

A study on the use of advanced manufacturing technologies by manufacturing firms in a small, geographically-isolated, developed economy: The case of Malta

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Abstract

During the last twenty years, many authors have investigated the use of advanced manufacturing technologies (AMT) in large, developed economies; and/or in newly industrialized states. In this work we complement these studies through a survey/interview-based investigation of the use of and attitude towards AMT in Malta, a developed nation that is small, insular and peripheral, but that has still succeeded in setting up a substantial and diverse manufacturing base. We focus specifically on production automation technologies, and address characteristics on the general attitude to and use of automation; perceived impediments to automation use; preferences pertaining to equipment procurement; uptake of and attitude towards reconfigurable automation systems; frequency and extent of production system changes; and related product design issues. We introduce the notion of real and virtual barriers to the use of manufacturing automation, pertaining to whether a barrier is genuine or whether it refers to a potentially mistaken perception, and show that companies having a positive attitude towards automation are more likely to focus on the real barriers. We find a unique blend of characteristics that can be compared to those found in large, fully developed economic regions on the one hand, and to the newly industrialized countries on the other hand. We posit that many of the findings reported in this work may be applicable to other similarly isolated and diverse manufacturing pockets in the developed world, and therefore offer new insight into the characteristics of, and into the difficulties faced by, manufacturing companies within such an environment.

Keywords: Advanced manufacturing technologies; Production economics; Production automation; Reconfigurable manufacturing systems; Empirical study

1. Introduction

1.1 Motivation and research questions

In order to remain competitive in today's global manufacturing environment, it is often essential for companies to maximize productivity using cutting edge production technologies and methodologies [1]. A number of forces have emerged in recent years that have changed the landscape of what is required for competitiveness. Firstly, manufacturing companies are faced with a highly increased demand for product variety in their production. Customers are

spoilt for choice, and tend to give their custom only to those manufacturers that are prepared to provide them with products that have been personalized to their specific demands – a situation that has led to the phenomenon of *mass customization* in production systems [2-3]. Secondly, the breaking down of barriers to trade and to the flow of information between different economies worldwide has meant that competition to a company can come from almost anywhere on the globe. If a company is not up to scratch on issues of productivity or quality, it is likely to lose out to myriad competitors who have easy access to its market [4]. Thirdly, the rate of advancement in the state of the art of production technologies has increased dramatically in recent years, fuelled by the ease with which research and development personnel worldwide can access background material and communicate with each other, by an increased awareness globally of the benefits of effective technology transfer, and by increased access to and use of high technology equipment development tools by the major industry players. This means that production equipment used by a company can quickly become obsolete.

The above problems may be exacerbated in economies that are small, and that are isolated from the major, highly developed industrial regions due to barriers of geography, finances and/or mentality. Typically, companies in such economies may suffer from reduced physical and/or financial access to suppliers and maintainers of advanced production equipment, reduced physical and/or financial access to major showcases of such technologies such as fairs and expositions, and reduced physical and/or financial access to the multi-disciplinary technical and training expertise that is required for the development and operation of *advanced manufacturing technologies* (AMT). Where there is a mentality barrier, companies may not even be aware of these problems of accessibility, and risk a slow and relentless (or sometimes very fast) death as their competitiveness erodes and they lose their previously established markets.

In this work, aspects of the use of AMT by manufacturing companies that are isolated geographically are investigated. Specifically, the research questions have been formulated as follows:

RQ1 – Do manufacturing companies that are relatively isolated geographically exhibit AMT usage patterns and attitudes that are different from those of non-isolated companies?

RQ2 – To what extent are such usage patterns and attitudes related to the size of the company, to the sub-sector in which it operates, and to whether company ownership is internal or external to the geographical isolation?

RQ3 – Do manufacturing companies that are relatively isolated geographically face problems related to the uptake of AMT that are different in their nature or extent to those faced by non-isolated companies?

RQ4 – Are all of the identified problems genuine, or could some of them be due to mistaken perceptions on the potential of AMT?

The investigation is carried out through an empirical study on the use of AMT in a small and relatively isolated economy, and on the real and perceived barriers to the implementation of these technologies. The results of the empirical study are discussed in the context of similar studies, available in the literature, that have been carried out on manufacturing companies that are located in non-isolated regions. The design, development and implementation of the knowledge gathering tool are described, and the results of the empirical study are analyzed and interpreted. The work is based on a sample of companies operating in the manufacturing sector of the island nation of Malta, taken as a case study for an economy of this type.

This work provides insight into the use of, and into barriers to the use of, AMT by manufacturing companies that are geographically relatively isolated. The identification, characterization, and eventual addressing of the barriers to AMT adoption in such regions can lead to an increase in the competitiveness of existing companies as well as facilitation of the emergence of new companies operating in sectors where AMT adoption is indicated for success. This work also adds to the body of knowledge that already exists on the use of AMT in different regions of the world, by contributing a study that is focussed on a very small, relatively isolated, and developed sovereign nation that is a part of a large, free trading block. The results of this study, although specific to the Maltese manufacturing environment, are expected to be relevant, to varying extents, to other pocket economies within the EU, as well as within the rest of the industrialized world. In addition to contributing useful new statistics to the existing literature, the results are intended to help guide individual company strategy, inter-company cooperative activity, and state policy and actions, in such regions.

This paper is organized as follows. Section 1.1 has served to introduce the general motivation and objectives of this work, as well as the specific research questions and the expected contribution of this work. In the remainder of section 1, the case study economy is described and characterized. A review of the relevant literature is given in section 2. The survey methodology is described in section 3. The survey results, together with general analyses of the full data sample, and connected discussion, are presented in section 4. Further analyses by company size, sub-sector and ownership are presented in section 5. In section 6 some further points for discussion are raised, and in particular the hypothesis of real versus virtual barriers to automation is explored. The concluding remarks and a summary of the general impact of this work are given in section 7.

1.2 The Manufacturing Industry in Malta

Malta is an independent island state located in the middle of the Mediterranean Sea, with a population of about 420,000 people. It is a member of the European Union (EU), and of the eurozone, and can therefore trade freely and relatively easily with all of the other states of the EU. The nation has a gross domestic product (GDP) of about €8.8 billion (2015 estimates) [5] (~ US\$ 9.7 billion, July 2016 rate of exchange), based on services, industry and tourism. The industrial sector in Malta comprises over 200 foreign owned companies and over 3000 locally owned manufacturing companies [6-7]. In 2012 these consisted of 13 *large* companies (with 250 or more employees: in Malta these companies typically have less than 1000 employees, with the exception of one company that has about 1500 employees and that is included in the present empirical study), 54 *medium-sized* companies (50-249 employees), 207 *small* companies (10-49 employees), and 3233 *micro* companies (less than 10 employees) [6]. The manufacturing sector in Malta typically accounts directly for about 11% of the national GDP (average for 2011-2015) [5], and has a diverse base that over the last two decades has seen a shift from low technology labour intensive manufacturing to high value added, knowledge intensive activities. The largest contributing sub-sectors (2010 data) are in the NACE (*General Industrial Classification of Economic Activities within the European Communities*) categories “Manufacture of electrical and optical equipment” (3.6% of GDP), “Other manufacturing” (mainly fuelled by furniture manufacture) (2.1%), “Manufacture of chemicals, chemical products and man-made fibres” (mainly fuelled by the manufacture of pharmaceuticals) (2.0%), and “Manufacture of food products, beverages and tobacco” (1.6%) [8]. The manufacture of rubber and plastic products is also substantial at 0.7% of the GDP.

In order to put these figures into perspective, the national GDP of Malta is of the same order of the GDP of a medium-sized European or North American city, such as Nottingham, UK, or Topeka, Kansas, US. The Maltese GDP per capita is about three quarters of that of Northern European countries or of North America, and Malta is generally included among the developed countries (e.g. [9]), in view of its well developed and modern infrastructures (e.g. legal, financial, communications). In line with other developed states (e.g. [10]), the share of the manufacturing sector to the nation’s GDP has been falling consistently in recent years as it is overtaken by superior growth in the services sectors. Notwithstanding its listing as a developed country, it is noted that the relative geographical isolation of Malta, its relatively recent entry into the EU (in 2004), and, particularly in the case of the locally-owned companies, an industrial sector that until about twelve years ago was still relatively protected from international competition, as well as possibly a residual insular mentality consequential to these factors, have meant that this small economy may still face some challenges in bringing its manufacturing base to a technological level that is comparable to that of its foreign competitors.

2. Literature Review

2.1 Impact and Formal Definition of AMT

The “*productivity paradox*” [11] describes a situation that emerged in the USA in the mid-1980s whereby manufacturing firms continued to lose their competitiveness despite continued efforts to reduce costs. It has since become generally accepted that there are four major competitiveness factors in modern manufacturing: *cost, time, variety* and *quality* (e.g., [12]), and that in order to be effective, a drive to improve competitiveness must address all four of these factors simultaneously, and can be realized through the effective adoption of AMT [13]. Indeed, various studies have shown that as long as AMT are used correctly, with adequate co-investment in implementation effort and in system integration where required, the adoption of AMT does in fact lead to improved manufacturing performance [14-17]. Other drivers for the use of AMT include, among others, the need to rapidly reconfigure manufacturing capability, and the need to minimize environmental damage [18].

AMT have been defined and sub-categorized in various ways, and a summary of some of the common typologies can be found in [19]. In particular, AMT have been classified into (i) *stand-alone systems* (e.g. computer-aided design – CAD, and computer-aided engineering – CAE systems); (ii) *intermediate systems* (e.g. computer numerically controlled machines – CNC, automated material handling systems – AMHS, automated storage and retrieval systems – AS/RS, and automated inspection systems – AIS); and (iii) *integrated systems*, sub-divided into *integrated process technologies* (e.g. computer-integrated manufacturing – CIM, and flexible manufacturing systems – FMS), and *integrated/logistic technologies* (e.g. just-in-time production – JIT, and manufacturing resource planning – MRP II) [20]. In the present study we focus mainly on CAD and on process automation, and are primarily concerned with intermediate-type systems and, if present, with integrated process technologies.

2.2 Adoption of AMT in Developed, and/or in Newly-industrialized Regions

The analysis of data, taken in the late 1990s, pertaining to over 2000 companies located across Canada shows that a significant proportion (of the order of one half) of manufacturing plants in this country were utilizing some form of process automation [21]. An analysis of the responses by company size showed that the larger the company, the greater is the likelihood of adopting automation. Other studies have confirmed this trend (e.g. [22]). An analysis by sub-sector in the Canadian study showed that the greatest uptake of process automation was in the automotive, electronics, and plastics industries. Preliminary analysis of a more recent survey has indicated that the percentage of Canadian manufacturers that adopt some form of AMT has continued to grow, however that the fraction of plants that *modify* or *develop* in-house at least one of their advanced technologies has remained more or less the same at about 20% in each case [23]. Another recent survey involving mainly Canadian SMEs indicate high AMT usage in production inspection and control, but low usage in automated handling of materials [24]. Studies focussing on large (> 500 employees) manufacturing firms in the US

[25], and in Germany [26] have indicated degrees of AMT adoption that are comparable to that of Canada.

Studies carried out in large, Western European countries / regions, other than the German study cited above, have generally indicated a lower uptake of AMT. A UK sample taken and analyzed concurrently with, and compared to, the above cited US study indicated a significantly lower adoption over all of the investigated categories of AMT [25]. A Sweden-wide study has indicated similarly modest AMT uptake [27], whereas the study of a small sample of manufacturing companies from Germany, Hungary, the Netherlands, Slovenia, Sweden and Switzerland indicated that over two thirds of the respondents were using mainly manual techniques for their assembly processes [28]. Two recent studies of Spanish manufacturing firms show a higher adoption of AMT, with about half the respondents reporting that they use CNC machines [29], and also about one half that they employ robots and automated handling systems [30].

A few studies reported in the literature have addressed AMT adoption characteristics in relatively smaller, developed, non-isolated regions within large developed markets. A recent analysis of a sample of medium-sized manufacturing companies across more than 15 sub-sectors, operating in the Canadian province of Quebec [31], indicates AMT adoption rates that are comparable to the earlier Canada-wide study cited above. Another recent study analyzed a sample of 20 sub-contractor type manufacturing SMEs operating in four sub-sectors (iron and steel foundry, non-ferrous metal foundry, polymer, and automotive) in Southern Sweden [32]. A *sub-contractor manufacturing SME* is defined as one that manufactures products according to designs developed external to their company, as opposed to *small manufacturer SMEs* that carry out product design activities in-house [33]. The Southern Sweden study found that the degree of AMT adoption depended on the type of manufacturing processes used in the company, as well as on the company culture (e.g. family owned businesses tended to have newer facilities).

A number of recent publications have addressed AMT use profiles in newly industrialized states. A Singapore sample taken and analyzed concurrently with, and compared to, the above cited Sweden-wide study has indicated uptakes that are somewhat less than those in Sweden over almost all categories of AMT [27]. Nation-wide surveys of Indian SMEs have indicated even lower uptakes [34-35]. Meanwhile studies carried out in Saudi Arabia and in Turkey (the latter focusing only on SMEs) have indicated moderate uptakes of AMT [36-37].

Due care must be taken in interpreting and comparing all of the above statistics since many of the baseline parameters (e.g. year of data collection, sample size, sample distribution, definition of AMTs) differ significantly. Thus, for example, the European survey results based on 27 respondents [28] would be expected to be far less representative than the mandatory Canada-wide surveys (e.g. [21], based on 2191 companies); and the means of Likert-type scores do not convey exactly the same information as percentage adoption rates. Nevertheless, all of these results contribute in a complementary manner to provide a picture

of the trends in AMT adoption in developed, non-isolated regions, and to provide baselines to which the Malta results can be compared.

2.3 Barriers to AMT adoption in Developed, and/or in Newly-industrialized Regions

Many studies on factors militating against the implementation of AMTs have been carried out over the years. A survey taken in the Canadian provinces of Ontario and Quebec in the late 1980s, specifically intended to gauge the perceptions (both positive and negative) of manufacturing managers regarding the implementation/use of production automation, indicated that the leading perceived problems at the time were in finding good technical support for the technology, and in justifying the initial investment [38]. In the 1996 survey of large US and UK firms [25], disruption during implementation, failure to achieve financial targets, and adverse effect on workflow were the leading anticipated problems that militated against AMT adoption in the US; while disruption during implementation and lack of system integration were the leading anticipated problems in the UK. In a study that was specifically focussed on the impediments to AMT adoption by Canadian manufacturers, based on data from a 1993 survey, the most frequently indicated impediments were cost related (capital, technology acquisition, related equipment acquisition, software development, maintenance). Only a relatively small percentage of respondents cited information-related impediments (lack of scientific and technical information, of technological services, and of support from vendors) [39]. In [40] the authors analyzed various studies carried out between 1990 and 2006, and identified investment justification as the biggest hurdle to AMT implementation.

SMEs in particular, although often dynamic by nature, suffer from chronic impediments such as limited finances, lack of skilled labour, limited time resources, and lack of advanced planning tools [41-42]. These resource limitations can effectively serve as barriers to AMT implementation. Other barriers that have been reported include resistance from employees, poor financial feasibility studies, and poor justification of AMT and its benefits (see for example [43] and the review therein). Many of these barriers were reflected also in the Southern Sweden study [32], where a lack of appreciation even to the potential of AMTs was evident among the surveyed sub-contractor type manufacturing SMEs.

A number of studies have addressed the problems associated with AMT implementation in newly industrialized countries [12,34,44-46]. Barriers include financial limitations, and lack of locally available expertise (suppliers, implementers, maintainers, highly skilled labour supply). In some cases, where the manufacturing sector is dependent on foreign direct investment, parent companies opt to exploit the low local labour cost through manual production, and do not seek to transfer AMT to the local plants [45]. In India, SMEs have been found to give high priority to quality, but low priority to flexibility, and this militates against flexibility-related AMT adoption [34]. In a regional study conducted in Mexico, the distant locations of AMT suppliers rated among the highest barriers reported [40].

In general, several authors have emphasized the importance of making parallel investment in activities that support the use of AMTs (e.g. planning, implementation, integration, training) in order to maximize the benefits in performance and even to avoid project failure [16-17,19]. In a Swedish study it was pointed out that automation should be part of an overall manufacturing strategy, and not a strategy in itself [47]. The study also highlighted the potential impact of automation decisions on other decision areas, such as in the quality management system, production planning and control, and personnel skill level planning. The authors advocated the adoption of an optimum level of automation, which they termed “rightomation”, as opposed to either under- or over-automation.

Cultural and/or insular characteristics, related to either the sector/size of the company or to the market/economy in which it is located, have been reported to influence AMT uptake and the problems related to their implementation. In the newly industrialized states, low labour costs still tend to militate against AMT [27,45]. The lack of local suppliers and maintainers of AMT in these states further impedes AMT adoption, and the nurturing of strong, long-distance international buyer-supplier relationships becomes crucial to help overcome this problem [46]. A common phenomenon in newly industrialized states is the so-called “*sandwich situation*”, where companies are caught between low-cost, low-quality manufacturers and advanced, high-visibility brand international manufacturers (e.g. [12]). These companies are then required to choose between a shift towards a significantly lower cost model, or a shift towards a significantly higher quality model, and in either case the introduction of new AMT becomes critical. SMEs, irrespective of location, have a tendency to be individualistic and distrustful, and this can serve as an impediment to cooperation between different companies operating in the same market, that might otherwise serve to overcome effects of scale that militate against AMT [42].

2.4 Manufacturing systems for product variety

A new class of manufacturing systems that promote agility, and that have been given considerable attention worldwide in the last 15 years, are *reconfigurable manufacturing systems* (RMS). More frequent introduction of new products, modifications to existing products, large fluctuations in product demand and mix, new product design standards, and rapid developments in process technology have created a challenge that may be best addressed by these systems [48]. RMS can combine the cost effectiveness of *dedicated manufacturing lines* (DML) with the versatility of FMS. This approach has received wide acceptance globally in the manufacturing industry in situations where product variety and manufacturing agility are keys to competitiveness (e.g. [49-53]). An accepted definition of a RMS is that of a manufacturing system where machine components, machines, cells, or material handling units can be added, removed, modified, or interchanged as needed to respond quickly to changing requirements [54]. While a RMS does not necessarily need to incorporate automation, the concept and benefits of reconfigurability apply also to automated systems, and these have been studied under the general umbrella of

reconfigurable automation systems [55-58]. In the present work, the application of reconfigurability principles to process automation is treated as a separate aspect of AMT.

2.5 *Design for automation*

One of the hallmarks of *concurrent engineering* is the consideration, during the product design stage, of needs that will be incurred during subsequent stages of the product life. These considerations are referred to collectively as *Design for "X"* principles, where "X" can refer to various needs such as manufacturability, assembly, quality and recyclability [59]. Of relevance to this work are the principles of *design for automation* (herein referred to as *DfA*), which refer to the incorporation of provisions in the design of a product in order to ensure that its manufacture can be easily automated (e.g. [60-61]). Thus, DfA is conducive to the use of AMT, and its investigation is relevant to the objectives of the present work.

3. Survey Methodology

In order to investigate the research questions posed above, an empirical study was conducted on the manufacturing industry in Malta, through the development of a survey questionnaire, and through the collection, analysis and interpretation of the survey data. The survey questions were designed carefully by the research team in order to address the objectives of the study, and were subjected to extensive discussion by the team in consultation with industry representatives from the Malta Chamber of Commerce, Enterprise and Industry (MCCEI). The survey was originally intended to be distributed by post, and was initially pre-tested on top management personnel from two different companies, who were asked to complete the questionnaire without help from the research team. This first pre-test suggested that the survey was not easily understood and that it might be too technical for everyone in industry to interpret and answer accurately. Therefore, in addition to a number of changes to both the structure of the survey and the syntax of the questions, it was decided to change the data collection methodology to be used. For each company that accepted to take part in the study, a member of our core research team would visit the company manufacturing plant, tour the manufacturing facilities, and fill in the questionnaire in the context of a semi-structured interview with a member of the technical top management of the company. This format would ensure consistency in the interpretation of the survey questions, and would also allow additional unstructured information to be collected from the respondents. This new approach was pre-tested successfully on a third company, and was therefore adopted for our study. It is pointed out that this data collection methodology places considerable demand on the time of the respondents, however our previous experience with the local manufacturing industry had shown that it had a very collaborative attitude with respect to University projects, and this attitude continued to be evident throughout our entire study.

The questionnaire was divided into two sections. Section 1 collected: (i) (preamble) general factual information about the respondent company for placing purposes (e.g. size and sub-

sector); (ii) factual information about product lifetimes, the extent of automation employed in the company, types of processes used, and extent of automation for each type of process; and (iii) information pertaining to the attitude of the company management towards automation and of the perceived barriers to its introduction. Section 2 was designed to be answered only by those companies that already employed some degree of automation, and collected: (iv) factual information about the types of automation used; (v) information pertaining to company preferences for the design and manufacture of production automation equipment; (vi) information pertaining to the adoption of, and attitude towards, reconfigurable and flexible automation; (vii) factual information about the characteristics of changes in the production automation system; and (viii) information pertaining to company involvement in the implementation of DfA principles. These eight question/data sets (i.e. (i) to (viii) as described in this paragraph) will be referred to throughout the rest of this paper.

An extensive list of manufacturing companies was compiled from databases held by the MCCEI; Malta Enterprise (the Government agency responsible for the promotion of foreign investment and industrial development in Malta); the national Employment and Training Corporation; and the telephone directory yellow pages. These companies were categorized according to sub-sector and, where known, according to size. Ten sub-sectors were selected as high priority in line with Malta's industrial strategy, and with their amenability towards the use of automation. A subset of companies from among those operating in these sub-sectors were chosen at random, while giving due attention to ensuring that all sub-sectors, as well as all four size categories, were adequately represented in our sample. Selected companies were contacted by phone and asked to participate in the study. Almost all of the contacted companies acquiesced to grant us an interview. Between August 2008 and October 2009, we surveyed a total of 70 companies, distributed by size and sub-sector as shown in Table 1. A

Table 1
Distribution of survey respondents

<i>Sub-sector</i>	<i>Size</i>				<i>TOTALS</i>	
	<i>Micro</i>	<i>Small</i>	<i>Medium</i>	<i>Large</i>		
Electronics	3	4	7	1	15	21.4%
Medical	2	0	3	1	6	8.6%
Pharmaceuticals	2	3	1	1	7	10.0%
Plastic-ware	3	6	0	2	11	15.7%
Beverages	0	2	1	2	5	7.1%
Chemical	1	2	2	0	5	7.1%
Food	3	1	4	0	8	11.4%
Glass	2	1	1	0	4	5.7%
Textiles	1	2	1	1	5	7.1%
Woodworks	2	1	1	0	4	5.7%
<i>TOTALS</i>	19 27.1%	22 31.4%	21 30.0%	8 11.4%	70	

Table 2
Respondents profile

Owner / Managing Director / Chief Executive Officer	19
Director	5
General Manager	10
Other top management post (e.g. Production Manager, Operations Manager)	27
High middle management post (e.g. Section Manager, Senior Process Engineer)	9
TOTAL	70

distribution of the positions within their respective companies, or the job titles, of the respondents is given in Table 2.

4. Survey Results, Analysis and Discussion

4.1 Data set (ii) – Basic information on production, processes and automation

The following distribution of typical product lifetimes was indicated by the respondents: more than five years – 65.7%; two to five years – 21.4%; 13-24 months – 2.9%; 7-12 months – 2.9%; less than six months – 5.7%. The dominance of long life cycle products in the local industry was somewhat unexpected in the light of several studies and of conventional wisdom that propose that product life cycles are getting shorter (e.g. [62-65]). Since there is no earlier baseline study of the life cycles of products manufactured in Malta to which to compare our results, it is not possible to establish a trend in this respect, and indeed our study sets the first baseline. It is noted that the presumption that life cycles are decreasing has been challenged in the literature (e.g. [66]). Alternatively, the long life cycles of products manufactured in Malta may be a vestige of the nation's former "less developed country" status (and lower labour costs) of the not too distant past, which may have triggered a mechanism [67], that may still endure, whereby the manufacturing lines transferred by foreign parent companies to the Maltese subsidiaries would consist mainly of the proven, established products within their portfolio, which are expected to have long life cycles.

The proportion of respondents that utilize fully manual techniques is of 90.0%, while 64.3% utilize semi-automated techniques, and 32.9% utilize fully automated techniques. The fraction of companies that utilize any form of process automation (semi- or fully automated) is of 78.6%. Thus the general uptake of automation compares very favourably with that of other countries reviewed in section 2.2. For the respondents that utilize fully manual techniques, the leading reason was stated to be product complexity (31.7% of this subset of respondents), followed by variety (23.8%) and (low) volume (20.6%). For the respondents that use semi-automated techniques, the main stated reasons were (high) volume (55.6%), quality (31.1%) and variety (26.7%); while for the respondents that use fully automated techniques, the main stated reasons were (high) volume (56.5%), quality (39.1%) and complexity (26.1%). It is noted that *fully manual techniques* were clearly defined in our questionnaire as processes

needing continuous human intervention (86-100% of the time); *semi-automated techniques* were defined as processes needing partial human intervention (11-85% of the time); and *fully automated techniques* were defined as processes needing minimal human intervention (0-10% of the time).

The proportions of respondents that employ the various manufacturing processes, and the data pertaining to the use of automation for each type of process, are given in Table 3. The processes that are most commonly used are object/material transfer, inspection, and packaging, however in each of these three types of processes only about a third of users report any automation. The proportion of companies employing AMHS is of the same order as that in Sweden and Singapore [27], Quebec [31], and India [34].

Table 3
Breakdown of manufacturing processes and use of automation*

<i>Type of Manufacturing Process</i>	<i>Proportion of respondents that use this type of process</i>	<i>Proportion of users that apply this type of process in a manual or mechanized manner</i>	<i>Proportion of users that apply this type of process in a semi- or fully automated manner</i>
Casting	1.4 %	100.0 %	0.0 %
Injection/blow moulding	27.1 %	68.4 %	36.8 %
Forming	8.6 %	33.3 %	66.7 %
Particulate processing	1.4 %	100.0 %	0.0 %
Material removal	31.4 %	72.7 %	31.8 %
Heat treatment	50.0 %	51.4 %	48.6 %
Cleaning/surface treatment	32.9 %	60.9 %	43.5 %
Coating / deposition	17.1 %	75.0 %	25.0 %
Welding/brazing/soldering	30.0 %	71.4 %	38.1 %
Mechanical assembly	40.0 %	71.4 %	35.7 %
Sorting	44.3 %	80.6 %	29.0 %
Object/material transfer	85.7 %	68.3 %	38.3 %
Inspection	84.3 %	71.2 %	35.6 %
Printing	44.3 %	38.7 %	61.3 %
Packaging	84.3 %	67.8 %	35.6 %
Other	18.6 %	38.5 %	84.6 %

*Entries in the two right-hand columns of this table may add up to more than 100% due to multiple and different applications of the same type of process by individual companies.

4.2 Data set (iii) – Perceived barriers and attitude towards automation

The reported barriers to the implementation of automation are listed in Table 4, sorted in decreasing order of prevalence of the identification of the barrier as a “big problem” for the implementation of automation equipment (other than robotics). The table also gives the corresponding response prevalence for the implementation of robotics, as well as the prevalence among the respondents for the identification of each barrier as a “small problem” for the implementation of robotics and of other automation equipment. The results indicate that the major barriers relate to cost issues, as well as to perceptions regarding volume

justification and appropriateness for the products. In the specific case of robotics, the perceptions that production volumes are too low, or that the product is not amenable to automation, are more prevalent. Robots are also perceived to be associated with a higher technical challenge (and of requiring more expertise) than other forms of automation. A significant number of respondents have identified technological difficulties, and the lack of time to study the opportunities, as small problems, which is interpreted to mean that while these companies acknowledge these barriers, they feel that these problems can be surmounted if they apply some extra effort in this regard.

Table 4
Perceived problems in implementing automation and robotics

<i>Problem description</i>	<i>Big problem</i>		<i>Small problem</i>	
	<i>Automation</i>	<i>Robotics</i>	<i>Automation</i>	<i>Robotics</i>
Equipment is too expensive	41.4 %	41.4 %	10.0 %	2.9 %
Implementation is too expensive	31.4 %	32.9 %	15.7 %	12.9 %
Not appropriate for the volumes	27.1 %	37.1 %	8.6 %	8.6 %
Not appropriate for the products	21.4 %	41.4 %	4.3 %	10.0 %
No in-house expertise	14.3 %	20.0 %	7.1 %	4.3 %
No time to study opportunities	11.4 %	12.9 %	18.6 %	15.7 %
Other problem	11.4 %	10.0 %	0.0 %	0.0 %
Insufficient maintenance support	10.0 %	10.0 %	10.0 %	12.9 %
Too much product diversity*	8.6 %	7.1 %	0.0 %	0.0 %
No appropriate suppliers identified	7.1 %	5.7 %	14.3 %	8.6 %
No physical space available*	7.1 %	1.4 %	0.0 %	0.0 %
Too technically difficult to implement	2.9 %	8.6 %	21.4 %	11.4 %

**Not included among the suggested options in the questionnaire*

The extent of the financial barrier appears to be consistent with findings reported for other countries/regions, and in general it appears that Maltese companies have similar problems with financing as do companies in the other reviewed countries.

The other questions in this data set probed the general attitude to automation, including the presence/perception of client/customer pressure to use automation, and knowledge of competitor practices. The proportion of respondents that said that they would consider implementing/upgrading automation if resources were available was of 71.4%; while 8.6% were uncertain; and 20.0% said that they would not. The most prevalent expectation for the rate of return on investment was of one to three years, indicated by 42.9% of respondents; while 20.0% were content with a period of over three years; and 14.3% expected a return within a year. A further 22.9% of respondents could not give an answer on their expected rate of return. Only 10.0% of respondents reported that their clients/customers demanded that they use automation; 84.3% said no; and 5.7% were uncertain. Meanwhile, 28.6% of respondents reported that all of their competitors use automation; 35.7% said that some of

their competitors do; 14.3% said that none of their competitors do; and 21.4% were uncertain.

The issues and responses discussed in the previous paragraph have been tested for their validity as different aspects of a single unidimensional construct that measures the company attitude towards automation, by assigning numerical scores to the response options on a 4-point scale (see Appendix: Q1.6 – Q1.9). The Cronbach α for this construct was equal to 0.64, and this was considered to represent an adequate internal consistency in line with the literature recommendations [68-69]. Company attitude towards automation could therefore be grouped into four general categories, that we have labelled as follows: *Excellent* (11.4% of respondents); *Good* (47.1%); *Fair* (31.4%); and *Poor* (10.0%).

4.3 A note on section 2 of the survey questionnaire

Section 2 of the survey, comprising of data sets (iv) to (viii), required responses only from those companies that already use some form of automation, and therefore a total of 55 companies (78.6% of surveyed companies) addressed this section. All percentage rates pertaining to responses to this section, unless otherwise stated, are calculated in relation to this partial sample (n=55).

4.4 Data set (iv) – Types of automation used

The prevalence of the different types of automation are given in Table 5. The results show that the predominant type of equipment that is used by manufacturing companies in Malta is the specialized automation equipment (herein referred to as SAE), which refers to expensive, high technology manufacturing equipment that is standard and that can be purchased off-the-shelf, and that can then be programmed by the user for each particular job as required. Examples of this type of equipment are surface mount technology (SMT) equipment and wave soldering machines for assembling printed circuit boards (PCBs). The use of this equipment does not involve a large effort into the design and planning of the automation system – companies generally need to learn only how to use and program the equipment. It was noted however, that 70% of the subset of respondents that use SAE were also found to employ other types of automation that do require system design, planning and development.

A substantial portion of respondents (55.7% of the total sample) utilize either flexible / reconfigurable automation equipment, or pneumatic / hydraulic automation devices, or dedicated automation equipment. In these cases significant effort needs to be expended in carrying out technical feasibility analyses and mechanical/electrical design of the automation system.

Table 5
Adoption rates of automation typologies

<i>Type of automation facility</i>	<i>Adoption rate*</i>
Specialized Automation Equipment	65.7 %
Flexible or Reconfigurable Automation Equipment	38.6 %
Pneumatic/Hydraulic Automation Devices	32.9 %
Dedicated Automation Equipment	31.4 %
Computer Aided Design (CAD)	18.6 %
Machine Vision	17.1 %
CNC Machines (Machining)	11.4 %
Programmable Industrial Robots	10.0 %
Other	2.9 %

**calculated in relation to the total sample (n=70)*

The adoption of CAD in Malta is quite low in comparison to that reported in a number of the reviewed studies [27,31] and indicates below average design activity when compared to other developed economies. The presence of CNC machines on company production lines would also appear to be somewhat low, and would indicate that the local industry tends towards a “softer” type of manufacture that does not rely heavily on the in-house manufacture of complex mechanical product components. Our results in this regard however may not be directly comparable to those of the Quebec and Swedish studies [27,31], since in our survey the presence of non-production CNC machines (e.g. those used for the manufacture of tools or jigs) would not have been reported.

The diffusion of machine vision is quite high, considering that this off-the-shelf technology requires extensive programming and testing. The diffusion of robots is comparable to that reported in a number of studies carried out in Europe and in newly industrialized countries [27,32,34], but low compared to the Canadian results [21,31]. None of the surveyed companies use FMS.

4.5 Data set (v) – Design and manufacture of production equipment

The company preferences with respect to the design and manufacture of production automation equipment are shown in Table 6. A substantial amount of work is carried out in-house, and a not-insignificant percentage of equipment manufacture is outsourced to local suppliers, however the vast majority of respondents that use automation outsource both the design and the manufacture of some of their equipment to foreign suppliers. In both cases, around 95% of the respective subset of users stated that they do this either because the equipment is standard, or because they perceive foreign suppliers to have superior know-how. Almost three fifths (58.2%) of all companies that use automation outsource *both* the design *and* the manufacture of *all* of their associated equipment *exclusively* to foreign suppliers. It was noted that the percentage of companies in Malta that develop their automation equipment in-house is higher than that indicated for Canada [23] – possibly the

insularity of the island, and the lower availability of external suppliers, forces a greater proportion of local manufacturers to search for and to develop internal solutions.

Table 6

Design and manufacture of production automation equipment

	<i>In-house</i>	<i>Outsourced local</i>	<i>Outsourced foreign</i>	<i>By mother company</i>
Design	30.0 %	9.1 %	85.5 %	7.3 %
Manufacture	25.5 %	16.4 %	90.9 %	9.1 %

4.6 *Data set (vi) – Attitude towards reconfigurable automation*

The general attitude towards reconfigurability in automation was surmised from three questions, the responses to which displayed an adequate internal consistency with a Cronbach α of 0.62 (see Appendix: Q2.5, Q2.6, Q2.9). These questions inquired about (i) assignment / allocation of equipment when faced with new products, (ii) design considerations for production equipment / systems, and (iii) the fate of production equipment at the end of product life. Company attitude towards reconfigurability in automation could therefore be grouped into three general categories, that we have labelled as follows: *High* (56.8% of valid responses); *Medium* (36.4%); and *Low* (6.8%). These results indicate that manufacturing firms in Malta have a good appreciation of the benefits of reconfigurability, and of the importance of maintaining an agile production system.

In response to the other questions in this data set, 65.5% of the respondents that use automation indicated that they consider purchasing equipment with extra in-built capabilities to cater for possible future products, and 9.1% said that they sometimes do this. Meanwhile 50.9% of the respondents indicated that they sometimes invest in equipment that is not used to its full potential.

4.7 *Data set (vii) – Characteristics of changes in the production system*

In some cases pertaining to this data set, some of the respondents were unable to answer one or two of the questions, and were therefore omitted from the sample for the specific question under consideration. For this data set, the applicable sample size is recorded in brackets for each reported statistic.

About half (48.4%) of the respondents (n=31) indicated that they only make major changes to existing production systems / equipment every few years; while 29.0% do this approximately every year; 6.5% every six months; 3.2% every three months; and 12.9% every month. Nearly one third (30.9%) of the respondents (n=55) indicated the introduction of a new product (including upgrades) as a trigger for changes in the production system; while 25.5% indicated capacity requirements; 25.5% indicated quality requirements; 16.4% indicated new regulations; 9.1% indicated customer complaints; and 10.9% indicated other

reasons such as the drive to improve competitiveness. Close to half (45.5%) of the respondents (n=55) indicated that typical modifications to their production systems changes included minimal hardware changes; while 29.1% indicated software changes; 20.0% indicated substantial hardware changes; 1.8% indicated completely new set-ups; and 5.5% indicated other reasons such as the introduction of extra steps for auditing purposes. About two thirds (67.6%) of the respondents (n=34) indicated that they effect production system modifications in less than a month; while 17.6% indicated one to three months; 11.8% indicated four to six months; and 2.9% indicated more than six months.

4.8 Data set (viii) – Design for automation

Out of the 55 respondents of section 2 that answered the survey question regarding their involvement in the implementation of DfA principles, 23.6% indicated that they have no control over product design. This group of manufacturing companies would be categorized as sub-contractors as defined in [33]. Meanwhile, 43.6% indicated that they do employ DfA principles; 10.9% indicated that they sometimes do; and 1.8% indicated that they don't. For the remaining 20.0% of companies, these principles were not applicable due to the nature of the products (e.g. formulation of chemicals).

4.9 Other useful information extracted from the interviews

The semi-structured nature of the interviews permitted the extraction of additional useful information from the survey respondents, which may otherwise have been missed or insufficiently emphasized. This information is summarized below.

4.9.1 Product lifetimes and volumes

Many of the respondents complained of low production volumes, and that consequently profits were low, and that this often resulted in a lack of funds for investments and/or improvements. In some sectors, markets were reported to be very unstable, with drastic volatility in production volumes. A few companies reported that they found it hard to remain competitive since the market is no longer protected. A number of respondents noted that while the market continues to demand lower and lower prices, production costs have remained the same or increased – an indication that a review of production technique is warranted.

4.9.2 Implementation of automation equipment

Many barriers to automation still exist in Malta, however as will be discussed in section 6 a critical task may be to distinguish between real and virtual barriers. Many respondents reported that automation often simply cannot be justified financially, or that automation is difficult to implement because their product portfolios are made up of high variety with low standardization. Some respondents stated that they have never had an application where automation could be implemented, or that to implement automation their factory would

need to be rebuilt from scratch. In particular, most companies do not see the need to use robots. Even in the food industry, where automation has been a natural choice for many years, robots are generally considered as not being feasible. Many companies are uncertain as to whether they should invest in automation or not, because their demand fluctuates a lot. The time required to implement automation may also be an issue with many companies.

Some companies have never even considered automation. A number of companies have equipment that is so old that it is reaching the end of its life, however their management appears to lack the will to study new opportunities or is simply afraid of changes. At the other extreme, parent companies sometimes demand the use of automation by their subsidiaries in Malta. In the electronics industry customers often require that the testing be automated.

4.9.3 Financial difficulties

Companies reported that they often experience difficulties in obtaining funding or other help to invest in better machines or automation or even to expand their premises. In particular no return is envisaged in implementing robotics. Respondents reported that the implementation of automation may require larger physical space, and obtaining a larger factory area often proved to be an issue with many companies. In some cases the mother company itself may discourage the implementation of automation due to lack of funds.

4.9.4 Design and manufacture of automation equipment

Many manufacturing companies in Malta are unaware of the existence of local automation solution suppliers. However many companies acknowledge that foreign suppliers at times make response times longer and are more expensive. In general, many of the respondents prefer foreign suppliers.

4.9.5 Other general views

Importation and retailing is proving more profitable than manufacturing for some companies, thus justifying the shift towards more retailing or even the complete closing down of production factories. This appears to be particularly true for the furniture industry, where many companies now only manufacture customized products where intricate workmanship is required. In the textiles sector, many companies opt to manufacture uniforms which although specific to the particular school or place of work, ensure the securing of a specific captive market and therefore of production volume.

Micro companies often have only one person doing all the various managerial jobs including maintenance. This allows only minimal time to study opportunities for improvement. Many companies (of all sizes) complain about a general lack of open networking, and that there exist no initiatives to encourage the sharing of solutions within and across sectors. In some cases companies are not even aware of their local competitors.

5. Further Analysis

5.1 Correlation statistics and analysis by company size

A pair-wise correlation analysis was carried out on a number of characteristics pertaining to company/product attributes and the use of automation, to search for specific correspondences that can be revealed by the data. In order to carry out this exercise we have assigned numerical scores to the relevant survey response options as indicated in the Appendix. The Pearson correlation coefficient was computed for each pair of the selected characteristics, and the results of this analysis are presented in Tables 7 and 8. In this section we discuss these correlation results, as well as other (descriptive) statistics pertaining to company size.

The results for the full sample (Table 7) show a marked correlation between company size and the degree of adoption of automation. Indeed all of the large and medium companies that were surveyed implement some form of automation, in contrast to 81.8% of small companies and 42.1% of micro companies. All of the micro companies made use of fully manual techniques for some of their production, as opposed to 90.9% of the small companies, 85.7% of the medium companies, and 75.0% of the large companies.

Table 7

Intercorrelations between selected characteristics (from the responses to Section 1 of the survey)

	1	2	3	4	5	6
1 Company size	1.00					
2 Product lifetime	-0.02	1.00				
3 Highest degree of automation	0.52**	0.01	1.00			
4 Perceived barriers to robotics	0.17	-0.01	0.12	1.00		
5 Perceived barriers to other automation	0.14	0.03	0.08	0.45**	1.00	
6 Attitude towards automation	0.43**	0.14	0.56**	0.25*	0.17	1.00

* $p < 0.05$ (two-tailed); ** $p < 0.0005$ (two-tailed)

Table 8

Intercorrelations between selected characteristics (from the responses to Section 2 of the survey)

	1	2	3	4	5
1 Company size	1.00				
2 Variety of automation facilities	0.63**	1.00			
3 Equipment design confidence	0.20*	0.02	1.00		
4 Equipment manufacturing confidence	0.22*	0.09	0.79**	1.00	
5 Attitude to reconfigurability in automation	0.11	0.05	-0.09	-0.15	1.00

* $p < 0.2$ (two-tailed); ** $p < 0.0000005$ (two-tailed)

The results in Table 7 also reveal a strong correlation between company size and the general company attitude towards automation, as described by the construct defined at the end of section 4.2, with a clear tendency for this attitude to be more positive with increasing company size. The descriptive statistics for this relationship are shown in Table 9.

Table 9
Company attitudes towards the implementation of automation

<i>Attitude</i>	<i>Company Size</i>			
	<i>Micro</i>	<i>Small</i>	<i>Medium</i>	<i>Large</i>
Excellent	0.0 %	9.1 %	14.3 %	37.5 %
Good	36.8 %	50.0 %	47.6 %	62.5 %
Fair	42.1 %	27.3 %	38.1 %	0.0 %
Poor	21.1 %	13.6 %	0.0 %	0.0 %
<i>TOTALS</i>	<i>100.0 %</i>	<i>100.0 %</i>	<i>100.0 %</i>	<i>100.0 %</i>

Other (expected) correlations displayed by Table 7 are those between the general company attitude towards automation and the actual implementation of automation, as well as between the extents to which the company feels that there are barriers to the implementation of robotics, and of other automation equipment. An interesting positive correlation that appears in Table 7, albeit at a lower level of significance, is that between the extent to which a company reports barriers to automation and its general attitude towards automation. Thus the data on perceived barriers must be interpreted with care – whereas a long list of reported barriers could be expected to indicate a negative attitude towards automation, it may also be the case that a company that has a positive attitude towards automation may be more aware of the real barriers that must be overcome. This notion is explored further in the discussion in section 6.1.

With respect to the perceived problems in implementing automation, we noted a deviation in the responses from the micro-sized companies, in that unlike in the other size categories these companies tended to highlight *inappropriateness* of automation for their products / volumes ahead of the *high price* of equipment / implementation. This may imply that many micro-sized companies may be dismissing automation prematurely, prior to making any financial considerations.

The results in Table 8, based on the sub-sample of companies that already employ some degree of automation, show a strong correlation between company size and the variety of automation facilities used for production. The results also show an (expected) very strong correlation between company confidence in production equipment design (defined and quantified as shown in the Appendix: Q2.3) and company confidence in production equipment manufacture (Appendix: Q2.4). The results did not indicate a correlation between company size and company attitude towards reconfigurable automation (i.e. the null

hypothesis of no correlation could not be rejected). We have carried out a separate correlation analysis between company attitude towards automation, and company attitude towards reconfigurability in automation, for those companies that answered both sets of relevant survey questions, and find that there is no evidence for correlation between these attitudes ($r = -0.19$, $p < 0.25$).

All of the interviewed micro-sized companies that use automation utilize exclusively equipment that has been designed and manufactured by foreign external suppliers. The custom for the few local external designers / manufacturers of automation equipment comes mainly from small and medium-sized companies (not from large companies). A possible explanation for these data as extracted from the discussions held during the semi-structured interviews is that whereas micro-sized manufacturers tend to be the most risk-averse and would therefore refrain from developing customized equipment locally; and whereas large manufacturers would have the resources to set up an internal automation department for locally developed equipment; small and medium-sized companies may lack the resources for in-house development of equipment, but may be prepared to entrust the development of some of their non-standard production equipment to specialized local automation providers.

5.2 Analysis by manufacturing industry sub-sector

The survey data were analyzed by manufacturing sub-sector, in order to extract comparisons between the various sub-sectors with respect to a number of key characteristics, and also in order to identify any characteristics in which a particular sub-sector appeared to deviate substantially from the industry average. The rankings of the surveyed sub-sectors with respect to six key characteristics are shown in Table 10. Thus for example, respondents within the beverages sub-sector reported the most extensive use (per company) of automation and also displayed the best attitude towards the implementation of automation. The responses also indicate that companies within this sub-sector are the most likely to develop some of their production equipment locally (either in-house or outsourced to local developers), and also that they have the most extensive in-house application of DfA principles. The results also indicate that respondents in the glass-ware sub-sector that use automation, are the most likely to have production equipment that is reconfigurable.

Table 10
Sub-sector rankings for six key characteristics

Ranking	All respondents			Respondents that use automation		
	Product lifetime	Use of automation	Attitude towards automation	Local development of equipment	Attitude towards reconfigurability	In-house application of DfA principles
1	Beverages ¹	Beverages	Beverages	Beverages	Glass	Beverages
2	Food ¹	Textiles	Textiles	Medical	Medical	Woodworks
3	Medical	Food	Food	Electronics	Beverages	Medical
4	Textiles	Pharmaceuticals	Electronics	Plastics	Electronics	Plastics
5	Electronics	Chemical	Pharmaceuticals	Chemical	Textiles	Glass
6			Chemical			Food
AVG	----	----	----	----	----	----
6	Chemical	Glass		Textiles	Pharmaceuticals	
7	Plastics	Electronics	Medical	Glass	Plastics	Electronics
8	Glass ²	Medical	Plastics	Pharmaceuticals	Woodworks	Textiles
9	Woodworks ²	Plastics	Glass	Food	Food	Pharmaceuticals
10	Pharmaceuticals	Woodworks	Woodworks	Woodworks	Chemical	Chemical

¹All respondents in the food and beverages sub-sectors reported a typical product lifetime of over 5 years, and are ranked jointly first under “product lifetime”.

²Glass and woodworks sub-sectors ranked jointly eighth under “product lifetime”.

The results in Table 10 offer rich opportunities for interpretation and discussion, however many of these are considered to pertain strictly to the Maltese context, and therefore herein we touch only briefly on a few of these. Malta has a long standing beverages Industry that produces wines, beers, juices, soft drinks and water, and it is therefore no surprise that companies within this sub-sector have matured to the extensive use of automation and that most have learnt to develop some of their production equipment in-house. When the local cost of labour was still low, Malta had a thriving textiles manufacturing industry, based on manual production. With increased labour costs, the local presence of this sub-sector has progressively diminished, and the few companies that remain can only survive through extensive use of automation. The local glass-ware sub-sector thrives on variety, and therefore the progressive companies within this sub-sector that employ automation must of necessity assign major importance to reconfigurability. At the other end of the rankings the local woodworks sub-sector suffers from very disadvantageous economies of scale, and following Malta’s entry into the EU and the dismantling of protective legislation many companies stopped manufacturing furniture and shifted to a policy of import and sales. As indicated in section 4.9.5, most of the companies that continue to manufacture furniture have settled for a niche market of custom-made items, and therefore tend not to utilize automation. The (few) companies that continue to manufacture standard items do use automation, and in this case place high emphasis on designing all of their products such that they can extract maximum benefit from these technologies.

An analysis by sub-sector of the perceived barriers to automation showed only minor deviations from the general norms reported in section 4.2. This result indicates that these perceived barriers are not sector-specific.

5.3 Analysis by company ownership

An analysis of the data by company ownership (Maltese vs foreign) shows a significant, but not overly large, propensity towards automation in the foreign owned companies in comparison to the locally owned companies. The proportion of foreign owned companies that use automation is of 85%, as compared to 74% of Maltese companies; the proportion of foreign owned companies that have an *excellent* or *good* attitude towards automation is of 63%, as compared to 56% of Maltese companies; and the proportion of foreign owned companies that have a *high* attitude towards reconfigurability in automation is of 67%, as compared to 48% of Maltese companies.

6. Further Discussion

6.1 Real versus virtual barriers to automation

Our interviews and the survey responses have served to highlight a number of very real barriers to the implementation of manufacturing automation in the Maltese industry, however they have also served to highlight a number of potentially mistaken perceptions regarding automation, which we are here calling *virtual barriers*.

The problems that are faced by many companies, and that we have judged to be *real*, include the following: insufficient funds for the initial investment; no in-house expertise; no time to study opportunities for production optimization / automation; inadequate maintenance support; limited locally available know-how; volatile markets; and unacceptable length of time required for the implementation and commissioning of automation solutions. The virtual barriers are identified to be the following widespread *but potentially mistaken* perceptions: automation (including robotics) is always prohibitively expensive to implement; low product volume and/or high product variety preclude the use of robotics and automation; the manufacture of complex products cannot be automated; the implementation of automation is too difficult and/or challenging; the implementation of automation requires larger physical space; the implementation of automation requires a factory to be rebuilt from scratch; and there is no locally available know-how.

Guided by the above discussion, we have defined each of the reported barriers to the implementation of robotics and of other automation equipment as being either real or virtual, as detailed in Table 11. A new correlation analysis exercise, between each of the two sets of

Table 11

Barriers to automation: Tentative classification

<i>Barrier</i>	<i>Classification</i>
Equipment is too expensive	Real
Implementation is too expensive	Real
Not appropriate for the volumes being produced	Virtual
Not appropriate for the products being produced	Virtual
No in-house expertise about the subject	Real
No time to study the opportunities	Real
Other problem	-
Insufficient maintenance support would be available	Real
Too much product diversity	Virtual
No appropriate suppliers identified	Virtual
No physical space available	Virtual
Too technically difficult to implement	Virtual

Table 12

Correlations between perceived real/virtual barriers and attitude towards automation

<i>Barrier set</i>	<i>Correlation to company attitude towards automation</i>
Perceived real barriers to robotics	0.35**
Perceived virtual barriers to robotics	-0.08
Perceived real barriers to other automation	0.31*
Perceived virtual barriers to other automation	-0.14

* $p < 0.01$ (two-tailed); ** $p < 0.005$ (two-tailed)

reported barriers and company attitude towards automation, was carried out. The results are presented in Table 12, and support strongly the premise that the two types of barriers are distinct. In particular, the results indicate that companies having a more positive attitude towards automation are more likely to focus on the real barriers to AMT implementation.

We recommend that any approach, by the state or by an industry federation, which is aimed at increasing the adoption of automation in the manufacturing sector, would need to dispel first the virtual barriers through a campaign of education and information dissemination. This would maximize the potential for success of subsequent / concurrent measures aimed at addressing the real barriers, e.g. the provision of tax incentives or grants to encourage the development of new manufacturing systems, increased emphasis on engineering and technical training of local automation experts, the development of new studies and methodologies for the implementation of automation within volatile markets, and the development of a culture through which the long term (as opposed to the short term) benefits of an automation strategy are recognized.

6.2 Other general perspectives on the results of the study

This study has indicated that the manufacturing sector in Malta has a number of contrasting traits. The general percentage uptake of automation technology appears to be very high and is comparable to that in North America, however the uses of CAD systems and of robotics are relatively low. The percentage uptake of robots is comparable to that of most other European countries, and of the newly industrialized countries, that have been reviewed, and in the Maltese case this can perhaps be attributed to a lack of appreciation of the full capabilities of these machines. The low use of CAD is indicative of the relatively low product design activity carried out on the island, however the figures also indicate that a substantial proportion of companies that do carry out product design do not make use of CAD technology. The problems with lack of expertise are similar to those reported for the newly industrialized states. The problems with financing are similar to those reported for most other places on the globe.

The study has shown that trust in the local know-how for the development of automation equipment is very low. This can possibly be addressed by increasing the local training effort (as indicated in section 6.1 above) and by encouraging the local automation providers to increase their exposure on the local market; however it is also important to recognize and accept that many local companies need to obtain solutions from foreign suppliers, and therefore every effort should be made to improve the accessibility to these suppliers.

The studies on manufacturer attitude to reconfigurability in automation, and on the characteristics of production system changes, are to the best knowledge of the authors the first of their kind to have been carried out. The results indicate that the manufacturing industry in Malta is very receptive to the need to incorporate reconfigurability in their automated production systems. While much of this can come from the inherent reconfigurability of SAE, the general positive attitude has been seen also for other types of automation systems. The data gathered on production system change characteristics can serve as a baseline for other similar studies that may be carried out in the future or elsewhere.

7. Conclusion

This work has involved an extensive investigation of various characteristics pertaining to the use of manufacturing automation in the small island state of Malta. The results show that there is a unique blend of characteristics that can be compared to those found in large, fully developed economic regions on the one hand, and to the newly industrialized countries on the other hand. Some of the results involve issues that have not yet been explored in other types of economic regions – these include the analysis of empirical data related to preferences pertaining to equipment procurement; to the uptake of and attitude towards reconfigurable automation systems; to the frequency and extent of production system changes; and to the application of design for automation principles; as well as the categorization of impediments to manufacturing automation into real and virtual barriers.

Malta contrasts with all of the other reviewed economies in that while it is a developed country, it is at the same time small and insular, and is peripheral to a vastly larger, fully developed mainland. Further distinguishing features are that Malta has only been promoted to “developed” status in various international listings during the last 10 to 15 years, and still harbours some remnants of a developing market, yet at the same time its manufacturing sector has already passed through the cycle, seen in many other developed nations, of rising to about a quarter of national GDP contribution and then falling steadily, in relative terms and mainly due to superior growth in the services sector, to about an eighth of GDP.

The results presented here serve as a case study on the use of production automation in an isolated group of diverse and generally unconnected manufacturing firms operating within, but in relative geographical isolation to, a large developed market. In this regard, many of the findings reported in this work are expected to be applicable to other similarly isolated and diverse manufacturing groups in the developed world, and offer new insight into the characteristics of, and into the difficulties faced by, manufacturing companies within these groups.

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Appendix: Numerical score assignments to specific survey response options (for consistency and correlation analyses)

Preamble: number of employees (company size)	01-09 (micro)	10-49 (small)	50-249 (medium)	250+ (large)	
Score:	1	2	3	4	
Q1.1: Product lifetime	< 6 months	07-12 months	13-24 months	2-5 years	> 5 yrs
Score:	1	2	3	4	5
Q1.2: Highest degree of automation	No automation (fully manual)		Semi-automated	Fully automated	
Score:*	1		2	3	
Q1.4: Perceived barriers to robotics	S = number of small problems; B = number of big problems				
Score:	S + 2B				
Q1.5: Perceived barriers to other automation	S = number of small problems; B = number of big problems				
Score:	S + 2B				
Q1.6: Consider implementing/upgrading automation	No	Uncertain		Yes	
Q1.7: Expected rate of return	< 6 months	6-12 months	1-3 years	> 3 years	
Q1.8: Clients / customers demand automation	No		Uncertain	Yes	
Q1.9: Competitors use automation	None	Uncertain	Some	All	
Scores:	1	2	3	4	
Latent Construct: Attitude to automation	Extracted from the responses to Q1.6, Q1.7, Q1.8, Q1.9				
Score:	Unweighted average score, rounded to nearest integer				
Construct statistics:					
Rotated factor loadings	Q1.6: 0.733; Q1.7: 0.662; Q1.8: 0.591; Q1.9: 0.784				
Cronbach α	0.6399				
Q2.1: Variety of automation facilities	F = number of different types of facilities as indicated in survey response				
Score:	F				
Q2.3: Location of equipment design	Mother company	Outsourced foreign	Outsourced local	In-house	
Equipment design confidence Score:*	1	2	3	4	
Q2.4: Location of equipment manufacture	Mother company	Outsourced foreign	Outsourced local	In-house	
Equipment manufacture confidence Score:*	1	2	3	4	
Q2.5: Equipment for new product	Design new	From mother company	Adapt existing		
Q2.6: Production equipment development	For specific product only	Allows for future close variants	Allows for future more distant variants		
Q2.9: Equipment fate at end of product life	Sold or disposed of	Dismantled for future use	Set up for different product		
Scores:*	1	2	3		
Latent Construct: Attitude to reconfigurability in automation	Extracted from the responses to Q2.5, Q2.6, Q2.9				
Score:	Unweighted average score, rounded to nearest integer				
Construct statistics:					
Rotated factor loadings	Q2.5: 0.741; Q2.6: 0.785; Q2.9: 0.761				
Cronbach α	0.6215				

* Not additive in the case of multiple selected options. Highest individual score applies.