A framework for evaluating and selecting Technologies appropriate for mass customisation

Partson Dube
Mechanical Engineering and Industrial Engineering Technology
University of Johannesburg
Johannesburg, 2006, SA
partsond@uj.ac.za

Charles Mbohwa
Quality and Operations Management
University of Johannesburg
Johannesburg, 2006, SA
cmbohwa@uj.ac.za

Abstract

The current research seeks to develop a framework for selecting and evaluating the appropriate Technology for Mass Customisation (MC). A Technology evaluation criterion was proposed. The criteria assigns a high weighting to factors that leads to MC capability. The proposed selection criteria of Technology is objective and reduce any subjectivity. The benefits of Technology and the objectives of MC were identified in the literature review. Under the guidance of the firm's technical staff, a thorough analysis of the benefits of Technology on MC was done. The research was conducted at a Metal Casting Company in South Africa. Metal Casting industry produces a high variety of products, which are highly customised, which requires extensive investment in Technology to increase flexibility and responsiveness. Selection of Advanced Technology is a subjective process influenced by human preferences, the proposed selection procedure is objective and it factors in the MC objectives. This research has managed to come up with a Technology selection criteria for MC; this research will alert the stakeholders in the metal casting industry about importance of Technology in the success of MC and encourage objective investment in Technology.

Keywords
Technology, Mass Customisation, Metal Casting, South Africa,

1. Introduction

Customers for metal casting industry demand diversified and complex products which cannot be met with a mass production system but instead with a mass customisation system. (Pine, 1993) coined MC as; "providing tremendous variety and individual customization, at prices comparable to standard goods and services...with enough variety and customization that nearly everyone gets exactly what they want". From a manufacturing point of view Mass Customisation is; "the ability to provide individually designed products and services to customers through high-process flexibility and integration" (Fogliatto *et al, 2012).* This definition best suits the metal casting manufacturing environment that seeks to provide customers with "net-shaped" products according to customer specifications. Metal casting requires a highly responsive manufacturing system, flexible enough to produce a variety of products.

Manufacturers should invest in advanced technology, information technology and skilled work force to achieve MC (Salvador et al, 2015). Investment in AMT and information technology also requires a manpower which is technologically skilled, AMT, Information technology with technological skills are important enablers of mass customisation (Fogliatto et al, 2012). Knowledge or specification from the external environment is transmitted into the firm via the information system and this enhances competitiveness (Garcia-Morales et al, 2014)

This research was carried out in a metal casting (sand casting) firm, this company casts a variety of customer specified products, and nearly 100 percent of manufactured machine components in the industry are castings. The company is situated in Johannesburg the industrial hub of South Africa. The case company produces a variety of products for the following industry; mining industry, power generation, chemical and fluid transport, smelters, railway, automotive equipment for sugar mills, brick and cement. There is a wide range of products which requires a highly responsive and flexible manufacturing system. According to American Foundrymen's Society; "Technology advancement plays an important role in lowering production costs, improving energy efficiency, enhancing environmental quality, and creating innovative new cast products". According to American Foundrymen's Society; "Traditionally, metal casters are not always able to respond quickly to changes in the customer's design (and vice versa)". This research seeks to identify the different types of technologies employed by the firm and furthermore assess how these technologies can be aligned to mass customisation objectives. The main objective of this study is to develop a framework that can be used by investors in selecting Technology for mass customisation without any human subjectivity. "Technology advancement plays an important role in lowering production costs, improving energy efficiency, enhancing environmental quality, and creating innovative new cast products".

Literature review on advanced manufacturing and mass customisation in Section 2, methodology in Section 3 and results and findings in Section 4 and conclusion and recommendations in Section 5.

2. Literature Review

2.1 Mass Customisation

The mass production paradigm was best suited for a homogenous market were the needs of the customers were uniform, but in in this day and age the world has become a global village, competition in the marketplace has increased, customers have more choice and more power (Blecker et al, 2005). "The mass production paradigm no longer present a successful solution" (Blecker et al, 2005). Diversified products is not the answer to the challenge that the manufacturers are facing today but customers now require personalized products (Blecker et al, 2005). Mass customization is manufacturing products according to the customer's specification (Pine et al,1999). Customers they pay for what they want "Customers do not want choice; they want exactly what they want" (Pine et al,1999). Diversification is not equal to mass customization. Mass customization has grown in use due to heterogeneous demand of customers especially in the casting industry, the demand of customers is diversified Flavio et al[5]. According to Porter 1998 value is offering a product to the marketplace at price lower than similar products in the marketplace. Mass customization is a hybrid strategy (craft and mass production) which offers variety and personalization through flexibility and quick responsiveness at lower price to the customers.

According to [9] implementation of Mass customization will improve the economies of scope, through product modularization, providing tremendous variety, at prices comparable to standard goods and services. In

modularization permutation and combination of different parts resulting in a variety of products and this leads to mass customization because customers are able to make a choice of modules from an assortment of modules. (Pine, 1993) emphasised the importance of responsiveness and flexibility in his definition: 'developing variety and customization through flexibility and quick responsiveness'. From this definition, it quite clear that AMT is an integral element of MC. Successful AMT implementation leads to business performance improvements and achievement of MC targeted objectives.

2.2 Advanced Manufacturing Technology

The ability to fulfil the customer order on time depends on a lot of factors, this ability is enhanced by the use of advanced technology in manufacturing. Advanced Technology provides the following capabilities; product design according to customer specifications, rapid prototyping (RP), computer aided process planning, monitoring the process and production. The latest Technologies that are used in metal casting industry are; Computer aided manufacturing/Computer aided designing, RP, computer simulation of the solidification processes. These ATM enhance the quick development of casting design components and process and improves the repeatability of the process. The use of ATMs will reduce the lead-time of manufacturing a casting. Computer simulation reduces the cost of experimental runs.

According to American Foundry men's Society "Modern ATMs are increasing the ability to monitor, control the production processes. The use of sensors, process automation, process control computers have enhanced the flexibility of the foundry operations."

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According to (Kotler, 1989) application of MC will increase the variety of products, at prices equal to mass produced products. In modularization permutation and combination of different parts resulting in a variety of products and this leads to mass customization because customers are able to make a choice of modules from an assortment of modules. (Pine, 1993) stressed the significance of" responsiveness and flexibility in his definition: 'developing variety and customization through flexibility and quick responsiveness". From this definition, it quite clear that AMT is an integral element of MC. Successful AMT implementation leads to business performance improvements and achievement of MC targeted objectives.

AMT is a term that encompass all technologies which "primarily utilize computers to control, track or monitor manufacturing activities (Boyer et al, 1997) "Advanced manufacturing technologies like flexible manufacturing systems (FMS), computer aided design (CAD), computer aided manufacturing (CAM), robotics, Computer numerically controlled machines (CNC), Electronic data interchange (EDI), all involve computers to monitor and store etc.,." (Boyer et al, 1997), are more likely to improve mass customization due to improved responsiveness and flexibility.

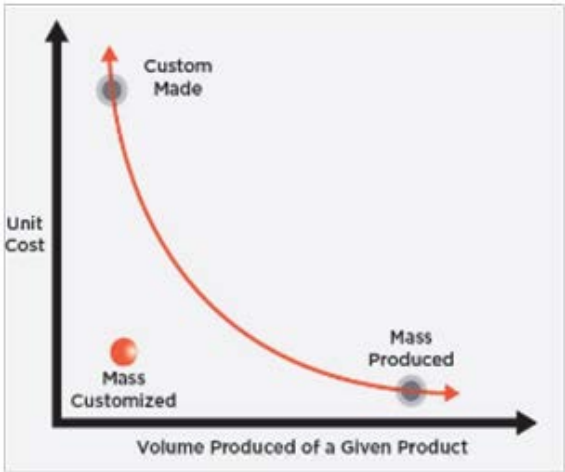

Figure 2.

Advanced manufacturing systems are flexible enough to produce an assortment of products. According to the diagram in Figure 2, low responsiveness results in very high level of customization, for example the craft industry, responsiveness is very low yet the level of customisation is very high resulting in high cost of products. High responsiveness results in a mass production environment, low level of customization. The main challenge to the manufacturer is to have high responsiveness and high customisation level. This challenge can best be addressed with a flexible manufacturing system.

AMT offers the following benefits; "greater flexibility; reduced lead times; reduced inventories; increased productivity; improved customer service; improved quality; improved communication with suppliers; better product design; better manufacturing control; supported integration; reduced costs; reduction of machine tools; and competitiveness" (Al-Ahmari, 2002).

3. Methodology

The research was conducted at a metal casting firm. A quantitative approach was employed. Using a questionnaire the research gathered the opinions of the engineers, metallurgist, chemists, sales and purchasing staff on the impact of Technology to mass customisation. The coded benefits of AMT are listed in Table 1 from the literature review:

Table 1. AMT Benefits

BAMT1	Reduced time to generate price quote and prototype
BAMT2	Shorter and more reliable overall lead times
BAMT3	New product development capability
BAMT4	Improved product quality and quality assurance
BAMT5	Creates technical standards for machine tools and components
BAMT6	Reduced defects
BAMT7	Reduced space and facility occupation by reduced inventory
BAMT8	Reduced stock outs
BAMT9	Better supervision utilisation through less routine

ATMs in the firm were identified and recorded in Table 5. Through consultation with experts in the firm, mass customisation objectives were aligned with AMT benefits using the interaction matrix in Table 3. A high score of the weight indicates an extreme level of importance of the AMT benefit to mass customisation.

The w-weight of the AMT benefit, was derived from the mean of the participants ratings (Staff opinion on AMTs), a 7-point scale, ranging from "strongly disagree" (1) to 7"strongly agree" was used (see Table. 3). Participants were

requested to rate the level of importance of each AMT objective criterion on a scale of 1 (not important) to 7(extremely important), mean and the standard deviation entry by the participants is shown in Table. 3. All the data collected were analysed and conclusion and recommendations were made based on the actual outcome compared to theoretical data.

Coded benefits of mass customisation from literature review are listed in Table. 2.

Table 2. MC Objectives

MCC1	Low overhead and bureaucracy
MCC2	Optimum quality
MCC3	Elimination of waste
MCC4	Continual process improvement
MCC5	Low inventory carrying costs
MCC6	High Labour productivity
MCC7	Integration of thinking and doing
MCC8	High utilization of and investment in worker kills
MCC9	Sense of community
MCC10	Low total cots
MCC11	High production flexibility
MCC12	Greater variety at lower costs

4. Findings and Results

The case firm produces a variety of Iron and Steel castings for different industries; Mining Equipment, Power Generation, Chemical/Fluid Transport, Brick/Cement/Sugar Mill Equipment, Smelters, Transport: Automotive/Railway/Mining Equipment and General Engineering components. Technology used in the following categories was done: 1. Company interaction with the customers, 2. Pattern and product design, 3. Enterprise Resource Planning (ERP-SAP), 4. Quality checks, 5. Foundry Testing Equipment 6. CNC Machines

1. Company interaction with the customers

A customer can send the drawings and specification via e mail and fax. The company have a website where it advertise its business. The company uses a rapid prototyping system, a 3D is used to print a plastic prototype of a CAD generated diagram.

2. Pattern and product design

The drafts-man uses a CAD/CAM system to develop part drawing and process planning. Drawings are stored and modified according to customer's specifications resulting in improved flexibility. A CNC machine produce the wooden patterns.

3. Enterprise Resource Planning (ERP-SAP)

An enterprise resource planning software (SAP) is used to manage production, financial, sales, warehouse department and human resource department

4. Quality checks

Material Testing Equipment

A computerised Universal Testing Machines are used to check compression, tensile, transverse test of metals and their alloys.

5. Foundry Testing Equipment

A Universal strength machine is used to test various strength for moulding and core sands, it is interfaced to the computer, can conduct tests for compression, tensile, shear and splitting strength.

Metallurgical Equipment

Computer interfaced metallurgical microscope is used to analyse the specimens using an image software analyser.
6. CNC Machines
A CNC machine machines wooden and plastic patterns.

In Table. 3, the advanced technology benefits are compared to determine their levels of importance, the level of importance for ATM is given as 'w-weight'. The 'w- weight' is the mean of the AMT Cost Benefit scores entered by the participants. The mean w shows the level of importance of each benefit to cost reduction, the higher the value the higher the importance. Participants perceive BAMT3, BAMT4, BAMT5 and BAMT6 as important factors to cost reduction and MC. The standard deviation is significantly high in BAMT2, BAMT8 and BAMT9 showing a divergent view of these benefits. All Participants almost agree that investing in AMTs will reduce defects (BAMT6) and improved product quality (BAMT4) proved by a low SD value.

Table 3. AMT Cost-Benefit Perceptions (Staff Opinion)

		SD	Mean
BAMT1	Reduced time to generate price quote and prototype	0,690066	5,14
BAMT2	Shorter and more reliable overall lead times	1,112697	5,71
BAMT3	New product development capability	0,534522	6,57
BAMT4	Improved product quality and quality assurance	0,48795	6,71
BAMT5	Creates technical standards for machine tools and components	0,816497	6,00
BAMT6	Reduced defects	0,377964	6,86
BAMT7	Reduced space and facility accupation by reduced inventory	0,690066	5,86
BAMT8	Reduced stock outs	1,112697	4,29
BAMT9	Better supervision utilisation through less routine	1,345185	5,86

Different ATM benefits may have different impacts to mass customisation capacity in different industries, some are more important than others are. The level of AMT Cost Benefit significance with respect to mass customisation benefit is determined by the Interaction Matrix (Table 4.) The following objectives are significantly addressed by investing in Technology; MCC2, MCC3, MCC5, MCC6, MCC10 MCC11 and MCC12, this means that the Technology is a very important aspect to Mass Customisation.

Table. 3. Interaction Matrix

Mass Customisation Success Factors

Benefits of AMT	MCC1	MCC2	MCC3	MCC4	MCC5	MCC6	MCC7	MCC8	MCC9	MCC10	MCC11	MCC12	Weight-w
BAMT1	0	0	1	0	0	0	0	0		1	1	1	5,142857
BAMT2	0	0	1	1	1	1	0	1	0	1	1	1	5,714286
BAMT3	0	1	0	1	0	0	1	1	0	0	1	1	6,571429
BAMT4	0	1	1	1	1	1	0	1	0	1	0	0	6,714286
BAMT5	0	1	1	0	1	1	0	1	0	0	1	1	6
BAMT6	0	1	1	1	1	1	0	0	0	1	0	1	6,857143
BAMT7	1	0	1	0	1	0	0	0	0	1	1	0	5,857143
BAMT8	0	0	1	0	1	0	0	0	0	0	1	0	4,285714
BAMT9	0	1	1	0	1	1	0	1	1	1	1	0	5,857143
Weight - W	5,9	32,0	46,4	25,9	41,3	31,1	6,6	30,9	5,9	36,1	39,4	30,3	

Table. 3. Interaction Matrix

Benefits of AMT	Mass Customisation Success Factors												
	MCC1	**MCC2**	**MCC3**	**MCC4**	**MCC5**	**MCC6**	**MCC7**	**MCC8**	**MCC9**	**MCC10**	**MCC11**	**MCC12**	**Weight-w**
BAMT1	0	0	1	0	0	0	0	0		1	1	1	5,142857
BAMT2	0	0	1	1	1	1	0	1	0	1	1	1	5,714286
BAMT3	0	1	0	1	0	0	1	1	0	0	1	1	6,571429
BAMT4	0	1	1	1	1	1	0	1	0	1	0	0	6,714286
BAMT5	0	1	1	0	1	1	0	1	0	0	1	1	6
BAMT6	0	1	1	1	1	1	0	0	0	1	0	1	6,857143
BAMT7	1	0	1	0	1	0	0	0	0	1	1	0	5,857143
BAMT8	0	0	1	0	1	0	0	0	0	0	1	0	4,285714
BAMT9	0	1	1	0	1	1	0	1	1	1	1	0	5,857143
Weight - W	5,9	32,0	46,4	25,9	41,3	31,1	6,6	30,9	5,9	36,1	39,4	30,3	

The benefits of AMTs in the firm with respect to MC are shown in Table 5. First of all, the contribution of the AMT is established, if the AMT has no contribution to the MC objective, a '0' is assigned, otherwise '1', for example CNC machines does not fulfil objective MCC1, a '0' is assigned, it fulfils objective MCC2 therefore '1' is assigned. The final score (W) is the sum all the weights, for example CNC Machines have a score of 320. The higher the score, the more important is the benefit to mass customization. Investment in CNC Machine, Rapid Prototyping CAD/CAM offers high benefits to mass customisation.

Table 5. AMTs contributions to MC

	MCC 1	**MCC 2**	**MCC 3**	**MCC 4**	**MCC 5**	**MCC 6**	**MCC 7**	**MCC 8**	**MCC 9**	**MCC 10**	**MCC 11**	**MCC 12**	Total- W per AMT
Weight - W	5,857	32	46,43	25,86	41,29	31,14	6,571	30,86	5,857	36,14	39,43	30,29	
CNC Machines	0	1	1	1	1	1	1	1	0	1	1	1	320,011
ERP	1	0	0	0	0	0	0	0	1	1	1	0	87,284
Rapid Prototyping	0	1	0	1	0	1	1	1	0	1	1	1	232,291
CAD/CAM	0	1	1	1	1	1	1	1	0	1	1	1	320,011
Internet	1	0	0	0	0	0	0	0	1	1	0	0	47,854
metallurgical microscope	0	1	1	1	0	0	1	1	0	1	0	0	177,861
Material Testing Equipment	0	1	1	1	0	0	1	1	0	1	0	0	177,861
Foundry Testing Equipment	0	1	1	1	0	0	1	1	0	1	0	0	177,861

5. Findings and Results

The results show that ATMs in the factory have more impact to Mass Customisation, there are high score for CNC machines and the CAD/CAM, flexibility in the factory is more important to MC. The company has islands of technology that needs to be integrated to form a responsive system with reduced transfer lead times. This research has contributed by introducing a method of selecting Advanced Manufacturing Technology based on Mass Customisation benefits. Future research must focus on quantitative methodology, in order to generalise the findings of this research in the metal casting industry.

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Biographies

Partson Dube is currently a lecturer in the Department of Industrial Engineering at the University of Johannesburg. Mr. Dube holds a Bachelor of Engineering degree in Industrial Engineering from the National University of Science and Technology (Zimbabwe) and a Master of Engineering in Industrial Engineering. He has taught courses in production engineering, operations research, information systems and project engineering. Mr. Dube served is a member of the South African Institute of Industrial Engineering.

Charles Mbohwa is an Associate Professor, and Director of Master of Engineering in Manufacturing Systems and Master of Science in Industrial Engineering in the A. Professor Charles Mbohwa is a Professor in the Faculty of Engineering and the Built Environment. He is currently Acting Executive Dean, Faculty of Engineering and the Built Environment at the University of Johannesburg and is an established researcher and professor in the field of sustainability engineering and energy. Upon graduating with his BSc Honours in Mechanical Engineering from the University of Zimbabwe in 1986, he was employed as a mechanical engineer by the National Railways of Zimbabwe. He holds a Masters in Operations Management and Manufacturing Systems from University of Nottingham and completed his doctoral studies at Tokyo Metropolitan Institute of Technology in Japan. He was a Fulbright Scholar visiting the Supply Chain and Logistics Institute at the School of Industrial and Systems Engineering, Georgia Institute of Technology, a Japan Foundation Fellow, is a Fellow of the Zimbabwean Institution of Engineers and is a registered mechanical engineer with the Engineering Council of Zimbabwe. He has also visited many countries on research and training engagements including the United Kingdom, Japan, German, France, the USA, Brazil, Sweden, Ghana, Nigeria, Kenya, Tanzania, Malawi, Mauritius, Austria, the Netherlands, Uganda, Namibia and Australia. He has had several awards including British Council Scholarship, Japanese Foundation Fellowship, Kubota Foundation Fellowship; Fulbright Fellowship.
His research activities and interests are in sustainability engineering and Operations/Engineering Management.