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Full Length Research Paper

Benefits of advanced manufacturing technologies

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There are important benefits related to advanced manufacturing technologies (AMT) and their competitiveness. However, enterprises might not decide to invest in AMT because the benefits are questionable, because there is evidence in literature as in plants all around the world that benefits are less than expected. The purpose of this project was to collect evidence of AMT benefits and through the literature review determine the main benefits that are reported and then a questionnaire with 35 items divided into four sections: Design, technical, marketing, and costs, was formulated and applied to production managers in Ciudad Juarez, Chihuahua, Mexico, asking for waited and really obtained benefits. A descriptive analysis and a factor analysis was applied using principal components and varimax rotation and the results indicate that the main waited benefits are related to techniques and operative aspects, marketing, waste reduction (time and material), quality and knowledge management, product design, space usage and inventory; while the really benefits obtained are related to technical and operative benefits, flexibility in process, marketing, cost and time reduction, product design and quality.

Key words: Advanced manufacturing technologies (AMT) benefits, factor analysis, AMT adoption, AMT implantation.

INTRODUCTION

A general definition of AMT is given by Zairi (1992), according to him AMT is a social-technical system that requires continue revisions, readjustments, and changes to adapt to the requirements of the competitive world (flexibility). This definition is very general, and might not be sufficiently precise. In the glossary of statistic terms of the Organization for Economic Cooperation and Development (OECD), it is defined as equipment controlled by computer or that is based in micro-electronics and it is applied to the design, manufacturing or product manipulation (OECD, 2011).

In the literature there are several definitions, including other confusing descriptions such as the terms “integrated manufacturing systems” referring to the use of computers but not all the technologies include computing systems; misconceptions prevail while considering the distinction between the two types of technologies designated “hard” and “soft”. The former incorporates computing systems, in contrast to soft technology where is optional for the control of operations and generally consists in methods and administrative tools. This lack of agreement about the most fundamental issue as it is the definition constitutes a source of confusion, not to mention the diversity about benefits or the complexity involved in the components of AMT.

For instance, one of the AMT component listings is proposed by Small and Yasin (1997), whom divided into two types, hard and soft. In hard technologies are classified the following technologies:

1) Robots
2) Computer aided design (CAD)
3) Computer aided manufacturing (CAM)
4) Computer aided engineering (CAE)
5) Computer integrated manufacturing (CIM)
6) Computer numerical control (CNC)

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7) Flexible manufacturing systems (FMS's)
8) 3D Digitalization
9) Fast prototypes
10) Local area network (LAN)
11) Wide area network (WAN)
12) Technology information and communication (TIC)
I13) Industrial automatization
14) Automated guided vehicle (AGV).
15) Automated inspection (AI)
16) Artificial intelligence in industry
17) Laser technologies to process material and measures
18) Electronic data interchange (EDI)
19) Computer aided process planning (CAPP)
20) Automatic loads and downloads of items
21) Automated tools change
22) Computer aided inspection, test and tracking.
23) Item identification for industrial automated (bar code)
24) Supervisory, control and data acquisition (SCADA)

In soft technologies are classified resources such as:

1) Production system just in time (JIT)
2) Manufacturing resource planning (MRP II)
3) Enterprise resource planning (ERP)
4) Group technology (GT)
5) Manufacturing cells (MCs)
6) Total quality management (TQM)
7) Statistic quality/process control (SQC / SPC)
8) Single minute exchange of die (SMED).
9) Total productive maintenance (TPM)
10) Manufacturing technique: Lean manufacturing.

When these technologies are applied to the different production systems, several benefits are reported but their level of wellbeing varies differently, depending on the author. Table 1 list the benefits and illustrates that there are benefits mentioned by several authors while there are others mentioned occasionally. The benefits more cited are management control and improvement in work environment; those benefits are mentioned in seven of the eight references.

Also, the benefits related to the flexibility of the production system are mentioned, (third row) this might be explained simply because with AMT a wider and deeper family of products can be produced. The same applies to the response capability to engineering changes, that is improved because the design changes are frequent, and finally, the company improves its image. All these benefits have been mentioned by six of eight references.

In the same way, the less reported benefits are the stability of the operations, an enhanced capability to apply engineering changes (different than respond to engineering changes), and the invoicing is faster than before.

A superficial review of the Table 1 indicates the lack of agreement between experts regarding the benefits; although, there are no contradictions, it might be confusing about the expectations of a certain AMT project. Therefore, this research focused on the determination of the benefits that are being achieved in the industrial plants in Ciudad Juarez, Chihuahua, Mexico, given that is one of the largest industrial areas in the country and the AMT projects might not be well documented about the benefits. It is important to mention that this sector in Juarez, represents 50% of the exports of the manufacturing automotive sector in Mexico; and the assembly plants association Asociación de maquiladoras A.C. (AMAC) has in its records 352 enterprises as members in different areas, this data indicates the economic importance of this region (INEGI, 2010).

The objective of this project is to identify the benefits that the industrial plants located in the city of Juarez, Chihuahua, Mexico consider in the AMT planning and those that were really obtained once the technology has been transferred and installed. In this sense, this project results represent empirical evidence for the enhancement of this body of knowledge in one way or another.

METHODOLOGY

The methodology that was used in this research project is based in the data compilation done by a three phases process; phases that are explained in the following paragraphs.

First phase: Questionnaire construction

The initial phase was the literature review to determine the research reports related to benefits of AMT and list them. The objective is the determination of the benefits the assembly plants could seek before the AMT investment is made and those that are obtained once the AMT is deployed. The main benefits found in the literature review are presented in Table 1 and were used to build a questionnaire with 32 items in issues related to design, engineering-technical, marketing, and process flexibility. The initial survey was applied to 26 engineers working in manufacturing plants; this test led to several modifications of the questions or items before its validation. A blank space was left in each of the questions for the report of another benefit or observation about the question. Finally, 10 benefits were eliminated of the initial questionnaire and 13 more were added, resulting in a final survey of 35 items divided into four sections: Design, technical, marketing and costs. The questionnaire had two columns, one for the "before" and another for the "after" when the deployment of the AMT has been made. For the evaluation was used a "Likert" scale with a one to five range. The one indicated the total absence of that benefit while the five indicated that the benefit of the AMT was successfully acquired (Likert, 1932).

Second phase: Survey application

During the second phase, a total of 241 engineers working in the industrial sector in different positions, engineering, management and supervision were contacted and interviewed. The listing of engineers came from the Association de maquiladoras, A.C. de Ciudad Juarez, Chihuahua (AMAC). An appointment was

Table 1. Benefits of AMT investments.

Benefit attainable with AMT	Author								Total
	A	B	C	D	E	F	G	H	Citations
Improvement in management control	*	*	*		*	*	*	*	7
Improvement in work environment	*	*	*	*	*	*		*	7
Flexibility	*		*	*	*	*	*		6
Expansion in products line and depth		*	*		*	*	*	*	6
Improve the capability to respond to engineering changes	*	*		*	*		*	*	6
Improve the company image.		*	*	*	*		*	*	6
Improve the response to the variability of the products mix.	*	*			*	*	*		5
A better integration between the technology through functions		*	*		*	*	*		5
Improves the attitude of the work force.	*				*	*	*	*	5
Improvement of the capability to respond to the variability of the suppliers quality.	*	*	*	*	*				5
Improvement of the management attitude.	*		*		*	*		*	5
Time reduction for the development of products		*	*		*	*	*		5
Better work relations.		*		*	*	*		*	5
Improvement of the capability to respond to the variability of the delivery time of the suppliers.				*	*	*	*	*	5
Surpassing the deficiencies produced by the lack of ability in production management.	*	*	*		*	*			5
Improve the response to the variability of product changes		*	*		*	*			4
Reduction of work in process inventories (WIP)	*				*	*		*	4
Better manufacturing integration process			*	*	*		*		4
Outperforming the ability deficiencies.	*		*		*		*		4
Lower cost of forecasting.	*			*		*		*	4
Enhance operation stability.	*		*					*	3
Larger capacity to apply engineering changes.	*				*				2
Faster invoicing	*					*			2

Code of authors: A : Kakati (1997); B : Beaumont and Schroder (1997); C : Noori (1997); D : Swink and Nair, (1997) ; E : Millen and Sohal (1998); F : Stock and McDermott (2001); G : Efstathiades et al. (2002) ; H : Dangayach and Deshmukh (2006).

established with them by telephone and the questionnaire was applied in the work place. Three visits per interviewed were considered as convenient to get satisfactory answers for both parts. After three visits or three memos by email without an answer, this sample element was discarded.

Third phase: Information analysis

In the third phase was done the capture and analysis of information. Two data bases were constructed and passed through Statistical Package for Social Sciences, v. 17 (SPSS); one related to the planned or expected benefits, and the other with data of the real benefits obtained from AMT. In each one was built and related the corresponding cases to the answered surveys, these appear in rows; while the 35 columns represented the evaluated attributes as obtained benefits after the AMT application. Before the analysis the validation test Cronbach's Alpha was applied, in which it is recommended a value higher than 0.8; also, the impacts of the benefits or items were analyzed if they were eliminated from the questionnaire (Nunnally and Bernstein, 2005; Cronbach, 1951). With the validated questionnaire, it was done a descriptive analysis of the problems and the median was obtained, because the data was ordinal, also were obtained the 25 and 75 percentiles, this allowed to obtain the inter-quartile range as a position measure and data dispersion (Denneberg and Grabisch, 2004; Pollandt and Wille, 2005; Tastle and Wierman, 2007).

With the objective to determine the feasibility of a factorial analysis, the correlation matrix was obtained, observing that the most of the correlations were higher than 0.3; also, the anti-image correlations were analyzed. The KMO (Kaiser, Meyer, Olkin) index was calculated; since it is recommended an index higher than 0.75, the Bartlett Sphericity test was applied to measure the sample adequacy; the commonality was analyzed for every one of the attributes (Nunnally, 1978; Nunnally and Bernstein, 2005; Tung and Lee, 2010; Lee and Lee, 2011).

A factorial analysis was applied to determine the factors by means of the principal component analysis method using the correlation matrix for the extraction of the components. The important factors were those with an upper or equal value to one or half of their eigenvalues, conditioning the search to 100 iterations for the convergence of the result (Streiner and Norman, 1995; Boivin and Serena, 2006; Chen and Lin, 2008). Besides, with the objective of a better interpretation of critical factors, it was made a factor rotation by the varimax method (Levy and Varela, 2003). The activities that integrate the factors were identified by the highest value that the factorial charges contained, which is a correlation measure with the factorial axis (Nunnally and Bernstein, 2005; Torkzadeh et al., 2005).

RESULTS

The results section is divided into several sub-sections, according to the information presented.

Table 2. Questionnaire validation.

Parameter	Planned benefit		Obtained benefit	
Cronbach's Alpha	0.963		0.968	
Two halves test	First half	0.931	First half	0.937
	Second half	0.947	Second half	0.957

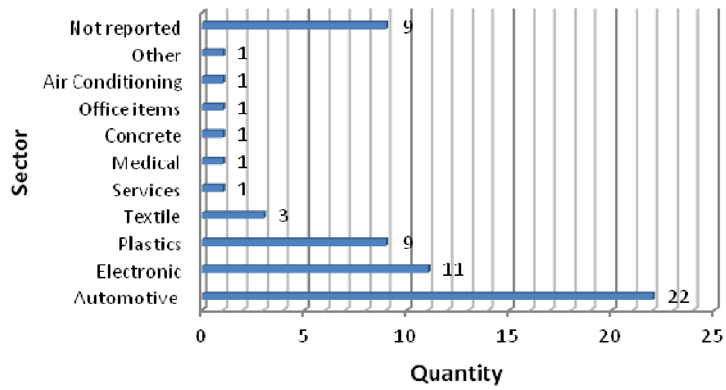

Figure 1. Sectors surveyed.

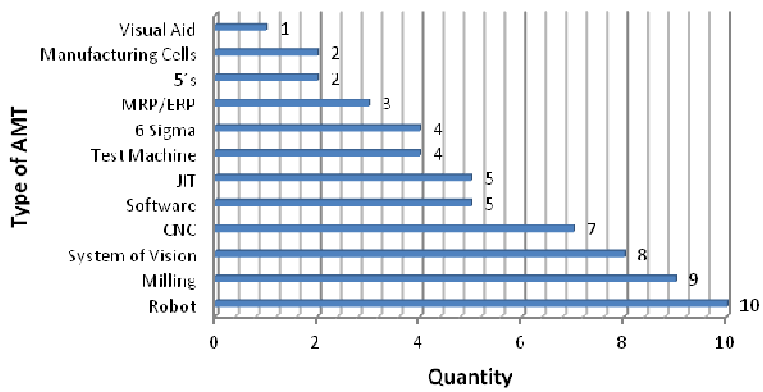

Figure 2. AMT recently acquired.

Questionnaire validation

For the validation of the questionnaire, that is, to determine if they obtained information can be considered as valid, the results of the analysis are shown in the Table 2. As can be seen, the obtained values are higher than 0.8 of the inferior limit, concluding that the questionnaire was adequate to obtain information; thus, it was valid and can be applied for the analysis.

Sample composition

A total of 60 surveys of different companies were received. The sectors of the plants are illustrated in Figure 1, where clearly can be seen that the automotive sector was the most polled, with 22 elements; followed by the electronic and plastic sector with 11 and 9 surveys respectively. The other sectors were from building materials, medical, among others; however, 9 of those did not report the sector.

Regarding technologies recently acquired, the enterprises declared that the robots integration to the production systems was the most frequent investment, with 10 cases; in the same way, milling machines, vision systems and generic equipment CNC, had 9, 8, and 7 answers respectively. The systems in which less investment was reported are soft ones such as the systems 5'S, manufacturing cells, and visual aids. Figure 2 illustrated the details of the AMT that have been acquired recently.

Table 3. Descriptive analysis: expected benefits.

Benefit	Median	Percentiles		IR
		25	75	
Larger market coverage	3.308	2.517	3.974	1.457
Maintain level of competitiveness	3.273	2.389	4.068	1.679**
Time reduction between the order reception and delivery time	3.27	2.429	3.973	1.544
Higher product quality	3.256	2.438	3.974	1.537
Higher plant capability	3.231	2.339	3.936	1.597
Fast response to the customer's needs	3.22	2.469	3.854	1.385*
Higher feasibility	3.205	2.412	3.923	1.511
Higher Sales	3.194	2.308	3.968	1.66
Better managerial experience	3.179	2.394	3.872	1.478
Reduction of delivery time	3.15	2.412	3.8	1.388*
Early introduction to the market	3.118	2.344	3.853	1.509
Reduction of adjustments time (system and AMT)	3.105	2.329	3.829	1.5
Reduction of reprocessing time and waste-scrap	3.098	2.347	3.768	1.421*
Improved plant utilization	3.079	2.265	3.816	1.551
Better engineering administration	3	2.172	3.855	1.683**
Reduction in the production lot size	3	1.975	3.809	1.834**
Machinery flexibility	2.974	2.25	3.697	1.447
Reduction in the process time	2.973	2.216	3.711	1.494
Enhancement of flexibility	2.973	2.23	3.697	1.468
Better organization for production operations	2.972	2.194	3.844	1.649
Higher labor productivity	2.971	2.214	3.708	1.494
Process flexibility	2.946	2.203	3.708	1.506
Volume flexibility	2.943	2.157	3.729	1.571
Improve the inventory rotation	2.939	2.136	3.721	1.584
Design quality	2.893	2.054	3.732	1.679**
Reduction of manual material handling	2.889	2.139	3.657	1.518
Reduction of variety of products and parts	2.886	2.129	3.662	1.533
Reduction of the production cost	2.868	2.145	3.625	1.48
Reduction of part variety	2.838	2.108	3.618	1.51
Reduction of the cost of labor	2.829	2.057	3.724	1.667
Effective use of space-floor	2.825	2.125	3.636	1.511
Time reduction from the concept to production	2.824	2.132	3.603	1.471
Reduction of the number of machines	2.811	2.068	3.603	1.535
Reduction of the design time lapse	2.806	2.048	3.7	1.652

A detail that is important to mention is that from the 60 answered surveys, 14 were answered by women and 46 by men, this is important to mention because it indicates that from day to day women are occupying high level administrative positions in the Juarez industry. Besides, 11 enterprises had a number of workers in the range 50 to 250, 46 were larger with 250 plus, and three did not report the size, with this information can be deducted that the polled enterprises were at least median.

Descriptive analysis: Expected benefits

Table 3 presents a descriptive analysis of the expected benefits by means of investments on any type of AMT. The most expected benefit is to enhance the market coverage, which is related closely to the second benefit, this one associated to the level of competitiveness related to a quick customer response, through the reduction of the time lapse between the arrival of a production order and the delivery time.

Here, it is important to mention that, the less expected benefits are associated with the reduction of number of machines that operate in a system or production line, the time reduction of the design and the reduction of the levels of inventory in process; commonly known as work in process (WIP). However, when the inter-quartile ranges are analyzed to determine the consensus of the polled in relation to a benefit real value, it is observed that a faster response to the consumer is achieved; as a result, there

Table 4. Descriptive analysis: Obtained benefits.

Benefits	Median	Quartile 25	Quartile 75	IR
Reprocessing and waste reduction	4.348	3.589	4.946	1.356*
Maintain the competitiveness level	4.326	3.558	4.919	1.361*
Better engineering experience	4.317	3.458	4.951	1.493
Increase of the product quality	4.298	3.534	4.883	1.348*
Reliability increases	4.244	3.468	4.856	1.388
Volume flexibility	4.186	3.304	4.826	1.522
Reduction between the conceptualization and the manufacture of the product	4.179	3.411	4.782	1.371*
Faster response to the consumer needs	4.15	3.371	4.788	1.417
Time reduction between the client’s order and delivery time	4.15	3.286	4.8	1.514
Increase of the plant capability	4.125	3.167	4.813	1.646
Better design quality	4.108	3.31	4.757	1.446
Better organization for production operations	4.077	3.155	4.782	1.627
Enhance process flexibility	4.071	3.279	4.726	1.447
Reduction of the design time	4.056	3.29	4.722	1.432
Increase market share	4.051	3.25	4.718	1.468
Increase of overall flexibility	4.051	3.177	4.756	1.579
Increase of the labor productivity	4.05	3.25	4.7	1.45
Reduction in processing time	4.049	3.227	4.72	1.492
Improve the utilization of the plant	4.026	3.069	4.744	1.675
Better administration experience	4.025	3.227	4.688	1.46
Sales increases	4	3.04	4.727	1.687
Time reduction of adjustments (system and AMT)	3.969	3.125	4.684	1.559
Reduction in delivery times	3.941	3.176	4.649	1.472
Reduction in material handling	3.914	3.143	4.615	1.473
Reduction in the production cost	3.868	3.158	4.579	1.421
Faster and earlier entrance to market	3.867	3.033	4.636	1.603
Better use of the space	3.862	2.842	4.686	1.844**
Reduction in the variety of parts and products	3.844	3.016	4.614	1.599
Reduction in the variety of parts	3.833	2.818	4.611	1.793**
Machinery flexibility	3.824	3.015	4.632	1.618
Reduction of the production lot size	3.793	2.765	4.656	1.892**
Improve inventory rotation	3.788	2.969	4.591	1.622
Reduction of work in process invesntories	3.78	3.11	4.487	1.377*
Reduction in the machinery	3.759	2.667	4.606	1.939**
Reduction of the cost of the workforce	3.649	2.9	4.433	1.533

is a reduction in delivery times, reprocess, and scrap. These values are indicated with an asterisk (*) in Table 3. The highest values of the interquartile range –IR- are those where there is no generalized consensus about the value that the benefit must have. The items are: Reduction in the lot size, better engineering experience, issues that help to maintain to the competitiveness level. These high values are illustrated with double asterisks (**) in Table 3.

Descriptive analysis: Obtained benefits

Table 4 presents the descriptive analysis of the benefits given by AMT; they are ordered in a descendent way in function of the median. Clearly, it is observed that the most mentioned benefits are the ones related to the reduction of reprocessing and scrap-waste; also, it can be observed that AMT helps to sustain the competitiveness level in the environment of the enterprise. Additionally, a better experience of engineering is achieved and the quality of the product is increased, which is reflected in a reliability enhancement. On the other hand, the benefits that were less obtained are the ones related with the reduction of the workforce cost, the reduction number of machinery for the production process, the reduction of the WIP, and the diminishment of the inventory rotation.

Regarding the attributes with a lower value in the

Table 5. Factorial analysis: Expected benefits.

Benefit	FC	Factor
Reduction in the number of machinery	0.816	
Reduction in the production lot size	0.781	
Reduction of the variety of products and parts	0.771	Techniques and operative aspects 16.16%
Reduction in the variety of parts	0.706	
Improvement in the inventory rotation	0.694	
Market share increase	0.819	
Faster responses to the consumer needs	0.785	
Reduction of delivery times	0.772	
Reduction between the time of order reception and delivery time	0.772	Marketing aspects 16.01%
Increase of sales	0.753	
An earlier entrance to the market was achieved	0.745	
Maintain the competitiveness level	0.613	
Reduction of time of adjustment (system and AMT)	0.793	
Reduction of reprocessing and waste	0.65	Waste reduction (time and material) 16.16%
Better organization of production	0.648	
Better experience of engineering	0.749	
Better administration experience	0.671	
Increase of labor productivity	0.643	Quality and knowledge management 10.80%
Enhancement of reliability	0.626	
Increase of the quality of the products	0.608	
Quality in design	0.864	
Reduction of time design	0.808	Design aspects 9.27%
Reduction between conceptualization and manufacture of the product	0.688	
Improve the plant utilization	0.708	Space usage 7.36%
Increase of the plant capability	0.688	
Reduction of WIP	0.627	Inventory 3.35%

inter-quartile range; as a result, those with great consensus in relation to the real value; having values close to the median, such as the reduction of work in process, reduction of the time between conceptualization and manufacture of the product, sustain competitiveness level, reduction of reprocessing and scrap and increase of the product quality. It is important to mention that with exception of the benefit of obtaining a better engineering experience, the first four attributes with a lower inter-quartile range also have the largest median. Therefore, it can be concluded that these attributes are really important; in Table 4 are designated with a simple asterisk (*).

Regarding the benefits with not much consensus, therefore with an unclear value or importance, they have the highest values of the IR, among them, the reduction in machinery, reduction of the production lot size, a better use of the used space, and a reduction in the variety of parts. These values are indicated with a double asterisk (**) in Table 4.

Factorial analysis: Expected benefits

In the feasibility analysis of the factorial analysis was obtained a KMO of 0.777 indicating an acceptable sample adequacy. The Bartlett's Sphericity Test gave a chi-square value of 1081.37 with 595° of freedom, indicating a significance of 0.00, concluding that the factorial analysis can be applied. Only seven factors explain the 74.43% of the total variance contained in the data. The results of the factorial analysis are illustrated in Table 5.

Factorial analysis: Obtained benefits

In the feasibility analysis of the factorial analysis was obtained a KMO of 0.784, which indicates an acceptable value of the measure of sample adequacy. Besides, it was realized the Bartlett's Sphericity test and it was obtained a chi value of 1178.75 with 595° of freedom,

Table 6. Factorial analysis: Obtained benefits.

Benefit	FC	Name
Reduction of the variety of parts	0.787	Technical and operative aspects 17.99%
Reduction of the variety of products and parts	0.728	
Improve the inventory rotation	0.704	
Reduction of the material handling	0.693	
Reduction of the production lot size	0.651	
Reduction of the number of machinery	0.631	
Process flexibility	0.776	Flexibility 15.64%
Machinery flexibility	0.729	
Reduction of the reprocess and waste	0.721	
Reduction of the WIP	0.697	
Volume flexibility	0.679	
Fast responses to the consumer needs	0.837	Marketing aspects 12.08%
Reduction of delivery times	0.729	
Time reduction between the order reception and the delivery time	0.726	
Cost reduction of workforce	0.799	Cost and time reduction 7.54%
Reduction of the processing time	0.754	
Reduction of the cost of production	0.726	
Reduction of the design time	0.828	Design aspects 7.48%
Design quality	0.751	
Time reduction between conceptualization and manufacture of the product	0.654	
Reliability increment	0.782	Quality 6.23%
Increment in the quality of the product	0.759	

which indicates a significance of 0.00. As a result, it was concluded that the factorial analysis could be applied. It was found that only six factors explain the 75.81% of all the variance that was found in the data. The result of the factorial analysis is illustrated in Table 6, where it indicated the name of the benefit, the factorial charge that the benefit has related to the factor that is associated, the name of the possible factor, and the quantity of variance that is explained by it.

Conclusions

After the analysis of 60 enterprises of several industrial sectors of Juarez, Chih, it was concluded that unquestionably, the enterprises that invest in AMT have a better market share, because they sustain the level of competitiveness, have advantages because of better time to market, increase their products quality and overall production capacity. These results coincide with the findings reported by other researchers.

In relation to the multivariable analysis, AMT improves soft production technologies and technical aspects of production operations, improves the marketing measures, reduces wastes (such as time, and material through the process), improves quality, and enhances the effectiveness of knowledge management and the use and operation of these technologies, increases the efficiency of design and the use of occupied space, also improves the handling of inventory.

In the same way, enterprises that had investments in AMT, in the univariable analysis have obtained a reduction of the reprocessing operations and waste, helping to maintain competitiveness level, have achieved a better engineering experience, improved products quality and their reliability; finally, flexibility for better response to production volume changes.

Related to the multivariable analysis, were observed improvements in the techniques and operative aspects of the production system, increments in the operative flexibility, a series of benefits of the marketing type, reduction of the cost and time in the production process, improvements in design of parts and products, and finally, a significant improvement of overall quality levels.

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