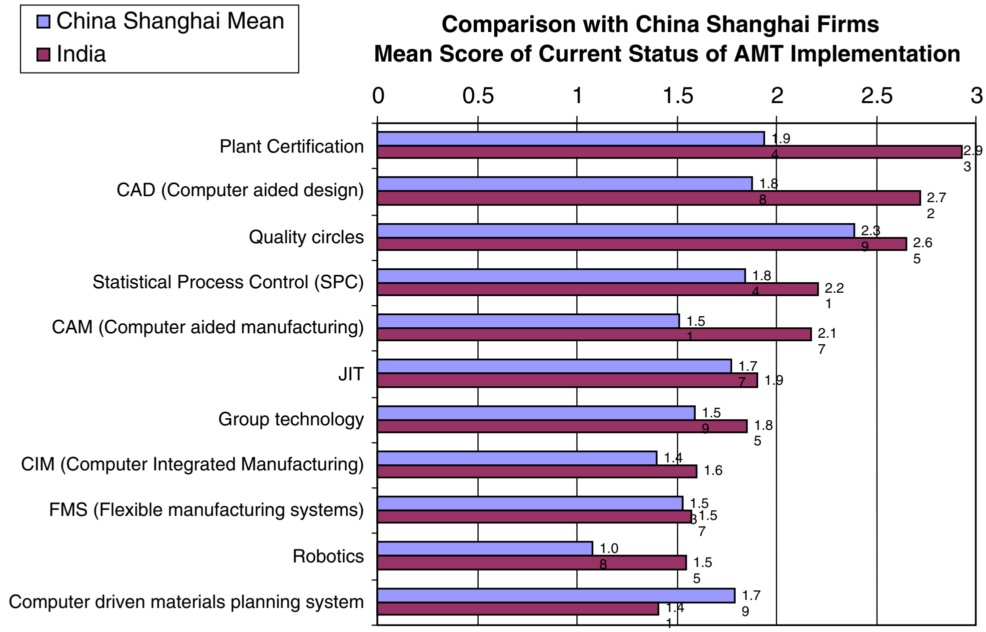
On the other hand, manufacturing resource planning/ enterprise resource planning and rapid prototyping systems have significant higher rank in Indian firms than in Canadian firms, probably because India has numerous talented software engineers, facilitating integration of IT technology. Automated systems for inspection/testing and high speed machining are easy to deploy, they can help to boost productivity and to improve product quality; they are also ranked higher by Indian firms than by Canadian firms.

7.2 Comparison with Shanghai area Chinese firms: grand average score 1.69

In the survey of Pyke, Farley, and Robb [15], a list of 16 manufacturing technologies is used. Eleven technologies in their list are also presented in our survey. The comparison of mean score of these 11 technologies is given in Fig. 3: Mean score comparison with China- Shanghai Firms. For almost all technologies, the mean score of Indian firms is higher than that of Chinese firms in one of the best developed Chinese region, Shanghai. The grand average of 25 technologies in our survey is 2.00, a value above the 1.69 grand average of 16 technologies in the Chinese study [15], the value 1.69 here is computed from their published data.

However it is not suggested that AMT use in India is necessarily higher than AMT use in China. There are some differences between the two surveys. Pyke, Farley, and Robb [15] surveyed 120 firms, while our survey has a smaller sample of 32 companies. The survey methodology of interviewing all firms in Pyke, Farley, and Robb [15] may have better quality responses to the questionnaire, since a more interactive face to face clarification and verification are possible and a completed response is ensured. Firms surveyed by Pyke, Farley, and Robb [15] have 836.51 employees on average, while based on categorical answers of the number of employees; the average number of employees of firms in our survey is estimated to be 2800. As we said earlier further studies should refine these results. Since our list of AMTs has 25 technologies and the list in Pyke, Farley, and Robb [15] has only 16, comparing

Fig. 3 Mean score comparison with China Shanghai firms



ranks of 11 mutual technologies in the two lists may not be very appropriate due to the large difference between the two technology lists. Therefore we do not compare ranks of these technologies between Indian firms and Chinese firms as we did between Indian and Canadian firms in the previous section.

8 Effect of company size and product categories

8.1 Higher AMT implementation in larger companies

As stated earlier in Sect. 3.2, we classify companies having less than 1000 employees as small companies, and companies having more than 1000 employees as large companies. We compared mean scores of each AMTs between 14 small companies and 18 large companies. We also performed a t-test for each technology to test our null hypotheses that large companies have higher mean scores of current AMT adoption levels.

We find evidence supporting the fact that large companies have higher degree of current AMT implementation than small companies do. Besides overall larger resources, larger companies can invest more on adoption of AMTs with supporting infrastructure that leads to better performance and thus prompts AMT adoption further [2]. Diaz et al. [7] finds that a certain minimum size of a firm is also an important determinant of AMT investment. In this study, first, for 16 technologies out of a total of 25 technologies, large companies have higher mean scores of current AMT status than small companies; and for 7 technologies, the mean scores of large companies are statistically significantly greater than that of small companies at a significance level of 0.05 (p values smaller than 0.05). This is somewhat unlike Zhao and Henry [19] study done in the context of AMT adoption success factors, where larger number of employees (as a measure of company size) did not seem to imply greater ease of AMT adoption and therefore higher adoption rate.

Table 4: Company size and product category comparison gives detailed mean values and p-values from our t-tests. "Small size mean" column gives mean values of small companies; "large size mean" column gives mean values of large companies. A 'yes' in "S.M. < L.M." column indicates that mean values of small companies are less than that of large companies.

8.1.1 More AMT adoption for larger companies in higher level technologies

Here we would like to re-examine our data of small companies and large companies based on the three levels of AMTs as classified in Sect. 4 AMTs in three levels. We expected that the difference in the degree of AMT adoption between small companies and large companies would increase as AMTs move to higher levels, since higher level AMTs are more advanced and complicated, require more capital, and depend more on other technologies. Thus, large companies would have more advantage in adopting higher level AMTs than small companies. Our findings confirmed our expectations; they are presented in Table 5: Mean Scores and p-values for Three levels.

Certainly the mean score of large companies for AMTs in any level is greater than that of small companies; but

Table 4 Company size and product category comparison

AMT Technologies	Current AMT Status: Large vs Small Size				Current AMT Status: Product Categories			
	Small Size Mean (S.M.)	Large Size Mean (L.M.)	S.M. <L.M.	p * Value	Equipment Mean	Parts/Assembly Mean	Others Mean	p # Value
Design and Engineering								
1. CAD	2.79	2.67		0.27	2.82	2.80	2.42	0.13
2. CAM	1.83	2.39	Yes	**0.03**	2.10	2.22	2.00	0.81
3. QFP	1.85	2.35	Yes	**0.04**	2.55	1.89	2.00	0.14
Materials & Production.								
4. Computer – driven material handling	1.08	1.67	Yes	**0.01**	1.25	1.22	1.67	0.25
5. FCM/FMS	1.33	1.82	Yes	0.06	1.78	1.44	1.42	0.54
6. Lasers used in materials processing	1.15	1.38	Yes	0.19	1.30	1.44	1.27	0.86
7. Robotics	1.29	1.71	Yes	0.08	1.50	1.70	1.67	0.87
8. Rapid Prototyping Systems(RPS)	1.15	1.59	Yes	**0.04**	1.10	1.56	1.42	0.25
9. High speed Machining	1.75	2.25	Yes	**0.05**	1.90	2.33	2.10	0.49
10. Uniform Machine/ Assembly Line Loading	1.69	2.17	Yes	0.06	1.91	2.40	1.73	0.14
11. Optimization techniques software	1.17	1.75	Yes	**0.01**	1.60	1.78	1.64	0.86
Quality Control and Inspection								
12. Quality Circle	2.54	2.72	Yes	0.23	2.64	2.80	2.64	0.81
13. Automated systems used for inspection /testing	1.85	2.06	Yes	0.25	2.10	1.80	1.73	0.59
Network Communications								
14. LAN	2.62	2.61		0.49	2.64	2.70	2.45	0.72
15. WAN	2.18	2.53	Yes	0.16	2.22	2.44	2.27	0.86
16. Inter -company network	1.73	2.35	Yes	**0.04**	1.89	2.11	2.00	0.88
Integration & Control								
17. MRP II / ERP	2.33	2.41	Yes	0.38	2.18	2.60	2.30	0.34
18. CIM	1.70	1.53		0.29	1.33	1.78	1.40	0.35
19. AGV & robotics-auto- mated guided vehicles	1.08	1.20	Yes	0.26	1.20	1.11	1.10	0.87
Business Practice								
20. Concurrent &Multi-Departmental design teams	2.33	2.19		0.31	2.09	2.44	2.20	0.57
21. Benchmarking	2.00	2.00		0.50	1.90	2.11	2.10	0.78
22. Plant certification	3.00	2.88		0.11	3.00	3.00	2.90	0.36
23. Just-in-time inventory control	2.00	1.88		0.33	1.80	1.90	1.70	0.83
24. Group Technology	1.91	1.80		0.37	1.90	1.89	2.11	0.83
25. Statistical process control	2.42	2.06		0.10	2.00	2.30	2.20	0.67
Grand Average	**1.87**	**2.08**	**Yes**	**+0.08**	**1.95**	**2.07**	**1.94**	**^0.56**

[a] *P-value* from one tail *t-test* of testing difference between two means, shaded if smaller than significance level 0.05.
[b] *P-values* in “Grand Average” row come from a separate *t-test* on 25 pair mean scores, not averages from 25 *p-values* above them.
[c] *P-value* from *F-test* of testing difference among three means.
[d] *P-value* in the right bottom cell comes from a separate *F-test* on three groups of 25 mean scores, not an average from 25 *p-values* above it.

what is also interesting here is the decreasing pattern of p-values for increasing levels. The p-value for level I AMTs is 0.21, for level II 0.15, and for level III 0.05, suggesting large companies have higher advantage in adopting higher level AMTs (see note under Table 5 for the basic meaning of p-value).

8.2 Comparison among different product categories

Our questionnaire lists six product categories, plus the 7th representing “Others”. A responding company may choose one or several product categories that the company produces. Our survey data contains sufficient companies for three categories: 11 companies produce manufacturing equipment, 10 companies produce parts/components for assembling, and 12 companies selected “Others”.

We performed an F-test to see if there is a significant difference among the three product categories in the mean scores of current AMT adoption level for each of the 25 technologies. We found no significant difference at a significance level of 0.05 for any. One could expect some differences based on the product characteristics, but it would seem that the overall relevant AMT adoption process, despite differences in production methods of these products, on the whole, is not significantly different.

Since there is no significant difference found, detailed data of our F-test is not fully presented in this paper to save space. However, to satisfy possible interest in these values,

Table 5 Mean scores and p-values for three levels of AMTs

		Small size mean (S.M.)	Large size mean (L.M.)	S.M.<L.M.	P [a] value
Current AMT status	Level I	2.45	2.60	Yes	0.21
	Level II	1.83	2.02	Yes	0.15
	Level III	1.45	1.74	Yes	0.05

[a] P-value from a one tail t-test of testing difference between two means: Generally, the p-value implies that the mean score of large companies, as computed in the table, has 100*(1-p) percent probability to be statistically larger than the mean score of small companies. For example, p-value 0.15 for level II AMT suggests an 85% probability that the mean score of large companies is greater than the mean score of small companies.

mean scores of the three product categories and p-values for current AMT status questions are given and combined into Table 4: Company size and product category comparison, which also presents the results of the previous section. “Equip. mean” column gives mean scores of companies that produce manufacturing equipment; “Parts/assembly mean” column gives mean scores of companies that produce parts/components for assembling; “Others mean” column gives mean scores of companies that produce other products not listed in our questionnaire.

9 Conclusions and discussion

Consistent with Sabourin and Beckstead [16], we confirmed that reducing manufacturing cost is the most important general business strategy among surveyed companies in India, while using new materials is the least important. The survey showed that out of 25 AMTs the top six AMTs highly adopted by Indian companies are plant certification, computer aided design, local area network, quality circle, MRP/ERP, wide area network, where clearly information technology holds a very prominent place. The average score of AMT adoption degree of Indian companies in our survey is higher than that of Canadian companies and of Chinese companies in other surveys; while it shows considerable strength of Indian manufacturing sector, further studies should consider larger sample size to refine these results.

Comparison between Indian companies in our survey and Canadian companies in Sabourin and Beckstead [16] suggested that developed countries are more likely to adopt sophisticated and capital intensive technologies such as computer integrated manufacturing, and lasers used in materials processing. We also found that IT related techniques company-wide computer network and inter-company computer networks are adopted relatively less by Indian companies, coincident with high cost of telecommunication service in India. Conversely, benefiting from strong software industry in India, Indian companies adopted MRP/ERP and rapid prototyping system relatively more.

Our survey reinforced the expectation that large companies are more likely to adopt AMTs. As mentioned earlier, larger firms may tend to have, relatively more open business strategies that have higher consistency with AMT adoption, more concomitant infrastructure development, and more integrative IT approach, the factors that foster better performance, encouraging more AMT adoption [2, 4, 8, 14].

We find useful our categorization of 25 AMTs in three levels, based on continuity, investment, and dependence on other technologies. The level I technologies are less advanced, easy to implement, and have long history, while level III technologies are on the opposite side. As surmised, our survey data showed that level I technologies are highly adopted by Indian companies, with an average score 2.55; level II technologies scored 1.95, a modest degree of adoption; and level III scored 1.61, the lowest degree of adoption. This would seem consistent with technology scale - stand-alone AMTs, functionally oriented AMTs, and computer integrated (CIM) AMTs discussed in Brandyberry, Rai, and White [3].

Now we mention some important directions of future AMT survey research. Larger sample size will certainly enhance reliability of our findings; we are currently trying to get cooperation of Indian manufacturing associations for obtaining a larger sample in the future, but as mentioned earlier there are significant difficulties in getting the data. More advanced statistical techniques may also be used to discover in-depth patterns of relations among variables surveyed here. Similarly, analysis of AMT adoption success factors, obstacles, effect of research and development activities, availability of personnel related to AMT adoption, value of supportive IT techniques can offer useful managerial guidelines for controlling and accelerating the AMT adoption process. For example, Brandyberry, Rai, and White [3] suggest the need for AMT implementation strategies that are cognizant of fostering organizational integration of production processes and market-oriented flexibility of the production processes, and Das and Jayaram [6] provide contingency variables in AMT implementation that “guide the practitioners in narrowing their focus to a few key factors”. Some of the data in the survey in these areas is being collected and organized for analysis and for later possible publication. Inter-country comparison of AMT adoption is also an interesting topic; a standardized electronic questionnaire would facilitate such comparisons. The opportunity to survey manufacturing companies in different countries now, via the Internet, by a single unit of analysis seems a tempting endeavor.

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Appendix

Exhibit 1: brief advanced manufacturing technologies description

Table 6

Technologies	Brief description
I. Design and engineering	
1. Computer aided design and engineering (CAD/CAE)[a]	Use of computer-based software for designing and testing new products
2. CAD output to control manufacturing machines (CAD/CAM)[a]	Computer-aided manufacturing uses the output produced by CAD systems to control the machines that manufacture the part or the product
3. Quality function deployment	Structured approach to determine the product and service specifications needed to satisfy key customer requirements
II. Processing, fabrication, asssembly	
4. Computer-driven material handling[a]	Use of computer-controlled equipment to handle and store goods and materials
5. Flexible manufacturing systems[a]	Collections of computer-controlled machine tools, serviced by robots and/or automated material handling systems and overseen by computers
6. Lasers for materials processing	Lasers used for such processes as welding, cutting, treating, scribing and marking
7. Robots	Robots with sensing capabilities: Robots programmed to alter their function based on input from sensors more sophisticated robots; robots without sensing capabilities: Robots programmed to undertake simple tasks such as picking and placing, less sophisticated robots
8. Rapid prototyping systems	Systems capable of producing a prototype part from the output of a computer-aided design
9. High speed machining	Metal cutting machines operating at speeds of 10,000 rpm or higher
10. Uniform machine / Assembly line loading	Concurrent multi model, small batch production rather than larger single model production in sequence for minimizing demand uncertainty costs
11. Optimization techniques software[a]	Optimization systems such as advanced planning, scheduling, MRP, inventory management, forecasting, resource allocation systems as well as ERP systems
III. Quality and inspection	
12. Quality circle	A small group in which people who work in the first line work place, continually improve and maintain the quality of products, services and so on
13. Automated systems used for inspection/testing	Automated systems used for inspecting/testing incoming materials or final products for inspecting products for defects, blemishes, color, orientation, etc.
IV. Network communications	
14. Local area network (LAN) for engineering or production[a]	Communications networks within a plant used for exchanging information on the “shop floor”, and within design and engineering departments
15. Company-wide computer networks[a]	Communication networks within an enterprise extending beyond a single site; includes Intranets and wide area networks (WAN)
16. Inter-company computer networks[a]	Wide area communications networks that connect establishments with their subcontractors, suppliers, and customers
V. Integration and control	
17. Manufacturing resource planning (MRPII)/Enterprise resource planning[a]	Information systems used to keep track of machine loading, production scheduling, inventory control, and material handling
18. Computer integrated manufacturing[a]	Totally automated factory, where all activities are co-coordinated by computers
19. AGV and robotics-automated vehicles	Automated guided vehicles for inter-production-stage transportation and operations
VI. Business practice	
20. Concurrent- and multi-departmental design teams	Technologies that support designing activities carried out among different geographical areas and multiple departments
21. Benchmarking	Process of identifying, understanding, and adapting outstanding practices from organizations anywhere in the world to help your organization improve its performance
22. Plant certification	Documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, to ensure that materials, products, processes and services are fit for their purpose
23. Just-in-time inventory control	A process for achieving excellence in a manufacturing company based on the continuing elimination of things that do not add value to the product. It accomplishes this by moving material to the necessary place at the necessary time
24. Group technology	Grouping of similar parts into families for production in manufacturing cells for greater efficiency
25. Statistical process control	The practice of using statistical methods such as control charts and capability analysis to monitor and control a process

[a] Direct IT or IT related

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