Advanced Manufacturing Technology Adoption in Manufacturing Companies in Kenya

George M. Nyori, Peter K'Obonyo

Abstract**—**Over the past few decades, manufacturing has evolved from a more labor-intensive set of mechanical processes to a sophisticated set of information based technology processes. With the existence of various advanced manufacturing technologies (AMTs), more and more functions or jobs are performed by these machines instead of human labour. This study was undertaken in order to research the extent of AMTs adoption in manufacturing companies in Kenya. In order to investigate a survey was conducted via questionnaires that were sent to 183 selected AMT manufacturing companies in Kenya. 92 companies responded positively. All the surveyed companies were found to have a measure of investment in at least two of the 14 types of AMTs investigated. In general the company surveyed showed that the level of AMT adoption in Kenya is very low with investments levels at a mean of 2.057 and integration levels at a mean of 1.639 in a scale of 1-5.

Keywords**—**AMT adoption, AMT investments, AMT integration, companies in Kenya.

I. Introduction

MANUFACTURING processes and systems used in design and production are undergoing dramatic changes in response to new customer needs and emerging technologies. Complexity, dynamism and uncertainty have become dominant characteristics of recent competition patterns which have resulted in a demand-diversified market with more multifaceted products [3]. AMT appears to represent a perfect interaction between technological potential and the manufacturing challenges. The major benefits of Advanced Manufacturing Technologies (AMTs) include faster machine cycle, greater reliability, and reduced inventory, saving on labor, greater flexibility and improved quality. The use of AMTs permits the integration of the full spectrum of production functions and manufacturing processes with computer technologies [9]. With the use of computer technology, AMTs make the data storing and manipulation possible. Data held electronically can be changed and distributed easily and cheaply between these technologies. Companies therefore adopt these technologies for a wide range of activities, ranging from scheduling to quality inspection.

In the global business environment, technology is one of the salient elements for remaining competitive [6]. With globalization and free trade agreements, manufacturing companies in Kenya are under increasing pressure to adopt AMTs to simply survive the global competition.

Exposure to global competition reveals that manufacturing companies in Kenya can no longer rely on simple conversion of raw material into goods, but a process of conversion constantly reinventing itself. Globally products are now made better, faster and cheaper and manufacturing companies in Kenya cannot afford to do otherwise, else they will produce goods that are not globally competitive.

II. Advanced Manufacturing Technologies

Different studies have adopted wider definitions of AMTs. Reference [15] defined AMTs as a group of integrated hardware and software based technologies. These technologies are often referred to as intelligent or smart manufacturing systems and often integrate computational predictability within the production process [10]. Reference [1] used the term AMT to describe a variety of technologies that utilize computers to control, track, or monitor manufacturing activities, either directly or indirectly. Reference [13] regards AMTs as a wide variety of modern computer based technologies in the manufacturing environment. From these studies, it can be summarized that, AMT suggests both soft and hard technologies which are being employed to enhance manufacturing competencies. This study adopts the narrower form of AMT as the use of innovative technology to improve production processes and it is this concept that is further explored within this study.

Computer Aided Design (CAD) is extensively used in the design of tools and machinery used in manufacturing components. It is used throughout the engineering process from conceptual design and layout, through detailed engineering and analysis of components to definition of manufacturing methods [13]. Computer aided design consists of CAD computer, computer peripherals, operations software and user software. Computer-aided manufacturing (CAM) refers to the use of specialized computer programs to direct and control manufacturing equipment. When CAD information is translated into instructions for CAM, the result of these two technologies is called CAD/CAM [5]. Computer aided engineering (CAE) software assists the engineer while examining and testing design from a structural or engineering point of view. When CAD is integrated with CAE, it assists in the design and drawing process for new products or modifies existing products. It includes the direct graphic-interactive generation of two- or three-dimensional data models with subsequent graphic output, supporting activities such as calculations or simulations [13].

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The nature of manufacturing companies that deal with a variety of products and the type of processes involved, demand the technology advancement in material requirements planning (MRP). The MRP is software developed to determine material requirements for manufacturing companies. The extension of MRP, which is referred to as Manufacturing Resource Planning (MRP II), allows inventory data to be augmented by other resource variables, such as labor hours, material cost (rather than material quantity), or capital cost. In this case, MRP II is integrated with other computer files that provide data to the MRP system. An enterprise-wide resource planning tool, which is called Enterprise Resource Planning (ERP), is an information system for identifying and planning the enterprise-wide resources needed to take, make, ship and account for customer orders, which is the extension of MRP and MRPII [4].

Automated Materials Handling (AMH) systems improve the efficiency of transportation, storage, and retrieval of materials in and from warehouses. Automated storage and retrieval systems (ASRS) provide for the automatic placement and withdrawal of parts and products into and from designated places. The AMH can take the form of monorails, computerized conveyors, robots, or automated guided vehicles (AGVs). AGVs use embedded floor wires to direct driverless vehicles to various locations in the plant, delivering materials [2]. Industrial robots are substitutes for many repetitive manual activities [2]. A robot is a reprogrammable mechanical device that may have a few electronic impulses stored on semiconductor chips that will activate motors and switches. Robots are used to perform repetitive tasks such as picking and placing devices, spot welding, and painting. Robots are also widely used to carry out quality inspection on incoming or final products. When all the above technologies are integrated with system-wide production control, inventory and other systems, full computer-integrated manufacturing (CIM) is achieved.

Given the wide range of computer-based technologies that can be found in manufacturing companies, the holistic technology perspective, which covers the whole range of AMTs, is believed to be the research wave in manufacturing technology, which is in line with the focus of this study. Given the wide range of AMTs, this study adopts a similar list as that put forward by reference [12]. However, the management practice element, Just-in-Time (JIT), is excluded due to the fact that it is not a technology, but instead more of a practice.

III. Manufacturing Companies in Kenya

The implementation of AMTs is expected to face challenges in achieving its full potential in Kenya due to the current companies' capacity to assimilate technology. Manufacturing industry is the backbone of industrialization process in Kenya since it plays a crucial role in expanding the country's economy. Implementation of AMTs requires manufacturing companies to adopt new ways of thinking and doing work. Although Kenya's manufacturing sector enjoyed relatively rapid growth in the early post-independence years (1970s), it has generally been sluggish without dramatic shifts in performance. However, its performance has been shaped by some notable developments. The first of these is the carry forward of IS policies that were implemented during colonial rule and adopted by the independent government. The IS policy served to ensure the availability of basic products in the domestic market [7]. However, such products were overpriced and the policy distorted the evolution of industry by encouraging excess capacity and generalized inefficiency that undermined the ability of Kenyan products to penetrate to external markets. A change came when the government eventually recognized the need to shift focus toward export promotion in the mid-1980s [14]. However, immediate efforts to encourage exports were overshadowed by macroeconomic challenges and externally driven SAPs that were implemented half-heartedly and opportunistically.

Kenya is currently the most important source of FDI in Uganda and Rwanda. The region, particularly Uganda, is the most important export destination for Kenyan products. A distinctive feature of the manufacturing sector in Kenya is the coexistence of the modern sector alongside a rapidly expanding informal sector [7]. While the former comprises mainly of small, medium and large enterprises, the informal sector consists of semi-organized, unregulated, small-scale activities that use low level technologies and employ few people. A large proportion of industrial output is directed towards satisfying basic needs, namely the provision of low-income consumer goods and services [8].

While data on this sector is inadequate, it is one of the fastest-growing sectors and a major source of employment in Kenya. The small and medium-scale enterprises, which form part of the formal economy, are characterized by some degree of specialization. These enterprises manufacture a wide range of items generally designed to meet the domestic needs of low-income households although some are exported to neighboring countries [7]. The structure of Kenya's manufacturing sector has undergone minimal changes despite shifts in policies. Production is still largely geared towards consumer goods. Thus, the study of AMT adoption in manufacturing companies in Kenya is timely in order to examine their current practice in view of their technological adaptability. Indeed it is hoped that ideas and suggestions based on the findings from this study can be made in order to help enhance the effectiveness of manufacturing companies in developing countries, like Kenya, and thus maximize their contribution to the economy.

IV. Methodology

The study set its boundaries around AMT investment and integration of manufacturing companies in Kenya. As the majority of the AMT usage is by manufacturers producing discrete products, this study focused on the current industry distributions of manufacturing companies in Kenya listed under Kenya association of manufacturers [8]. Samples were taken from eight manufacturing sub-sectors which produce discrete products, covering the whole range of the industry. The eight sub-sectors include Food, beverage and animal feeds industry, Construction and material industry, Chemical and

Pharmaceuticals industry, Plastics, packaging and stationery industry, Power generation and electrical/electronic industry, Fabricated metals industry, Textiles, apparel, leather and foot ware and Automobile and parts industry. This is representative of the entire population of the companies in Kenya.

Advanced manufacturing technology results from substantive advancement in the current state of production of materials and products. These advancements include improvements in manufacturing processes and systems, which are often spurred by breakthroughs in basic science and engineering disciplines. The study investigated 14 AMTs in 5 domains based on their functionality. These domains included Product Design and Engineering Technologies (PDETs); Production Planning Technologies (PPTs); Material Handling Technologies (MHTs); Assembly and Machining Technologies (AsMTs) and Integrated Manufacturing Technologies (IMTs).

The AMT adoption was operationalized in terms of the level of investment in the technology and its level of integration. In level of investment companies were asked to indicate the amount of investment the company had in the individual technology, on a likert scale of 1-5, where 1 indicated little investment, 2 indicated some investments, 3 indicated moderate investment, 4 indicated substantial investment and 5 indicated heavy investment. The level of integration was determine by ascertaining on whether the piece of technology is connected to another appliance or system within the department, company or the enterprise, or just a piece of stand-alone technology. Companies were asked to indicate the level of integration, on a likert scale of 1-5, where 1 indicated no integration, 2 indicated limited integration, 3 indicated moderate integration, 4 indicated full integration and 5 indicated extended integration.

The two dimensions were treated with equal weight. However with regard to dependency integration depended on investment as illustrate in the course of our earlier discussion and definition of them. With regard to weighting, there is no available evidence to suggest that any one of the dimensions carries more weight than the other. In the absence of such evidence we preferred not to prejudge the matter but instead wait to see if the data suggest reformulation of the suggested scale.

Gaining admission to industrial organizations for the purposes of sociological research in Kenya is difficult and the author, dependent to a large extent on the efficacy of personal contact networks for the purposes of getting information. A letter of introduction accompanying the questionnaire was addressed to the Production Manager/Managing Director of the company. 183 questionnaires were either delivered or posted to all the identified AMT companies.

As the AMT plants were located at different places, geographically ranging from 5 to 700 km, data collection process took nearly 7 months. 101 companies showed positive response and data from these companies were collected for analysis. The respondents were required to fill up their job title and the duration in holding the position in the company. This information was deemed important in order to find out the credibility of the informant. Out of the 101 respondents whose data was collected the credibility of 9, representing about 9%, did not meet the standard required and so were rejected in the analysis. The analysis is therefore based on 92 companies. A brief look at the companies showed that all our sub-sectors were represented.

V. Results and Discussion

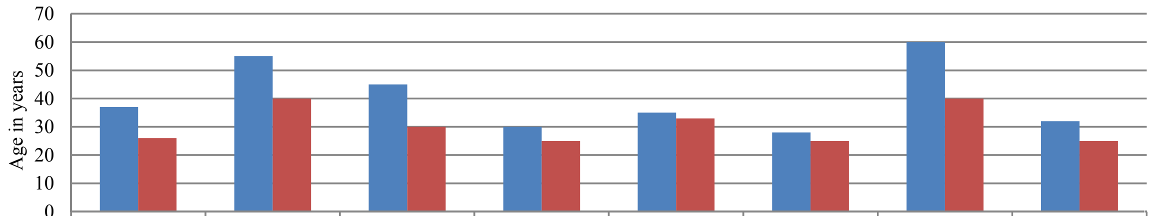
As the focal point of our study was on AMT manufacturing companies, data is presented in a disaggregated form by sub-sector. This allows better understanding about sub-sector differences in terms of the structure and composition of the different sectors that constitute in an aggregate. The collected data on the AMT manufacturing sub-sectors in Kenya provide a basis for understanding why companies in different sub-sectors might act differently in terms of adopting different AMT technologies.

Majority of the respondents (42.5%) were from top management levels, i.e. directors, managing directors, chief executive officers, or chairmen. In addition, approximately 40% of the respondents were directly responsible for manufacturing or operations or production issues of their companies. 17.5% of respondents were holding non-manufacturing-related positions such as administration managers (3), company secretaries (3), marketing managers (2), commercial managers (2), purchasing managers (2), human resource managers (2), and finance managers (2). Numerous elements of visited company profile were collected using the designed instrument. This included the sub-sector of the industry; the year of establishment and the company size which was assessed by capital invested and the number of full-time equivalent employees, where one part-time equals to half a full-time employee. The mean workforce number of companies surveyed was found to be low, at around 50 employees, it is no surprise that the top management level were in-charge of their manufacturing function and involved in decision making in manufacturing issues. At a glance, we can infer that the sampled information collected from the survey was highly credible and with good understanding of informants, with the average duration in their respective positions as 9 years.

Majority of the respondents were from food, beverage and animal feeds industry, which accounted for 31.5%, followed by the construction and material industry at 14.1%, chemical and pharmaceuticals industry at 12.0%, plastics, packaging and stationery industry at 12.0% and power generation and electrical/electronic industry at 10.9%. Other respondents represent a small fraction like fabricated metals industry at 7.6%, textiles, apparel, leather and foot ware industry at 6.5% and automobile and parts industry at 5.4%.

A. Age of Industry Stock

Majority of the companies surveyed were mature companies that have existed in the manufacturing scene for some time, with average being around 40 years. The fact that the median company age is around 30 years shows that across all the eight broad manufacturing sub-sectors there are some very old companies that are in existence in each of the sub-sectors. 28 percent of respondents have been trading for more than 50 years, with almost half of them in the food, beverage and animal feeds. There was only a small fraction of young companies, 12%, which had existed for less than 10 years. Power generation, electrical/electronic industry exhibited the highest mean and median age, 60 and 40. Fabricated metal industry was the youngest industry with mean age of 28. The results are shown in Fig. 1.



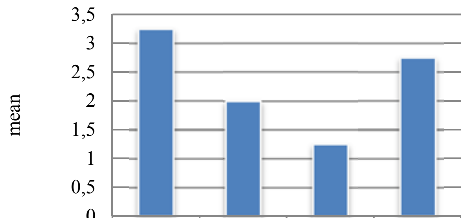
	Construction/ material	Food/ beverage/animal feeds	Textiles/ apparel/ leather/foot ware	Chemical/Pharmaceuticals	Automobile/parts industry	Fabricated metals industry	Power/electrical/electronic	Plastics, packaging and stationery
mean	37	55	45	30	35	28	60	32
median	26	40	30	25	33	25	40	25

Fig. 1 Company age by Sub-Sector

B. Product Design and Engineering Technologies

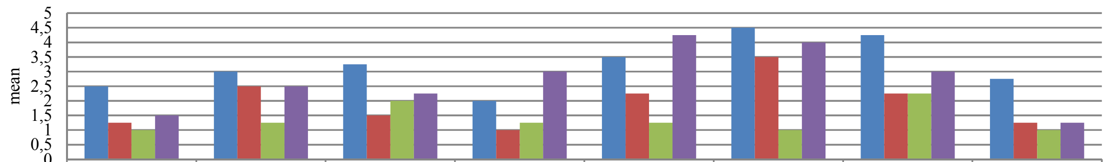
Manufacturing companies invested in various product design and engineering technologies. These technologies included CAD, CAE, CAM and GT. Companies used these technologies to assist them in designing and testing a product, controlling of manufacturing machinery and also for part classifications and coding systems. Fig. 2 shows the mean investment score of for each PDET. The results show that the most common PDET among the companies surveyed is CAD, with a mean investment score of 3.25; followed by CAM, with mean score of 2.75. The results show that the least investment is GT with mean score of 1.25.

Fig. 3 shows that across all sub-sectors investment in CAD takes the most important position while GT is worth the least. Fabricated metal industry relies on CAD the most, followed by automobile and parts industry. Similarly, CAE is relatively more important in fabricated metal industry and least important in chemical and pharmaceutical industry. For CAM investments, automobile and parts industry registered the highest mean score, 4.25, while packaging and stationery registered the lowest, 1.25. Power generation, electrical and electronic industry registered the highest mean score in GT.



	CAD	CAE	GT	CAM
MEAN	3,25	2	1,25	2,75

Fig. 2 Investments in Product Design and Engineering Technologies



	Construction/ material	Food/ beverage/animal feeds	Textiles/ apparel/ leather/foot ware	Chemical/Pharmaceuticals	Automobile/parts industry	Fabricated metals industry	Power/electrical/ electronic	Plastics, packaging and stationery
CAD	2,5	3	3,25	2	3,5	4,5	4,25	2,75
CAE	1,25	2,5	1,5	1	2,25	3,5	2,25	1,25
GT	1	1,25	2	1,25	1,25	1	2,25	1
CAM	1,5	2,5	2,25	3	4,25	4	3	1,25

Fig. 3 Investments of product design and engineering technologies by Sub-Sector

Comparison of the mean score of PDET investments with the employment band, as shown in Fig. 4, reveals that all surveyed companies invested the most in CAD followed by CAM then CAE and GT was the least. However in small industries investments of CAE and GT are very low. This indicates that these two technologies are not important for small industries. In general, the importance of these technologies increases with company size. Larger companies seem to depend on these technologies for their operations.

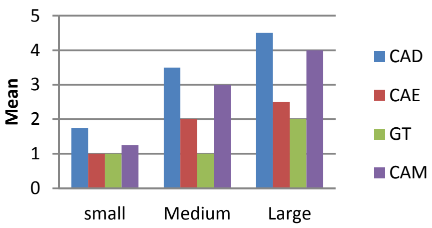
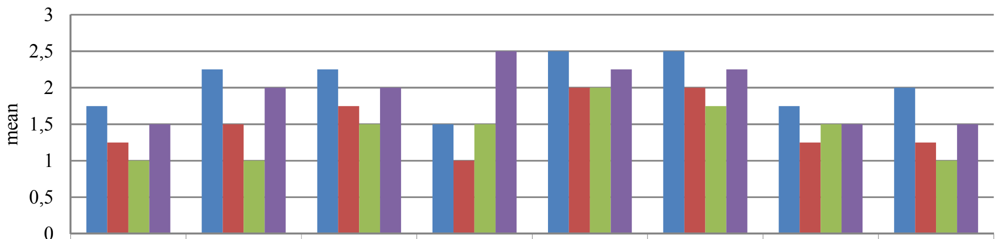


Fig. 4 Investments of PDETs by size

Overall, the results show that the levels of integration in PDETs are limited, since none of the scores is over 2.5 (half way). The mean score of PDET integration by Sub-Sector shows that the levels of integration are low, with a mean score of less than 2.5. In terms of the individual PDET, almost 90 percent of the respondents invested moderately in CAD, however the majority of them had their CAD either as stand-alone meaning no integration, or only integrated within the department. It is the same scenario for CAE. 66% of companies surveyed had little to moderate integrations. Majority of the companies that invested in CAE, 80% had the technology either with limited or no integration. Few companies surveyed invested in GT (with mean score around 2), and only 20% of those that had invested in the technology stated to have limited integration. The rest had not integrated the technology.

Fig. 5 compares mean score of PDETs with Sub-Sectors. The results shows that among the invested technologies in these domain automobile and parts industry had the highest mean score of 2.1875 followed by fabricated metal industry that had a mean score of 2.125. Construction and material industry had the least score of 1.375.



	Construction and material	Food/beverage /animal/feeds	Textiles/apparel/ leather/foot ware	Chemical/ Pharmaceuticals	Automobile/ parts industry	Fabricated metals industry	Power /electrical /electronics	Plastics/packaging / stationery
CAD	1,75	2,25	2,25	1,5	2,5	2,5	1,75	2
CAE	1,25	1,5	1,75	1	2	2	1,25	1,25
GT	1	1	1,5	1,5	2	1,75	1,5	1
CAM	1,5	2	2	2,5	2,25	2,25	1,5	1,5

Fig. 5 Integration of Product Design and Engineering Technologies by Sub-Sector

The most integrated piece of PDETs is CAM. Table I shows CAM investment and integration cross tabulation. 23 companies among the 29 that indicated little investment did not integrate the technology into the system. 4 of them indicated limited integration and the remaining 2 showed moderate integration. 3 companies indicated heavy investment and extended the integration to suppliers or/and customers.

TABLE I
CAM INVESTMENT AND INTEGRATION CROSS TABULATION

		CAM Integration					Total
		none	limited	moderate	Fully	Extended	
CAM Investment	little	23	4	2	0	0	29
	some	6	4	3	1	0	14
	moderate	3	9	4	5	0	21
	substantial	2	1	5	4	0	17
	Heavy	1	2	3	2	3	11
Total		35	20	17	12	3	92

C. Production Planning Technologies

Manufacturing companies invested in various PPTs, such as MRP, MRP II, and ERP to assist them in planning, scheduling, and controlling of material and resource requirements for the production of various products. ERP assisted companies in covering a wider scope by integrating the operations throughout the companies and also facilitates global integration.

The whole manufacturing industry seems to have agreement on the investments in PPTs. As shown in Fig. 6, surveyed companies' investments in MRP, MRP II and ERP are generally moderate. The ranking of investments in the three technologies, from highest to lowest were MRP, MRPII and ERP. The low mean scores is indeed quite an interesting discovery as it shows that surveyed companies are still very much at the early version of production planning tool.

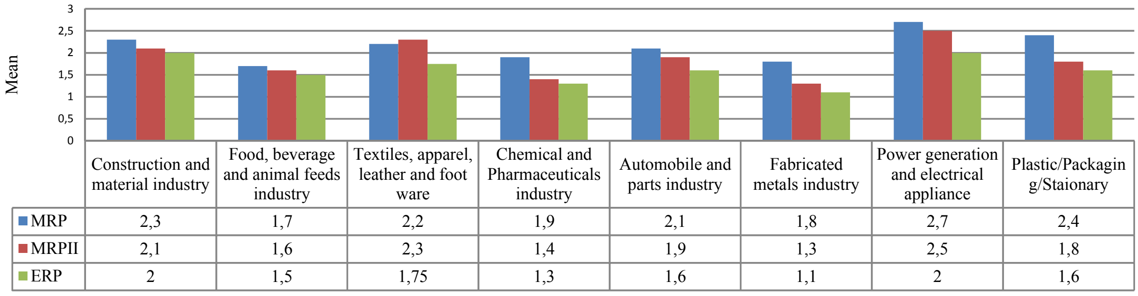


Fig. 6 Investment in Production Planning Technologies by Sub-Sectors

Investment of PPTs among the surveyed companies, based on their size, reveals that the larger the company the more likely they will invest in PPTs. Therefore, as shown in Fig. 7, the scale of investment grew with size of company.

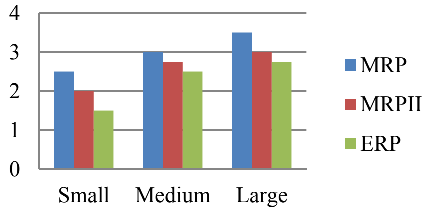


Fig. 7 Investments in PPTs with Company Size

The majority of companies who invested in PPTs had limited integration. As shown from Fig. 8, the study reveals that larger companies integrated their PPTs more than smaller companies.

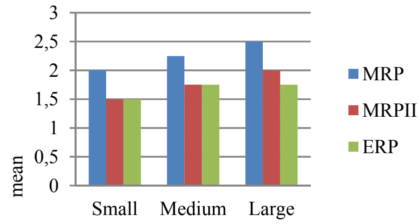


Fig. 8 Integration of PPTs by Company Size

By Sub-Sector, the results shows that the level of integration of PPTs is limited, with a mean score of 2, indicating that integration is only within the department. Fig. 9 shows that power generation electrical and electronic industry had slightly more integration as compared to other manufacturing industry. Chemical and pharmaceutical industry had the least integration across all PPTs.

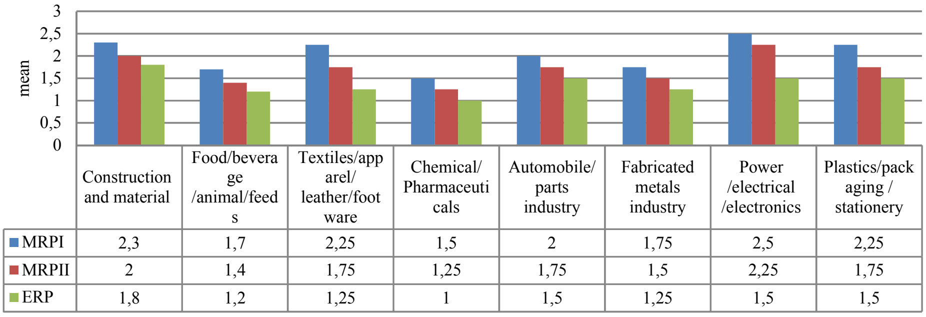


Fig. 9 Integration of Production Planning Technologies by Sub-Sector

In terms of the individual PPTs, MRP is the most invested and also the most integrated, as shown in the Table II. Fig. 9 shows that there is a positive relationship between the level of MRP investment and the extent of the integration. Out of the 27 Companies that showed little investment in MRP, 22 indicated no integration, 4 indicated limited integration and 1 indicated full integration. The result shows that companies that have moderate and heavy investment in MRP, tend to integrate this piece of PPT within the company or extend it to suppliers and or customers.

TABLE II
MRP INVESTMENT AND INTEGRATION CROSS TABULATION

		MRP Integration				Total
		none	limited	Fully	Extended	
MRP Investment	little	22	4	1	0	27
	some	5	5	1	0	11
	moderate	3	7	10	1	21
	substantial	2	3	14	1	20
	Heavy	1	0	8	4	13
Total		33	19	34	6	92

As shown in Table III, of those who invested in some levels of MRP II, only 10 % invested heavily and majority of them (94%) had no integration or little integration. In total, almost half of those companies that invested in MRP II did not integrate it in the company but operated it as stand-alone.

TABLE III
MRPII Investment and Integration Cross Tabulation

		MRP II Integration				Total
		none	limited	Fully	Extended	
MRP II Investment	little	34	2	1	0	37
	some	8	5	2	0	15
	moderate	3	4	9	0	16
	substantial	2	2	11	1	16
	Heavy	0	0	5	3	8
Total		47	13	28	4	92

The results also show that ERP is less popular among the companies surveyed. The number of companies that invested in and integrated ERP is significantly low. Companies either made little to moderate investment with none to limited integration.

D. Material Handling Technologies

Material handling technologies (MHTs) are AMTs used by manufacturing companies to facilitate the handling of material in manufacturing operations. ASRS use computers to direct automatic loaders to pick and place items for production processes or storage by automatic high-lift trucks. Companies employ transport automation by using AGVs to move materials to and from value adding operations.

The study shows that on average companies surveyed had little investments in MHTs. Generally, companies invested more in ASRS in comparison with AGVs. Fig. 10 shows that construction and material industry ranks the highest in MHTs investments. Fabricated metal industry had the lowest investment in ASRS with a mean score of 1.375. AGVs investment is slightly lower than ASRS investment. The leading industry, construction and material industry had a mean score of 2.25. The least investment in AGVs is in fabricated metal industry with almost negligible investment, i.e. a mean score of 1.25.

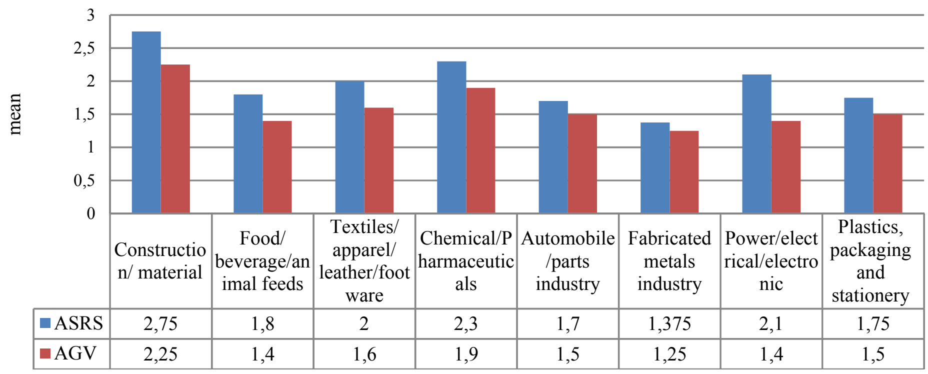


Fig. 8 Investment of Material Handling Technologies by Sub-Sector

Larger companies tend to invest slightly more in MHTs as compared to smaller companies. The mean score of investment of MHTs for large companies is between 2.75 to 3.5 while small companies have a mean score of 1.5. Fig. 11 shows mean Score of MHTs investment by company size

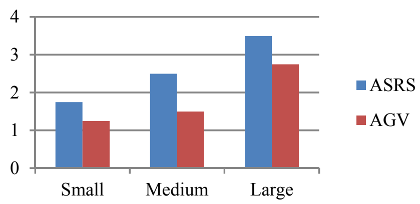


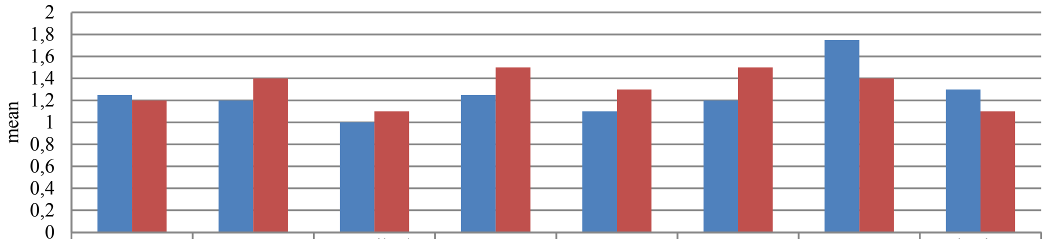
Fig. 9 Investment of MHTs by Company Size

Fig. 12 shows that material handling technology is either in stand-alone mode or only linked within the department. When comparing the level of integration of MHTs by type of Sub-Sector, all industries have almost the same level of integration. Power generation electrical and electronics industry integrated its automated storage and retrieval systems almost within the department (mean score of 1.75). However, the other industries showed power integration of their MHTs.

Larger and older companies tend to integrate their ASRSs further than younger and small companies. The AGVs is a stand-alone piece of technology in many companies. The conclusion we can draw from the study is that both the level of investments and integration of material handling technologies in the companies surveyed are very limited.

E. Assembly and Machining Technologies

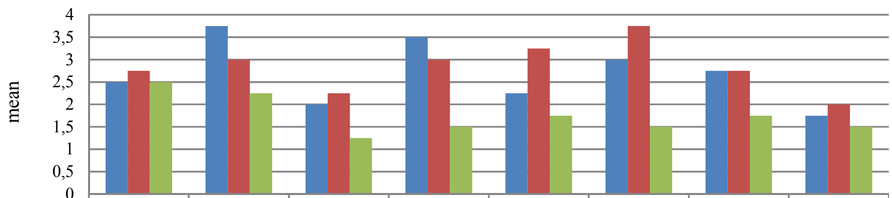
The study examined the level of investment and integration of 3 types of assembly and machining technologies (AsMTs); computer-aided quality control system (CAQCS), robotics and numerical control machines (NC/CNC/DNC). These assembly and machining technologies are used to perform repetitive functions and work without permanent alteration of the equipment. Computer-aided quality control system is used to perform quality inspection on incoming or final materials, robotics are used to carry out various operations like handling, process or assembly tasks, whilst numerical control machines exist for almost all types of machining, like turning machines, boring and milling machine, horizontal boring machines and machining centers.



	Construction/ material	Food/ beverage/animal feeds	Textiles/ apparel/ leather/foot ware	Chemical/Ph armaceutical s	Automobile/ parts industry	Fabricated metals industry	Power/electri cal/electronic	Plastics, packaging and stationery
ASRS	1,25	1,2	1	1,25	1,1	1,2	1,75	1,3
AGV	1,2	1,4	1,1	1,5	1,3	1,5	1,4	1,1

Fig. 10 Integration of Material Handling Technologies by Sub-Sector

Generally, industries invested the most in numerical control machines technologies. Fig. 13 shows that food, beverage and animal feed industry, fabricated metal industry, automobile and parts industry and the chemical and pharmaceutical industry invested more moderately in NC/CNC/DNC than the other industries, with a mean score of about 3. The investment in numerical control machines for other industries is less than moderate, the least being plastic, packaging and stationery with a mean score of 2. Investments in CAQCS are limited, except for food, beverage and animal feed industry and fabricated metal industry. Companies invested least in robotics technology with a mean score of 1.75.



	Construction and material	Food/beverage /animal/feeds	Textiles/apparel/ leather/foot ware	Chemical/ Pharmaceuticals	Automobile/ parts industry	Fabricated metals industry	Power /electrical /electronics	Plastics/packaging / stationery
CAQC	2,5	3,75	2	3,5	2,25	3	2,75	1,75
NC/CNC/DCN	2,75	3	2,25	3	3,25	3,75	2,75	2
Robotics	2,5	2,25	1,25	1,5	1,75	1,5	1,75	1,5

Fig. 11 Investment in Assembly and Machinery Technologies by Sub-Sector

Fig. 14 shows that regardless of the size of the company, most investments are made in NC/CNC/DNC, followed by CAQCs, and last come robotics technology. Worth noting is that medium sized companies made substantial investments in NC/CNC/DNC, significantly more than companies of the other sizes. For robotics and CAQCs, investment in these technologies grew with company size.

From the data it was also found that levels of integration of AsMTs increased with company size, except that large sized companies made the most integration in NC/CNC/DNC technologies. This result is contrary to the situation of investments analyzed by size where medium sized companies were leading. For computer-aided quality control system and robotics technologies, surveyed companies made slightly less integration. Even so, overall integration for either type of technology increased with size. The study reveals that integration of AsMTs increases with business years.

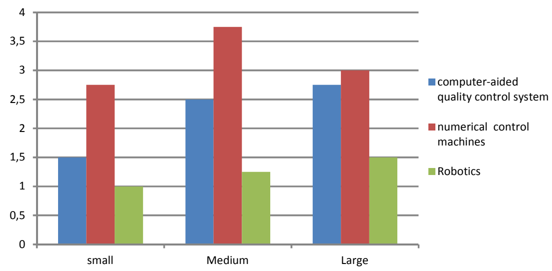
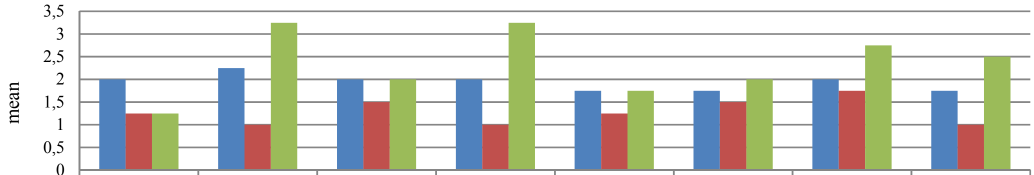


Fig. 12 Investment in AsMTs by company size

Levels of integration of AsMTs are limited. Fig. 15 shows that the highest to the lowest mean scores of integrations are numerical control machines, computer-aided quality control system, and robotics technology. Integration of CAQCS is on the highest level in the food, beverage and animal feed industry. Power generation, electrical/electronic made the most integration in robotics as compared to other industries.



	Construction and material	Food/beverage /animal/feeds	Textiles/apparel/ leather/footware	Chemical/ Pharmaceuticals	Automobile / parts industry	Fabricated metals industry	Power /electrical /electronics	Plastics/packaging / stationery
CAQCS	2	2,25	2	2	1,75	1,75	2	1,75
Robotics	1,25	1	1,5	1	1,25	1,5	1,75	1
NC/CNC/DCN	1,25	3,25	2	3,25	1,75	2	2,75	2,5

Fig. 13 Integration of Assembly and Machinery Technologies by sub-sector

Table IV shows that further investigation of CAQCS reveals that most companies that invested in CAQCS fall into little investment with no integration combination. The majority of surveyed companies that invested in CAQCS had limited investment in their CAQCS and none or limited integration. There were 2 companies that substantially invested and fully integrated this technology. One company substantially invested and extended CAQCS integration to supplier or customers. One company invested heavily and made full integration.

TABLE IV
CAQCS INVESTMENT AND INTEGRATION CROSS TABULATION

		CAQCS Integration					Total
		none	limited	moderate	Fully	Extended	
CAQCS Investment	little	35	4	2	0	0	36
	some	20	8	2	1	0	31
	moderate	3	4	3	3	1	14
	substantial	2	2	2	2	1	9
	Heavy	0	0	1	1	0	2
Total		55	18	10	7	2	92

Table V shows the distribution of respondents in terms of the level of investment in robotics and its level of integration. It is obvious that there are a limited number of companies investing and integrating in robotics technology. Among companies who provided valid answers in this section, 60% of them made little investment and no integration, with less than 25% of them making any integration.

Table VI reveals that NC/CNC/DCN is the most invested by the respondent companies, with a total of 77% of respondent companies, having some level of investments. Except for companies who made no integration, the largest group appears in the combination of substantial investment and limited integration (9), followed by heavy investment and moderate integration (8). Worth noticing is that the number of companies who made heavy investment and extended integration to suppliers or customers are 4 while the number of companies who made heavy investment and fully integration are 6.

TABLE V
ROBOTICS INVESTMENT AND INTEGRATION CROSS TABULATION

		Robotic Integration					Total
		none	limited	moderate	Fully	Extended	
Robotic Investment	little	56	2	0	0	0	58
	some	8	2	1	0	0	11
	moderate	5	3	0	0	0	8
	substantial	1	5	1	1	0	8
	Heavy	1	2	2	1	1	6
Total		71	14	4	2	1	92

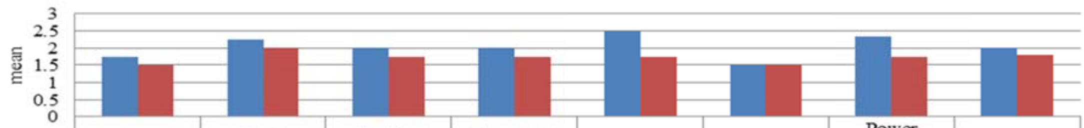
TABLE VI
NC/CNC/DNC INVESTMENT AND INTEGRATION CROSS TABULATION

		NC/CNC/DCN Integration					Total
		none	limited	moderate	Fully	Extended	
CAQCS Investment	little	21	1	0	0	0	22
	some	5	4	0	0	0	09
	moderate	5	6	2	1	0	14
	substantial	3	9	5	4	1	22
	Heavy	3	4	8	6	4	25
Total		37	24	15	11	5	92

F. Integrated Manufacturing Technologies

As the name of the technology group suggests, technologies within this group are already integrated in some forms, for example, FMC or FMS consist of two or more NC/CNC machines which are interconnected by handling devices and a transport system. The difference between FMS and FMC is that FMC is capable of single path acceptance of raw materials and single path delivery of a finished product, whilst FMS is capable of multiple paths, and may also be comprised of two or more FMCs linked in series or parallel. Another technology within this subgroup is ClM, which incorporates all elements in the manufacturing process from product design to distribution. It links the company beyond departments by integrating computer systems, thus islands of computer application in the companies are integrated.

Fig. 16 shows that the mean score of investments in FMC/FMS by surveyed companies is slightly higher than ClM. FMS/FMC registered a mean score of 2.05 as compared to CIM that registered a mean score of 1.725. It is the same scenario when compared by their Sub-Sectors. For most Sub-Sectors investments in FMC/FMS are slightly more than ClM.



	Construction and material industry	Food, beverage and animal feeds industry	Textiles, apparel, leather and foot ware	Chemical and Pharmaceuticals industry	Automobile and parts industry	Fabricated metals industry	Power generation and electrical/electronics	Packaging, Plastics and stationery
FMC/FMS	1.75	2.25	2	2	2.5	1.5	2.35	2
CIM	1.5	2	1.75	1.75	1.75	1.5	1.75	1.8

Fig. 14 Investments in Integrated Manufacturing Technologies by Sub-Sector

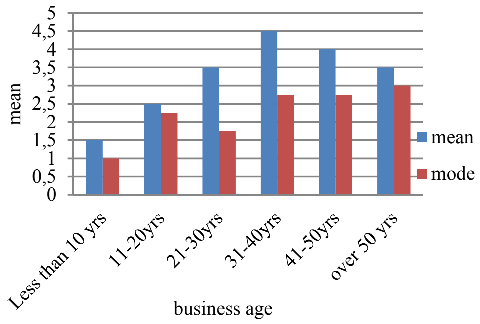
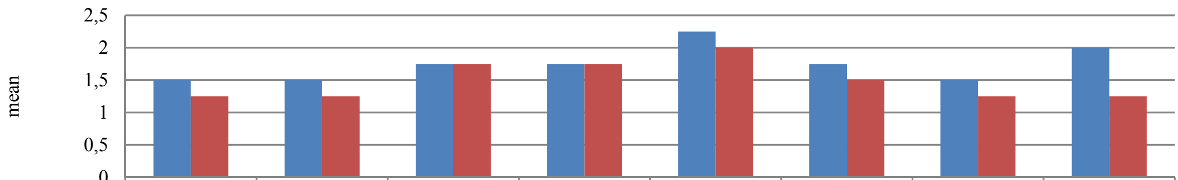


Fig. 15 Investment of IMTs by age bands

Fig. 17 shows that surveyed companies which are less than 10 years old invested the least in both FMC/FMS and CIM. Investments by companies in the age band of 31-40yrs are among the highest level. For the other age bands, investments in integrated manufacturing technologies decrease as history of business grow. Companies in the range of 21-30 years and 41–50 years are among those who invested almost moderately on integrated manufacturing technologies.

As the name suggests, one would have thought that integrated manufacturing technologies would be fully or extensively integrated within the company or to include their supply chain. However, the level of integration, as provided by the surveyed companies in Fig. 18, is rather low, both at mean score of 1.75 for FMC/FMS, and 1.5 for CIM which means that both IMTs have limited integration. This suggests that the technology is only limited to the department. Automobile and parts industry registered the highest level of integration for FMC/FMS at a mean score of 2.25 while construction and material industry and food, beverage and animal feed industry registered the lowest at a mean score of 1.5. The highest score for CIM was registered by automobile and parts industry with a mean score of 2. The rest of the sub-sectors registered low integration ranging from a mean score of 1.75 to a mean score of 1.25.



	Construction and material	Food/beverage /animal/feeds	Textiles/apparel/ leather/foot ware	Chemical/ Pharmaceuticals	Automobile/ parts industry	Fabricated metals industry	Power /electrical /electronics	Plastics/packaging / stationery
FMC/FMS	1,5	1,5	1,75	1,75	2,25	1,75	1,5	2
CIM	1,25	1,25	1,75	1,75	2	1,5	1,25	1,25

Fig. 16 Integration of Integrated Manufacturing Technologies by Sub-Sectors

Fig. 19 shows that surveyed companies in age bands 31-40 and 41-50 years made more integration in IMTs than companies in the rest of the other age bands. Moreover, companies in these two age groups made more integration in CIM than FMC/FMS which is contrary to the other age bands.

Table VII shows cross tabulations of CIM investment and integration. A few companies made CIM integration. 46 out of a total of 92 companies surveyed indicated that they made CIM integration. It is observed that companies investment little of these technology and having no integration form the largest group (40), followed by moderate investment with limited integration (8). There are seven companies which did some investment but with limited integration. 5 companies did moderate investment but integrated moderately. One company made heavy investment and extended CIM integration to suppliers or customers.

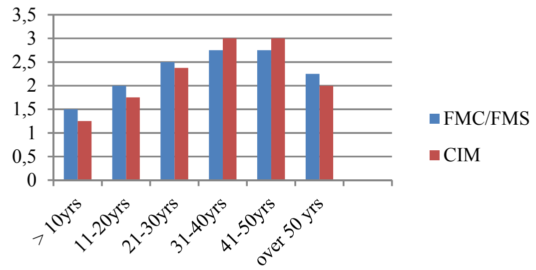


Fig. 17 Integration of IMTs by age band

TABLE VII
CIM INVESTMENT AND INTEGRATION CROSS TABULATION

		CIM Integration					Total
		none	limited	moderate	Fully	Extended	
CIM Investment	little	40	2	2	1	1	46
	some	4	7	1	1	0	13
	moderate	2	8	5	2	1	18
	substantial	0	4	3	2	2	11
	Heavy	0	0	2	1	1	4
Total		46	21	13	7	5	92

TABLE VIII
FMC/FMS INVESTMENT AND INTEGRATION CROSS TABULATION

		FMC/FMS Integration					Total
		none	limited	moderate	Fully	Extended	
FMC/FMS Investment	little	33	4	1	0	0	38
	some	6	5	1	0	0	12
	moderate	2	8	4	2	0	16
	substantial	1	5	5	4	1	17
	Heavy	0	2	3	5	0	8
Total		42	24	14	11	1	92

Table VIII shows cross tabulation of FMC/FMS investment and integration. One company made substantial investment and extended integration to supplier/customers. Five companies made heavy investment and fully integrated FMC/FMS.

G. Generation of AMTs Scores

For the purpose of summary and analysis, the aggregate AMTs investment and integration of surveyed companies generated ten AMTs investment and integration scores, which are product design and engineering technology investment score (PDETinv) and integration score (PDETint), logistics related technology investment score (PPTinv) and integration score (PPTint), material handling technology investment score (MHTinv) and integration score (MHTint), assembly and machinery technology investment score (AsMTinv) and integration score (AsMTint), and integrated manufacturing technology investment score (IMTinv) and integration score (IMTint).

Below lists the formulae of each investment and integration score for each AMT:-

1. $PDETinv = \frac{1}{4}[CADinv + CAEinv + GTinv + CAMinv]$
2. $PDETint = \frac{1}{4}[CADint + CAEint + GTinv + CAMint]$
3. $PPTinv = \frac{1}{3}[MRPinv + MRPIIinv + ERPinv]$
4. $PPTint = \frac{1}{3}[MRPint + MRPIIint + ERPint]$
5. $MHTinv = \frac{1}{2}[ASRSinv + AGVinv]$
6. $MHTint = \frac{1}{2}[ASRSint + AGVint]$
7. $AsMTinv = \frac{1}{3}[CAQCinv + ROBOTICSinv + NC/CNC/DCNinv]$
8. $AsMTint = \frac{1}{3}[CAQCint + ROBOTICSint + NC/CNC/DCNint]$
9. $IMTinv = \frac{1}{2}[FMC/FMSinv + CIMinv]$
10. $IMTint = \frac{1}{2}[FMC/FMSint + CIMint]$

Table IX shows the summary of AMT score per sub-sector based on the five sub-groupings. The table shows that most investments are made in AsMTs, which are just around the moderate level (mean score 2.43). PDETs ranked second with a mean score of 2.32, followed by PPTs (mean score of 1.869). Investment in MHTs was the lowest, at the mean score of 1.786. For most sub-sectors, the ranking of the scale of investment in different AMTs varied from sub-sector to sub-sector.

TABLE IX
AMTS SCORE PER SUB-SECTOR

	PDET inv	PDETint	PPTinv	PPTint	MHT inv	MHT int	AsMT inv	AsMT int	IMT inv	IMT int	AMT score
Construction and material Industry	1.56	1.38	2.13	2.03	2.50	1.23	2.58	1.50	1.63	1.38	1.79
Food/beverage /animal/feeds Industry	2.81	2.19	1.87	1.75	1.60	1.20	2.42	1.58	2.13	2.13	1.97
Textiles/apparel/ leather/foot ware Industry	2.25	1.88	2.08	1.75	1.80	1.05	1.83	1.83	1.88	1.75	1.81
Chemical/ Pharmaceuticals Industry	1.81	1.63	1.53	1.25	2.10	1.38	2.67	2.08	1.88	1.75	1.81
Automobile/ parts industry	2.31	1.69	1.60	1.43	1.60	1.30	3.00	2.17	2.13	1.38	1.86
Fabricated metals industry	3.25	2.13	1.40	1.50	1.31	1.35	2.75	1.75	1.50	1.63	1.86
Power /electrical /electronics Industry	2.94	1.50	2.40	2.08	1.75	1.58	2.42	2.17	2.05	1.38	2.03
Plastics/packaging/ stationery industry	1.63	1.44	1.93	1.83	1.63	1.20	1.75	1.75	1.90	1.63	1.67
Average	2.32	1.73	1.87	1.70	1.79	1.28	2.42	1.85	1.88	1.63	

Level of integration of AMTs invested is low. However it is worth noting that the ranking of mean score is very similar to the order of AMTs investments. Although integration of AsMTs was the highest, its mean score is as low as 1.854, which indicates that it is only limitedly integrated. Similarly, MHTs were the least invested by the respondents registering a mean score of 1.284. It is noted that the ranking of mean score in integration is very similar to the order of AMTs investments except for construction and material industry which registered the lowest integration at a mean score of 1.504. However the mean AMT index follows the same path with AMT investment.

The score for AMT for each sub-sector or individual company was calculated as;

$$AMTindex = \frac{1}{2}[AMTinv + AMTint]$$

The ranking of the scale of investment in AMTs shows that power generation, electrical and electronic scored the highest, 2.311 followed by food, beverage, and animal feed industry at 2.164. Plastic, packaging, and stationery scored the lowest at 1.668.

VI. Conclusions

In general, the sample of the companies surveyed showed that the level of AMT adoption in Kenya is very low with investments levels at a mean of 2.057 and integration levels at a mean of 1.639 in a scale of 1-5. The study shows that no particular sub-sector can claim to be dominant in all the AMTs. The largest sub-sector in numbers among the surveyed companies, food, beverage and animal feed industry have the highest level of investment and integration in IMTs but the lowest level of integration in MHTs. Power generation, electrical/electronics, the largest sub-sector in size, had the highest level of investment and integration in PPTs while plastics, packaging and stationery, the smallest sub-sector in size, had the lowest level of investment and integration in AsMTs. Fabricated metal industry had the highest investment in PDETs but food, beverage and animal feeds had the highest integration in the same AMT. Again construction and material industry had the highest investment in MHT but Power generation, electrical and electronics led in integrating the same AMT. Automobile parts industry had the highest level of investment and integration of AsMTs.

The majority of the companies being surveyed have been established for 30 to 50 years, which shows that these companies are mature in their life cycle. Being in their mature life cycle, these companies are unlikely to change their investment patterns drastically. Implementation of AMT in these manufacturing companies has been in stages from stand-alone to slowly moving to integrated systems. This can be proven with their inclination to have the lowest intention of introducing new product lines and new product models among other counterparts. Interestingly, companies younger than 10 years have the strongest motivation to provide customized products. 28% of surveyed companies have been trading for more than 50 years, with almost half of them in the food, beverage and animal feeds. Compared with others these companies invest and integrate the least in PPTs, MHTs, AsMTs and IMTs.

The study shows that smaller plants use an average of 3 different AMTs while larger plants use an average of 6 different AMTs. Given this evidence, we argue that the superior performance of larger plants is partly due to the increased use of AMTs by such plants. We also argue that, while size has indirect effect on AMT adoption [11] it also enhances the AMT adoption.

Investments of PPTs are still at an early stage of the material requirements planning tool, because they invest in MRP the most and ERP the least. However, it is noted that the younger a company is the less it invests in MRP. The survey also shows that investment in PPT largely depends on the size of a company. According to the study, the level of integration in PPT increases with the age of the technology. Since MRP is the earliest version of PPT and has been applied for the longest time, the level of integration of MRP is the highest in the surveyed companies. Similarly, as the latest version of PPT, ERP is integrated the least. Compared with companies from other industries, Power generation, electrical/electronic companies tend to invest more in PPT. Also, we find that companies older than 50 years tend to invest and integrate less PPT than younger companies.

Material handling technology is the least invested and integrated technology in this study. This technology is used by manufacturing companies to facilitate the handling of material in manufacturing operations. From any point of view, MHT gets the least attention. Companies barely invest and integrate MHT in their companies no matter which industry they belong to and how old their businesses are. However, the investment and integration of MHT is noticed to be highly related with company size. It is perhaps that companies are using MHT to deal with their vast material handling to support their mass production facilities.

Assembly and machining technologies are most widely applied for frequently repetitive functions. NC/CNC/DNC is the most widely applied AsMT. In particular, it is most applied in medium size companies. Moreover, investment in robotics and NC/CNC/DNC technologies increase with age bands. Automobile and parts industry have higher investment and integration of AsMT with levels increasing with company size. Integrated manufacturing technologies do not differ much across the Sub-Sectors. However, large companies tend to have higher investment in IMT due to their strong financial strength. In addition, except for the oldest and youngest age bands, investment of FMC/FMS and CIM, decrease as their age band grows. The older a company is, the less it invests in IMT. Integration of IMT is at low level for both FMC/FMS and CIM and it does not differ much for each sub-sector. IMT is second least invested and integrated among the five major AMT types.

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