THE IMPACT OF TOTAL PRODUCTIVE MAINTENANCE PRACTICES ON MANUFACTURING PERFORMANCE THROUGH SECS/GEM STANDARD FOR ELECTRONIC CONTRACT MANUFACTURING COMPANIES

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A thesis submitted in full fulfillment of the requirements for the degree of Doctor of Philosophy (Business Administration)

Centre for Graduate Studies
Open University Malaysia

2014

DECLARATION

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I hereby declare that this thesis is the result of my own work, except for quotations and summaries, which have been duly acknowledged.

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DECEMBER 2014

ABSTRACT

In an environment of intense global competition, it pays to consider both creative and proven systems that can be used to bring about effective and efficient manufacturing operation. Many electronic contract manufacturing companies have put forth huge amounts of effort and resources to achieve precise and reliable measurement of equipment performance. The objective of a concise measurement is to optimise this piece of asset for every dollar invested. However, it has failed on numerous attempts to achieve the desirable result due to hardware limitations, low degrees of data accuracy and the need for manual intervention. Integrating Total Productive Maintenance (TPM) methodology with SEMI Equipment Communication Standard (SECS) with Generic Equipment Model (GEM) enables data acquisition in a concise manner and keeps track of all real-time transactions that have taken place between the operator and the equipment. To achieve this integration process, a fast-track TPM implementation approach is required by re-engineering the TPM implementation process. The Re-Engineered TPM approach comprises of three TPM pillars (Asset Productivity (AP), Autonomous Maintenance (AM) and Planned Maintenance (PM)) instead of the original eight pillars. Apart from three TPM pillars, also included are SECS/GEM standard, direct and indirect labour utilisation hours, material and overhead cost. The main objective of this study is to determine whether the re-engineering effort, based on these three TPM pillars, SECS/GEM standard together with labour and cost, are able to minimise losses in production process and have positive impact on Output (Manufacturing Performance). The study also aims at evaluating whether the SECS/GEM standard integration with Autonomous Maintenance has the capability of real-time monitoring equipment performance on the production floor. Furthermore, the study aims to assess the impact on productivity, namely, the Output (Manufacturing Performance).

The three years, monthly data for the study was collected from ten Electronic Contract Manufacturing (ECM) companies in Johor, Malaysia. The data was analysed through descriptive statistics, regression analysis and panel data analysis. Based on the panel data analysis, the Hausman Test revealed that the Fixed Effects model was found to be the optimal model for this study. The result shows that six independent variables were significant, while one independent variable was not. The insignificant independent variable was SECS/GEM standard integration with Autonomous Maintenance. Further analysis was conducted through a qualitative study. The additional analysis shows that ECM companies do not fully understand the possible application of the SECS/GEM standard integration with Autonomous Maintenance in their manufacturing environment. Therefore, minimum effort was deployed by ECM companies in incorporating this standard into their equipment maintenance platform. However, these days many ECM

companies have started to purchase equipment with SECS/GEM standard in order to facilitate smoother future integration with Autonomous Maintenance or with other TPM pillars. This total integration of TPM (three pillars), SECS/GEM standard, labour and cost provides an avenue to monitor and address the operational losses in the production equipment in a timely manner. This system paves the way to improving Output (Manufacturing Performance).

Keywords: Total Productive Maintenance (TPM); Asset Productivity (AP); Autonomous Maintenance (AM); Planned Maintenance (PM); Output (Manufacturing Performance); Semiconductor Equipment and Materials International (SEMI); SEMI Equipment Communications Standard (SECS); Generic Equipment Model (GEM).

KESAN AMALAN PENYELENGGARAAN PRODUKTIF MENYELURUH KE ATAS PRESTASI PERKILANGAN MELALUI PIAWAIAN SECS/GEM BAGI SYARIKAT PEMBUATAN ELEKTRONIK KONTRAK

KRISHNAMOORTHY RENGANATHAN

DISEMBER 2014

ABSTRAK

Dalam persekitaran persaingan global yang sengit, adalah baik untuk mempertimbangkan sistem yang kreatif dan juga siatem yang telah terbukti untuk mendapatkan operasi pengeluaran yang berkesan dan cekap. Banyak syarikat pembuatan elektronik kontrak telah melaburkan usaha dan sumber yang banyak untuk mencapai satu ukuran prestasi peralatan yang tepat dan yang boleh dipercayai. Objektif mendapatkan satu ukuran yang tepat dan padat adalah untuk mengoptimumkan penggunaan setiap aset dan seterusnya pulangan kepada setiap wang yang dilaburkan. Walau bagaimanapun, usaha ini sering gagal untuk mencapai keputusan yang diharapkan kerana batasan perkakasan, data yang kurang tepat dan intervensi yang dibuat secara manual.

Mengintegrasi metodologi Penyelenggaraan Produktif Menyeluruh (TPM) dengan Piawaian Komunikasi Peralatan SEMI (SECS) dengan Model Peralatan Generik (GEM) akan memudahkan pemerolehan data yang ringkas tetapi padat dan juga dapat menjejaki semua transaksi yang masa-nyata, iaitu semasa ia berlaku di antara pengendali dan peralatan. Untuk mencapai proses integrasi ini, pendekatan pelaksanaan TPM yang pantas diperlukan dengan penjuruteraan-semula proses pelaksanaan TPM tersebut. Pendekatan TPM yang telah melalui proses penjuruteraan-semula terdiri daripada tiga daripada lapan tiang asal TPM; ia-itu Produktiviti Aset (AP), Penyelenggaraan Autonomi (AM) dan Penyelenggaraan Terancang (PM). Selain daripada tiga tiang TPM, pendekatan ini juga merangkumi piawaian SECS/GEM, jam penggunaan buruh secara langsung dan tidak langsung, serta kos bahan dan kos overhed.

Objektif utama kajian ini adalah untuk menentukan sama ada usaha penjuruteraan-semula, berasaskan kepada tiga tunggak TPM, piawaian SECS/GEM, bersama-sama dengan tenaga kerja dan kos, dapat mengurangkan kerugian dalam proses pengeluaran dan mempunyai kesan positif ke atas Output (Pembuatan prestasi). Kajian ini juga bertujuan untuk menilai sama ada integrasi piawaian SECS/GEM dengan Penyelenggaraan Autonomi mempunyai keupayaan untuk memantau prestasi peralatan di ruang pengeluaran tepat pada masanya; dan seterusnya, meningkatkan pengaruh ke atas prestasi, iaitu Output (Prestasi Pembuatan).

Data bulanan untuk tempoh tiga tahun bagi kajian ini dikumpulkan dari sepuluh syarikat Pembuatan Elektronik Kontrak (ECM) di Johor, Malaysia. Data yang diperolehi dianalisis menggunakan statistik deskriptif, analisis regresi dan analisis data panel. Hasil dari analisis data panel, Ujian Hausman menunjukkan bahawa model Kesan Tetap merupakan model yang optimum untuk kajian ini. Hasil kajian seterusnya menunjukkan terdapat enam pembolehubah bebas yang signifikan, manakala satu pembolehubah bebas tidak. Pembolehubah bebas yang tidak signifikan adalah integrasi piawaian SECS/GEM dengan Penyelenggaraan Autonomi. Analisis selanjutnya telah dijalankan melalui kajian kualitatif. Analisis lanjutan ini menunjukkan bahawa syarikat-syarikat ECM tidak memahami sepenuhnya penggunaan integrasi piawaian SECS/GEM dengan Penyelenggaraan Autonomi dalam persekitaran pengilangan mereka. Oleh itu, perhatian yang minimum telah diberikan oleh syarikat ECM dalam menggabungkan piawaian ini ke dalam platform penyelenggaraan peralatan mereka. Walau bagaimanapun, sekarang banyak syarikat ECM telah mula membeli peralatan dengan piawaian SECS/GEM untuk memudahkan integrasi dengan Penyelenggaraan Autonomi atau dengan tiang TPM lain pada masa akan datang. Integrasi TPM (tiga tiang) secara menyeluruh termasuk pawaian SECS/GEM, buruh dan kos memberi ruang untuk memantau dan menangani kerugian operasi dalam peralatan pengeluaran tepat pada masanya. Sistem ini membuka jalan untuk meningkatkan Output (Prestasi Pembuatan).

Kata Kunci: Penyelenggaraan Produktif Menyeluruh (TPM); Produktiviti Aset (AP); Penyelenggaraan Autonomi (AM); Penyelenggaraan Terancang (PM); Output (Pembuatan prestasi); Peralatan Semikonduktor dan Bahan-Bahan Antarabangsa (SEMI); Piawaian Komunikasi Peralatan SEMI (SECS); Model Peralatan Generik (GEM).

ACKNOWLEDGEMENTS

Firstly, I would like to thank God for blessing me with intellectual guidance, inspiration and health for making this dissertation possible.

In the course of this research study, a number of people have contributed to, and helped me in various ways. This doctoral work has taught me a whole lot of invaluable lessons and although some are not a part of this dissertation, it will continue to guide me throughout my life. This work would not be complete without acknowledging the efforts and contributions of the people who have been associated with my research work.

I would like to warm-heartedly thank my supervisor, Professor Dr. Mohd Ghazali Mohayidin of Open University Malaysia (OUM), for his guidance, invaluable help, ideas, suggestions and particularly being very patient in coaching me throughout this study. Our often long drawn discussions on various aspects of the research study helped me better understand the problem and the associated intricacies. Furthermore, I also really appreciate Prof. Ghazali for inspiring me to analyse into greater depth, to expand my viewpoint and to think critically.

I would like to express my gratitude to Dr. Rosmah Mohamed (OUM) who has always encouraged me in pursuing my research study. Also, my special thanks goes to Puan Nur Azlin, OUM Business School for her prompt and excellent administrative support in my dissertation work.

I would like to thank Mr. Kelly Wong from Universiti Putra Malaysia for coaching and guiding me with the statistical analysis tools.

Also extending my gratitude to Ms. Sim Biow Siong, Federation of Malaysian Manufacturers (Johor Branch) for her endless support in providing the information required for this study.

Thanks to everyone who participated in my dissertation: Puan. Rozaida, En. Mohd. Azri, Mr. Chandiran Suppiah, En. Suhairi Ahmad, En. Mohd. Fahmi, Mr. Subramaniam Jayaraman and Mr. Ravie Balan. Everyone in this group has provided me with valuable information relating to my study.

Next I wish to express my gratitude towards the examination committee comprising of Dr. Nitty Hirawaty (Universiti Putra Malaysia), Prof. Ir. Dr. Kanesan Muthusamy (Vinayaka Missions International University College), Dr. Zahir Osman (OUM) and Prof. Dato Dr. Kamaruddin Sharif (OUM) for their valuable feedback, expert advice and suggestions. Also thanks to the committee for their professional evaluation on my research work.

My special thanks and appreciation will go to Dr. Vatakkepat Parameswaran Nair for his moral support and always motivating me to successfully complete my doctoral journey.

I am also grateful for the superb facilities of the OUM Digital Library which has provided excellent research materials during my research study. In addition, thanks to all the librarians' assistance and especially to En. Shahril Effendi, for guiding on the use of online library website and providing with the necessary journals and research materials whenever needed.

Finally, my special gratitude goes to my family who has been extremely understanding and supportive of my studies. I sincerely thank my wife, Pathmavathy, for her sacrifices, understanding and love in supporting me throughout my studies. I also thank my son-in-law, Ashvin and my daughter, Shanthini who came forward to my help when I needed them and also to proof read my dissertation. My thanks also goes to my other daughter, Bavani and son-in-law, Kailash who always plays a motivational role in my studies. I feel very lucky to have a family that shares my enthusiasm in my academic pursuits.

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AM	Autonomous Maintenance
AP	Asset Productivity
ECM	Electronic Contract Manufacturing
EDB	Economic Development Board
E&E	Electrical and Electronics
ETP	Economic Transformation Programme
FE	Fixed Effects
GDP	Gross Domestic Product
GNI	Gross National Income
GEM	Generic Equipment Model
HRDF	Human Resources Development Fund
INSEP	Industrial Skills Enhancement Programme
IRDA	Iskandar Regional Development Authority
JIPM	Japan Institute of Plant Maintenance
MATRADE	Malaysia External Trade Development Corporation
MIDA	Malaysian Investment Development Authority
MNC	Multinational Corporation
NKEA	National Key Economics Areas
OEE	Overall Equipment Effectiveness
OLS	Ordinary Least Square
PEMANDU	Performance Management and Delivery Unit
PM	Planned Maintenance
RAM	Reliability, Availability and Maintainability
R&D	Research and Development
RE	Random Effects
SME	Small and Medium-sized Enterprises
SECS	SEMI Equipment Communication Standard
SEMI	Semiconductor Equipment and Materials International
TPM	Total Productive Maintenance
TQM	Total Quality Management
VIF	Variance Inflation Factor
WCM	World Class Manufacturing

CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia is strategically located in the heart of South-East Asia and is one of the most vibrant countries in this region. Malaysia is a dynamic country with excellent political stability, which ensures sustained and progressive economic growth. This has led Malaysia to achieve significant economic and social progress over the past several decades. To keep pace with this progress and to become a high-income nation, the Malaysian Government launched the Economic Transformation Programme (ETP), in 2010. The ETP is managed by PEMANDU (Performance Management and Delivery Unit) under the patronage of the Prime Minister's Department. ETP incorporates two crucial elements: the 12 National Key Economics Areas (NKEAs) and the six Strategic Reform Initiatives (SRIs), which comprise of policies and procedures that were implemented to create a vibrant business environment. It is a comprehensive economic transformation plan to propel Malaysia's economy into a high-income economy. The 2013 ETP annual report states that it has maintained a strong momentum in the last three years and this has helped the Malaysian economy achieve a GDP (Gross Domestic Product) growth of 4.7% in 2013 (Economic Transformation Programme, 2013).

In 2013, Y.A.B. Datuk Sri Najib Tun Razak, Prime Minister of Malaysia, stated in his speech that the ETP was formulated not only to help Malaysia achieve its ambition to be a developed nation by 2020, but also in response to the shift in the global economic order (Economic Transformation Programme, 2013). Also, in 2013 alone, the ETP contributed RM7.4 billion to Gross National Income (GNI), creating 29,373 new employment opportunities and drove RM8 billion worth of investments. These activities have increased the GNI per capita to US$10,060 during the year.

Apart from other sectors, the ETP has made great strides in supporting the Electrical and Electronics NKEA sector. This has encouraged the growth of small and medium-sized enterprises (SMEs). It has also led to the growth of several electronics manufacturing companies. In the overview of various sectors in ETP, the Electrical and Electronics (E&E) sector in the electronic manufacturing sector is one of the key contributors to the growth of Malaysian economy. Therefore, the Electrical and Electronics NKEA has put in place measures to enhance the capability and capacity of SMEs, pushing them to produce better quality and high value added products to meet world-class standards. All these measures by ETP have given investors confidence that the Government is firm yet flexible enough to accommodate their needs. While sourcing for more investors, ETP has declared that by 2020 E&E is expected to contribute a GNI impact of RM9.7 billion and create 56,800 high-income jobs (National Key Economics Areas, 2013).

1.1.1 Overview of Electrical and Electronics Sector

The E&E industry is one of the leading industries that contributes 24.5% to the manufacturing sector in the Malaysia’s Gross Domestic Product [Malaysia External Trade Development Corporation (MATRADE), 2013]. Also, E&E products have been in large-scale business transactions in Malaysia for several decades, since the industry’s inception in 1960's. Until today, the industry evolution has turned Malaysia into one of the leaders in the global E&E value chain. In 2012, Malaysia's exports of E&E products was valued at RM231.23 billion, with a share of 49.2% in manufactured goods exports and a share of 32.9% in Malaysia's total exports (MATRADE, 2013).

The industry can be classified into two sectors namely the Electrical and Electronics sector.

1. **Electrical Sector**

   The electrical sector since the beginning of 1960's has established several manufacturing plants to manufacture household appliances, electrical fittings, wires and cables, and automotive batteries. The industry then grew over the years, with the capability to supply high-end electrical products, including electrical components to both domestic and international markets.

2. **Electronics Sector**

   The electronics sector contributes over 38% of electronics exports comprising semiconductor devices, integrated circuits (ICs), transistors and valves (MATRADE, 2013). The Multinational Corporation (MNCs) and, SMEs continue to be the main catalyst in the development of the E&E sector. According to Ariff (2008), a number of SMEs in the E&E sector have progressed to become global suppliers to MNCs. The companies in this sector have been able to develop significant capabilities and skills in manufacturing a wide range of electronic products across all significant sub-sectors such as electronic components and parts; industrial electronics as well as consumer electronics. Furthermore, these companies continue to move-up the value chain to produce higher technology and value-added products through continuous Research and Development (R&D) activities. Also, the vast majority of these products and R&D activities are being out-sourced to several Electronic Contract Manufacturing companies locally.

Figure 1.1 illustrates the pie chart distribution on the top 10 major exports from January to May, 2014. This chart shows that the E&E sector accounts for 32.3% and has contributed to total exports of RM 103.02 billion.

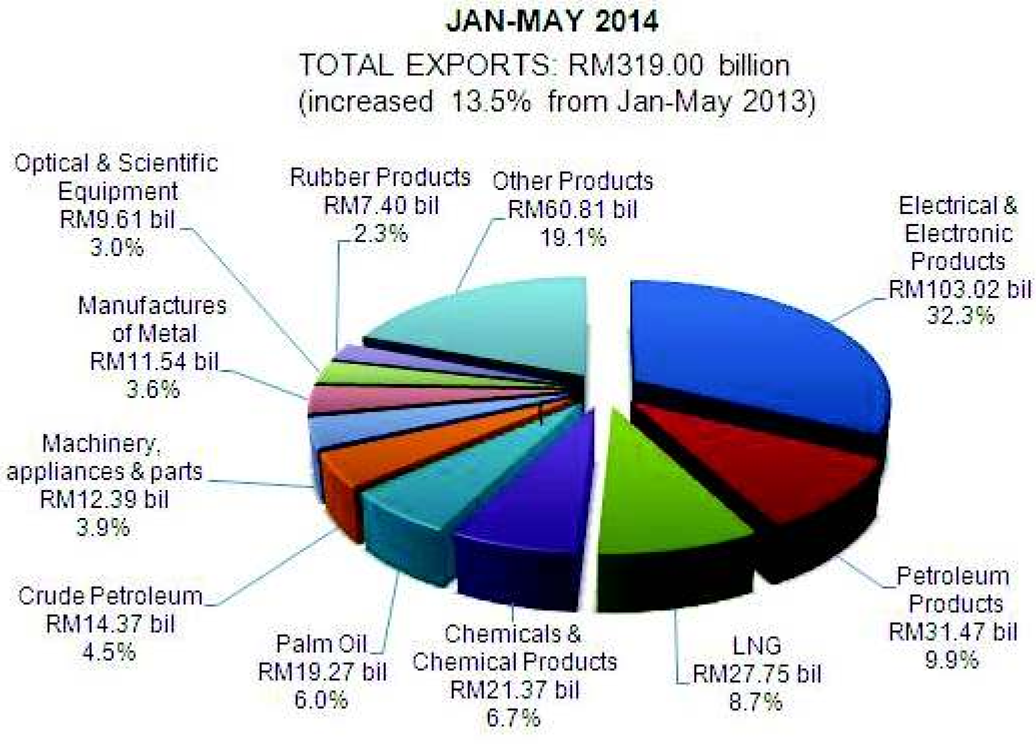

Figure 1.1: Top 10 Major Export Products
Source: MATRADE (2014)

Figure 1.1 also shows, that the E&E industry has the highest exports and has a significant impact towards the Malaysian economy. The E&E industry remains one of the key drivers of Malaysia's industrial development. This industry sector has accumulated vast experience in supporting the global SMEs and MNCs. Today, these companies are capable exporters that have been supplying various products worldwide. It is notable to highlight the following areas of specialisation that Malaysian companies are capable of:

1. Electronics Manufacturing services;
2. Wafer Fabrication;
3. Integrated Circuit designs;
4. Assembly, Packaging and Testing;
5. Parts and Components for electrical products;
6. Power and Energy generation;
7. Solar System solutions;
8. Light Emitting Diode (LED) Lighting solutions;
9. Consumer Electrical items; and
10. Information Technology (IT) parts and accessories.

Malaysian exporters have proven capabilities in producing high quality products and conforming to global quality standards. Moving forward, these companies are ready to adopt the current global trend for "green environmental friendly products" as well as establishing sustainability. The E&E sector is not only accountable for the highest exports in the manufacturing sector, but it is also accountable for water pollution, air pollution and solid waste (Iman, 2011). Therefore, the E&E sector needs to stay focused on "green manufacturing practices" to produce green environmental friendly products and to sustain green technological operations. Green manufacturing practices aim to minimise waste and pollution, and ensure no harm is done to the environment during any phase of the manufacturing process. Furthermore, the establishment of the Ministry of Energy, Green Technology and Water on 9th April 2009 by the Prime Minister, Y.A.B. Datuk Sri Najib Tun Razak has pushed business organisations to adopt a green culture in their operations. This government initiative illustrates that the Ministry of Energy, Green Technology and Water has taken a holistic approach to advocate green technology in the country.

All these efforts by the Malaysian government and companies have "opened-doors" for interested business partners to embark on the high-impact joint venture projects in the electronics sector. This also paves the way for new product development, innovation, R&D and other services within the Electronics and Electrical value chain.

Apart from MATRADE and ETP, the Malaysian Investment Development Authority (MIDA), which is the Malaysian government's main agency for the promotion of the manufacturing and services sectors have said the following:

"*Malaysia today is one of the world's top locations for offshore manufacturing and service-based operations. Many of the existing foreign companies have also continued to show their confidence in the country's potentials as an investment location through their numerous expansions and diversifications over the years, particularly in high technology projects* (MIDA, 2013)."

"*A market-oriented economy combined with a young, educated workforce, an excellent infrastructure, and a government committed to maintaining a business-friendly environment, has been Malaysia's formula for success in attracting investments into the country's electronics sector. Malaysia is now home to MNCs from the USA, Japan,* *Europe, Taiwan and Korea, manufacturing products ranging from semiconductor devices to consumer and industrial electronics* (MIDA, 2011)."

In the electronics manufacturing sector, the Electronic Contract Manufacturing industry has taken a vital role in the development of Malaysia as it has grown significantly over the past decades. This industry has been and always will be responsible for a sizeable share of global electronics manufacturing business. Pertaining to this, Malaysia has always positioned itself by building infrastructure and continuing to facilitate the growth of the Electronic Contract Manufacturing industry. Referring to Market Watch (2011), this industry has stayed as one of the strongest sectors in manufacturing with a remarkable effect on the country's manufacturing output (29.3%), exports (55.9%) and employment (28.8%).

For more than three decades, this industry has registered an excellent performance and attracted a large number of foreign capital investments to this country. Furthermore, the pressure on the Electronic Contract Manufacturing industry has always been intense with shorter product cycle time and on-time delivery of products. With reference to Liemt (2007), contract manufacturing in electronics has always emphasised shorter product cycle time and on-time delivery. Apart from this, customers also expect fast delivery of products, and demand perfection from the onset (right product and defect free). This industry is also highly competitive due to large number of electronic contract manufacturers in the global market producing similar products. Therefore, this makes it difficult for many Electronic Contract Manufacturers to stay in business. The next section introduces the background of Electronic Contract Manufacturing.

1.2 Development of Electronic Contract Manufacturing

Electronic Contract Manufacturing (ECM) integrates a wide array of productive functions pertaining to circuit board and hardware assembly, as well as product engineering at the board and systems level, component design, process engineering, parts procurement and product fulfilment. It also involves other functions such as logistics, distribution, after-sales services and repair or sometimes installation services.

The electronic components (e.g. resistors, diodes, transistors, capacitors, integrated circuits, central processing units, etc.) are connected together by soldering them to a printed circuit board. This process is known as the assembly of printed circuit boards. The final finish products are sub-assemblies or systems (e.g. motherboard, control panel, router, switching power supply, security power supply, lighting control, energy saving light controller, etc.)

The ECM industry is serving a growing range of product markets from personal computers, servers, internet routers, communications equipment (especially mobile phones), consumer products such as computer games, radio/television sets, industrial and automotive electronics and aircraft electronics.

1.2.1 Electronic Contract Manufacturing Companies in Johor

This research study is focused in the ECM companies in Johor. Over the past three decades, Johor's economy has undergone a structural transformation and even today new developments are taking place continuously within the ECM companies. Also, the close proximity to Singapore makes the state uniquely positioned in a win-win partnership with Singapore. Johor has the opportunity to attract ECM companies since the manufacturing cost in Singapore is too high, while Singapore benefits as these companies remain in close proximity for supporting services (e.g. technology, finance, etc.).

Manufacturing activities will always remain critical as they provide the bulk of employment opportunities in Johor. Referring to Hutchinson (2012) the Johor state manufacturing sector consists of some 4,700 firms and employs some 330,000 people. In addition Hutchinson said that the bulk of the employment is provided by a number of large electronics firms. The Malaysian Investment Development Authority (MIDA) and Iskandar Regional Development Authority (IRDA) has always conducted promotional missions with Singapore's Economic Development Board (EDB), encouraging Singapore-based companies to set up more ECM companies in Johor. The next section outlines the background on the ECM business environment to the research study.

1.3 Background to the Study

In the ECM business world, customers expect manufacturers to provide excellent quality, reliable delivery and competitive pricing. The business environment in the ECM industry is very volatile and is one of the most competitive industries in the world. The products' life cycles change very frequently due to their applications and to meet customer demands. Apart from this, the production scenario is highly challenging, often faced with huge losses and wastage that occur on the production floor. Some of the reasons for this wastage can be attributed to the operators skill set, inadequate knowledge of the maintenance personnel, inappropriate process flow, non-availability of components when required and poor infrastructure. Other forms of waste include frequent equipment failures, idle equipment and equipment running below the desired capacity.

Quality related wastes have significant impact on the industry due to wastage of raw material invested and monetary commitments. There are also other invisible wastes, like operating the equipment below the rated speed (speed losses), startup losses, and unplanned break down of the equipment in bottle neck processes. All these losses and wastages on the production floor need to be measured and quantified. The quantified data will allow taking timely, necessary corrective action in reducing the losses and wastages. There is a saying in the industry that "what cannot be measured cannot be managed effectively." Therefore, every company needs to measure their maintenance performance in order to remain competitive (Parida and Kumar, 2006).

In order for the ECM industry to stay competitive and sustain its performance in the production function, it has to develop an effective and efficient equipment maintenance system. The system should be able to facilitate real-time monitoring, assessing and establishing equipment losses and a structure to follow up with the equipment maintenance function. In addition to this, the system must be able to help in developing an efficient skilled workforce, assessing labour utilisation hours, material and overhead cost. Such a comprehensive maintenance system will position the ECM industry as a successful player in the global market.

1.3.1 Focus on Capital Investment

ECM companies are equipped with very complex and sophisticated production equipment. The equipment complexity is due the advancement in product technology and their application in the industry. Also the equipment are constantly being improvised to sustain the production of reliable and quality products. Given this complexity, equipment generally incur high capital investments and they also requires periodic upgrading. Another big challenge for the ECM companies is that, equipment may become obsolete as new products are periodically introduced. In some cases the capital return on investment (ROI) is very poor and there may be substantial revenues losses if the equipment are not performing effectively and efficiently. Given this scenario, ECM companies need to continuously monitor their equipment performance and keep close pace with their workforce skills. This can be achieved through a comprehensive, structured maintenance system with regular training and education for their workforce.

1.3.2 What are the crucial factors for the ECM Industry?

Effectiveness and efficiency of equipment plays important roles in the ECM industry. Referring to Mouzas (2006), effectiveness and efficiency are central terms in assessing and measuring the performance of an organisation. The industry has established an excellent performance which has attracted several companies to re-locate and invests in Malaysia. According to Seng et al., (2005) for more than two decades the development of the Malaysian manufacturing sector had registered an excellent performance and attracted a large amount of foreign capital investments into the country. Also the performance of the ECM industry has allowed Malaysia to enjoy its benefits in the competitive global market. This was made possible because the ECM industry managed to maintain the product quality, product cost and an effective and skillful workforce. However, as time passed, the impact of equipment effectiveness, cost of labour and the cost of equipment have become increasingly critical. This is because the ECM industry has to deploy highly sophisticated and automated equipment to produce new technological products. The maintenance of these equipment, skills training for the workforce, increasing labour cost, material and overhead costs have become critical for manufacturers.

In order to sustain and stay competitive, the industry is forced to evolve with new systems or models in equipment maintenance since manufacturing is always closely linked with manpower and equipment. Also maintenance is one of the strategies used in this competitive battleground (Murthy, 2002; Tsang, 2002). In this situation, a revolutionary concept of Total Productive Maintenance (TPM) methodology has emerged as an important operational strategy to address the production losses due to equipment inefficiencies. The next section discusses the TPM methodology and explains its application to the industry briefly.

1.4 Total Productive Maintenance

TPM seeks to maximise equipment effectiveness throughout the lifetime of the production equipment. According to Tajari and Gotoh (1992) TPM aims at improving existing plant equipment conditions and increase the knowledge and skills of frontline personnel on the production floor. It strives to maintain the equipment in optimum condition in order to prevent unexpected breakdown, speed losses and quality defects. TPM initiatives in production help in streamlining the manufacturing and other business functions, and garnering sustained profits (Ahuja and Khamba, 2007). TPM is adopted, in order to strengthen the manufacturing business performance and to achieve a world-class performance (Swanson 2001; McKone et al., 2001).

TPM in reality is not a new subject. It was first introduced in Japan back in 1971, as an offshoot of the Toyota Production System and it was made popular by the Japan Institute of Plant Maintenance (JIPM). It was only in the 1990's that JIPM actually opened its door, its secret about TPM, to the western world with its first TPM Instructors' class in the English language. Since then, many books, articles and literatures have been written in English about TPM.

So why is TPM gaining popularity? Its impact, in totality, on production is very appealing. Many companies in Japan have their manufacturing systems, modelled to the TPM methodology. TPM improves corporate business results, creates pleasant and productive workplace by changing the way people think and it works closely with equipment improvement activities (Suzuki, 1994). The adaptation of this Japanese culture of TPM is elusive for many western companies who failed to exploit it though the potential is clearly understood. However in the late 1980's, the TPM ideology started to penetrate into America. American manufacturing companies began adapting TPM to the western needs and culture, maneuvering TPM in between their existing and more mature quality system and company culture. The strategic outcome of TPM implementations is the reduced occurrence of unexpected machine (equipment) breakdowns that disrupt production and lead to losses, which can exceed millions of dollars annually (Gosavi, 2006).

Moving forward with TPM, the manufacturing companies were probably the pioneers of TPM since the early nineties, and the adaptation of this Japanese approach has been a challenging one. Traditional approach has yielded low mileage in total productivity. Also the traditional maintenance concepts are regarded as passive and non-productive to the current production function. The traditional maintenance has been considered as a support function, one that is non-productive and not a core function, thus adding little value to the business (Bamber et al., 1999). Hence, implementing TPM in manufacturing companies has emerged as an important operational strategy to overcome the production losses due to equipment inefficiency. Manufacturing companies striving for world class performance have shown that the contribution of an effective maintenance strategy can be significant in providing competitive advantage through its TPM program (Willmott, 1994).

TPM activities in a manufacturing company secure the physical improvement of personnel, equipment and the company as a whole. TPM activities target to improve equipment effectiveness and eventually to secure zero equipment failures, zero defects and reworks, and zero industrial accidents. TPM is focused on improving all the big picture indicators of manufacturing success (Marcus, 2004). TPM is also very much about safety, asset utilisation, expanding capacity without investment in new equipment or people, continuing to lower the cost of equipment maintenance and improve equipment uptime. TPM is a resource-based approach where all employees are responsible for contributing to avoid equipment deterioration, breakdowns, failures and stoppages (Halim and Ramayah, 2010). Implementing TPM requires a long-term commitment with the support of management to achieve the benefits of equipment effectiveness and operational excellence.

The basic practices of TPM are often called the pillars or elements of TPM. TPM paves the way for excellent planning, organising, monitoring and controlling practices through its unique eight-pillar methodology. TPM initiatives, as suggested and promoted by JIPM, involve an eight pillar implementation plan. The TPM pillars substantially increases labour productivity through controlled maintenance, reduction in maintenance costs, and reduced production equipment stoppages and breakdowns. The eight TPM pillars are: Asset Productivity, Autonomous Maintenance, Planned Maintenance, Training and Education, Maintenance Prevention, Quality Maintenance, Office TPM, and Safety and Environment that encompass almost all areas in operating a factory. It comprises and ranges from production to maintenance, quality to new equipment and product introduction, operational losses to safety, environmental and training to administrative functions. Ideally, everyone in the factory at every level is involved. TPM is a productivity movement that introduces a closely knitted, interlinked and structured production system with the objective of positioning the organisation to be more efficient and effective in the running of the day-to-day operations.

TPM implementation involves applying continuous improvement methods to reduce losses in operations. The actual process of adding value to products usually involves operator and equipment. Therefore TPM focuses its improvement activities on equipment-related losses. In an ideal factory, equipment would operate 100% of the time, at maximum of 100% capacity, with an output of 100% good quality units being produced. In reality, however, this is rare. The difference between the ideal and the actual situation is due to losses in operation. Manufacturing companies face these losses in operation on a daily basis. Therefore, TPM gives them the tool to identify the losses and make improvements through Overall Equipment Effectiveness (OEE) percentage. According to Nakajima (1988) OEE is a metric for the evaluation of equipment effectiveness and often used as a driver for improving equipment performance. Furthermore OEE measurement can be applied to several different levels within a manufacturing environment (Bamber, 2003). OEE is a product of availability (time e.g.

24hrs a day), the performance efficiency (speed utilisation rate) and the rate of quality (number of good products).

Therefore the formula is:

OEE% = Availability x Performance efficiency x Rate of Quality x 100

If you cannot measure it, you cannot manage it. The OEE concept paves the way for measuring the effectiveness of production equipment. It is also the backbone of many techniques employed in asset productivity programs.

1.4.1 Overall Equipment Effectiveness

OEE is the core metric for measuring the success of TPM implementation program, (Jeong and Philips, 2001). One of the important contributions of OEE was to consider equipment's hidden losses in computing equipment utilisation. The overall goal of TPM is to raise the overall equipment effectiveness (Shirose, 1989; Huang et al., 2002; Juric et al., 2006). OEE is calculated by obtaining the product of availability of the equipment, performance efficiency of the process and rate of quality products (Ljungberg, 1998; Dal et al., 2000).

TPM focuses on maximising the OEE with the involvement of each employee in the organisation. The TPM activities provide an effective measurement index through OEE that makes the improvement on the production floor (Suzuki, 1994; Shirose, 1996; McKone et al., 1999). Through TPM implementation, OEE has been widely adopted by many manufacturing companies especially the electronics manufacturers. The basic underlying approach of TPM is to maximise production equipment effectiveness, which is typically measured by OEE to improve the equipment effectiveness (Ramayah et al., 2002). OEE has become a very strategic measurement tool since electronic manufacturing companies' employ a big workforce with large number of equipment. Through OEE these companies can identify and address the equipment losses. Apart from this OEE also can facilitate in monitoring the overall manufacturing performance.

1.4.2 Re-Engineered TPM Approach

Many companies struggle to implement TPM, mainly due to insufficient knowledge and skills in understanding the activities' linkage with the 8 TPM Pillars. Apart from this, TPM implementation requires more time, resources and efforts. It usually takes between 3 to 5 years for visible results. This is the reason why few companies have fully implemented all TPM pillars. The overall percentage level of implementing TPM pillars in the companies range from 32% to 61%, and these levels affirm that these companies can be considered as TPM implementing companies (Pramod et al., 2006).

In today's competitive and fast moving environment, companies are looking for quicker and faster results. To achieve this, a fast-track TPM implementation approach is required. In recent years, many companies have attempted to implement TPM programs but less than 10% of companies succeeded in implementing TPM (Mora, 2002). Given the wide scope of TPM program (8 pillars), it can be a difficult task to carry all the 8 pillars of TPM at one go. Also, it can be a big challenge for companies to roll out TPM since there are already other existing practices. It can be difficult to change the mindset and paradigm of the workforce. Given these scenarios many companies typically embarked on their TPM journey with a few pillars in mind and leave the rest status quo until the right time.

The above situation prompts us to see new ways and methods of doing things. Therefore a new approach was needed for TPM program so that companies could see fast results that would impact their performance. Also the new approach must be able to increase the output at the most optimum efficiency level. After due consideration, the following major changes to the TPM approach was considered. The traditional JIPM approach of implementing eight TPM pillars was broken down and a Re-Engineered TPM approach was developed focusing on 3 TPM pillars (Asset Productivity (AP), Autonomous Maintenance (AM) and Planned Maintenance (PM) instead of the original 8 pillars. In the re-engineering effort, these pillars mainly focused on eliminating losses in production equipment, thus improving the overall operational losses on the production floor. The AP pillar, through OEE allows us to identify the losses from all areas - equipment, manpower, method and material. The AM and PM pillars support the activities by getting the operators from the AM team and the technician and engineers from PM team to address the losses in the production equipment. In addition to this, focus was placed on manpower utilisation and monetary related issues. Basically, “manpower” relates to the utilisation time of direct labour (operators) and indirect labour (technicians) and “monetary” relates to the material cost and overhead cost.

The operators’ and technicians’ performance vary from time to time depending on their capability. Also the communication among operators, maintenance people and engineers is very important, and in TPM these people collectively collaborate and interact with each other (Witt, 2006). When the performance of an operator or a technician drops, the production output also drops. This will result in poor equipment performance and will increase the cost and time on the maintenance of equipment. The major factor contributing to this is the skills and attitude of the operators and technicians themselves. Most of the operators and technicians tend to perform in an average manner and for most of the time they will be less productive and this will result in wastage of the planned production time (Subramaniam et al., 2007).

As for the material and overhead cost, it will also keep varying due to poor equipment performance. Poor equipment performance will lead to more raw materials being used and will incur higher overhead (facilities) utilisation time. Having proper systems in place will help to manage unwanted wastage, time and cost.

With all these inefficiencies with equipment, manpower and cost, the Re-Engineered TPM approach will have much better impact on the overall manufacturing performance. To further enhance this approach, we were looking into ways of collecting data on a real-time basis from the production equipment. Real-time data from production equipment will facilitate identifying the equipment losses. Through this process the equipment losses can be addressed timely without much loss to operations. Addressing these losses will impact improving manufacturing performance. The real-time data collection from the production equipment was made possible by Semiconductor Equipment and Materials International (SEMI).

1.4.3 Semiconductor Equipment and Materials International (SEMI) Standards

The SEMI standards facilitate real-time data collection from the production equipment. Apart from OEE as an efficient measurement tool in the manufacturing environment, the

SEMI standards offer a system to monitor the performance of equipment on the production floor. TPM, together with SEMI standards, provide meaningful information about the productivity, utilisation, equipment reliability, equipment availability and equipment maintainability for manufacturing operations. SEMI developed several standards and SEMI E10 standard together with OEE, specifically measures the performance of the equipment. This has created an increased acceptance and, greater interest to explore the application by the electronic manufacturing industries.

As mentioned earlier OEE has three generic elements: Availability, Performance and Quality which monitors the actual performance of the equipment. SEMI E10 compliments this with a common set of metrics for measuring equipment reliability, availability and maintainability. The performance efficiency measures how effectively the equipment is utilised and the effectiveness of quality products produced during the manufacturing process. To establish this link, the SEMI Equipment Communication Standard (SECS) and Generic Equipment Model (GEM) were established. It is defined as, a set of communication interface protocol between a host computer and the production equipment. SECS/GEM standard is a two way communication between a host and equipment on the production floor through the factory local area network (LAN). The factory provides the host system and the equipment manufacturer provides the equipment SECS/GEM standard messaging. Through this system the SECS/GEM standard provides reliable and accurate real-time information from the production equipment. The next section 1.5 introduces the problem statement and describes the issues that need to be addressed.

1.5 Problem Statement

ECM companies, to stay competitive and be successful, require effective and efficient maintenance practices and procedures that can be sustained. In today's competitive environment ECM companies are facing many challenges to stay in business. It is also obvious that the ECM companies in Malaysia are continuously facing stiff global market competition. Therefore, effective and efficient production equipment play a dominant role in manufacturing performance. Apart from this, the equipment performance has become more critical with the introduction of highly sophisticated and automated equipment in the ECM companies. For these equipment, using the traditional utilisation method and measurement is regarded as non-effective in the current manufacturing environment. Further referring to Seng et al., (2005) the traditional maintenance is regarded as passive and non-productive to the current manufacturing or production system. Also the ECM companies have invested in several programs such as maintenance management, preventive maintenance, continuous improvement activities and quality control circles in an effort to increase manufacturing performance. The benefits from these programs have often been limited because of unreliable or inflexible equipment (Garwood 1990; Tajiri and Gotoh 1992).

Some other problems such as non-skillful workforce, lack of training, operating procedures, etc. could indicate that there is a major "misfit" between the skills demand placed on the operator and the requirement of the equipment (Norris et al., 1992). Also, another area of concern is capital investment, buying of additional equipment due to ineffective and inefficient equipment performance. All these problems have made ECM companies realise the importance of establishing a systematic equipment maintenance that can be continuously applied. A comprehensive maintenance system will help ECM companies establish core competency in the global market.

As stated above, over the years ECM companies have explored many differing maintenance approaches on their production equipment to improve manufacturing performance. Due to these difficulties, a new approach through TPM concept was developed to study the impact on manufacturing performance. As stated by Ahuja et al., 2007 "*TPM is a production-driven improvement methodology that is designed to optimize equipment reliability and ensure efficient management of plant assets through the use of employee involvement, linking manufacturing, maintenance and engineering*." Hence, implementing TPM in ECM companies will emerge as an important operational strategy to overcome the production losses due to production equipment inefficiencies. However implementing TPM with all the eight pillars involves time, resources and effort as discussed in section 1.4.2. This has led to the development and introduction of the Re-Engineered TPM approach in ECM companies.

Furthermore, this study on the ECM companies has led to investigate the general questions, "Does Re-Engineered TPM approach and SECS/GEM standard integration impact manufacturing performance?" In addition to this, another question arises "Do Direct and Indirect Labour, and Material and Overhead cost have an impact on manufacturing performance?"

Examining the above general questions, revealed that very little empirical research exist on Re-Engineered TPM approach, labour and cost. Additionally, fewer ECM companies knew about the SECS/GEM standard application and its benefits. Therefore, the Re-

Engineered TPM approach with SECS/GEM standard integration with Autonomous Maintenance, labour utilisation and cost, creates an innovative maintenance system. Furthermore, the system holds the potential for enhancing the efficiency and effectiveness of production equipment. In addition, the system establishes and facilitates improving the ability and skills of all individuals in the ECM companies. Through this system, ECM companies not only establish a comprehensive maintenance system but also aim to improve the maintenance skills and knowledge of production operators and technicians. This system also allows better teamwork and understanding between the production operators and technicians. The ECM companies, through this system, will be equipped to operate effectively and efficiently. The next section 1.6 leads into developing the research questions for this study.

1.6 Research Questions

The objective of the study, creates the avenue for preliminary questions on the approach. How Re-Engineered TPM approach, SECS/GEM standard integration with Autonomous Maintenance, Direct and Indirect Labour, and Material and Overhead cost will impact Output (Manufacturing Performance)? The following research questions were developed and examined:

1. What is the impact of Asset Productivity on Output (Manufacturing Performance)?
2. What is the impact of Planned Maintenance on Output (Manufacturing Performance)?

3. What is the impact of SECS/GEM standard integration with Autonomous Maintenance on Output (Manufacturing Performance)?
4. What is the impact of Direct Labour on Output (Manufacturing Performance)?
5. What is the impact of Indirect Labour on Output (Manufacturing Performance)?
6. What is the impact of Material Cost on Output (Manufacturing Performance)?
7. What is the impact of Overhead Cost on Output (Manufacturing Performance)?

The above research questions are concise and focus on individual elements that provide the path in exploring and writing the research. The next section 1.7 discusses on the research objectives.

1.7 Objectives of the Study

The main objective of this study is to examine the extent to which a Re-Engineered TPM approach can assist in building an effective and efficient production system, with a focus on the effects of SECS/GEM standard integration with Autonomous Maintenance.

The specific objectives of the study are:

1. To evaluate the impact of Re-Engineered TPM approach (Asset Productivity, Autonomous Maintenance and Planned Maintenance) on Output (Manufacturing Performance).
2. To determine the effect of SECS/GEM standard integration with Autonomous Maintenance on Output (Manufacturing Performance).
3. To determine the impact of Direct and Indirect Labour on Output (Manufacturing Performance).

4. To evaluate the impact of Material and Overhead Cost on Output (Manufacturing Performance).

The specific objectives stated above facilitate the development of research methodology that will help to orientate the data collection, analysis and interpretation. It also summarises the research study.

1.8 Significance of the Study

Increased global competition is forcing ECM companies to implement world class maintenance techniques that will improve asset utilisation thus reducing capital expenditure. In any industry, maintenance becomes an integral part of business that influences the production activities (Liyanage and Kumar, 2003). This research study is also to understand the different elements within the production environment that influence the effectiveness and efficiency in a manufacturing company. For example, an efficient production model means obtaining maximum output while minimising required input, such as manpower (production operators), expenditure (material, equipment, facilities power, etc.). Therefore an effective and efficient maintenance program has a significant impact towards enhancing production efficiency, plant availability, reliability and profitability (Maggard and Rhyne, 1992; Jonsson and Lesshammar, 1999). This study has further led to investigate the inter-relationship between Re-Engineered TPM approach and SECS/GEM standard integration with Autonomous Maintenance that will impact on output (manufacturing performance). In addition, this study further evaluates the impact of direct and indirect labour and, material and overhead cost on output (manufacturing performance). The ultimate objective of this study is to improve equipment performance to its maximum capacity, increasing the productivity for ECM companies. The next section explains the scope of the study and introduces panel data analysis.

1.9 Scope of the study

The focus of this study is to develop an effective and efficient productivity system for ECM companies. For this study, the data was collected from ten ECM companies in the southern region (Johor) of Malaysia for a period of 3 years (Jan'2011 ~ Dec'2013). ECM companies were chosen for the study because they had the most relevant information with this research study and the framework. The competitive market and cost challenges have prompted several ECM companies to move towards integrating SECS/GEM standard with TPM methodology. This has created an avenue to automate real-time operational information from the production equipment. Such information together with Re-Engineered TPM approach helps operations by reducing misprocessing, improving equipment utilisation, improving cycle time of products, etc. In addition, the ECM companies can also closely monitor direct and indirect labour utilisation and as well material usage and overhead cost.

1.9.1 Panel Data

The scope of this study is to examine ten ECM companies through panel data analysis consisting of time-series cross-sectional data. Panel data refers to multi-dimensional data frequently involving measurements over a period of time. This data from the ten ECM companies contains real-time monthly data from the production floor. This type of data has the number of cases (monthly data) and over a time period 36 months (3 years) which is said to be long form. To analyse such data, STATA, a panel data statistical software is found to be more suitable to examine the impact on output (Manufacturing Performance). From each company, one similar assembly product line was identified and the data was collected repeatedly over a period of 36 months. The data was compiled monthly, starting from January 2011 to December 2013. The panel data had 36 monthly data from the assembly product line of ten ECM companies (36 months x 10 companies) for this research study. Attempts were made to collect data from more companies, however due to product complexity and diversification it was difficult to fulfill this requirement. Moreover it will be a challenging task to make comparisons between different product types which involve different processes. The next section describes and explains the definitions of terms used in this research study.

1.10 Definition of Terms

The following definition of terms will be used throughout this research paper.

Total Productive Maintenance (TPM) is a manufacturing improvement program that involves all levels of the workforce in the organisation working towards increasing productivity and reducing losses in operations. TPM strives towards improving the productive capacity and developing an effective and efficient workforce.

Overall Equipment Effectiveness (OEE) is a metric to monitor and assess the effectiveness of equipment, an operation or manufacturing process. It is gauged on equipment or operation that measures the productive and non-productive time. This technique works to eliminate the six big losses; downtime (caused by equipment failure), set-up and adjustment (conversion, alignment and fine tuning), equipment stoppage (misfeeds and component jams/assist), speed losses (not operating at ideal speed), startup rejects (initial check-out and reworks) and production rejects (caused by process defects and low yield) (Nakajima, 1989).

Manufacturing is the process of converting raw materials, components or parts into finished goods. Productivity is a measure of the efficiency of production. Productivity is defined as the actual output over the actual input (e.g. number of products per employee). In other words, the measure of productivity is defined as the total output per one unit of the total input. Figure 1.2, illustrates the transformation process between the input and output.

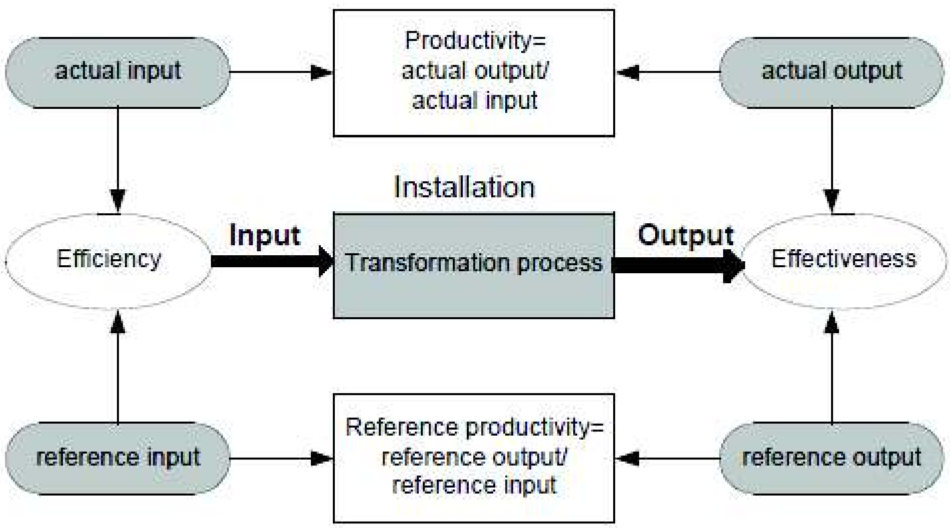

Figure 1.2: Input and Output Transformation Process
Source: Wauters and Mathot (2002)

Manufacturing performance measures how well companies use their assets to maximise the volume of production output. It is also a general measure of the company's output performance to its designed capacity.

Methodology is the strategy, plan of act, process or design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcomes.

Semiconductor Equipment and Materials International (SEMI), an organisation that developed the standards to define a common set of equipment behaviour and communications capabilities.

SECS/GEM standard is the equipment interface protocol for equipment to communicate with the host and vice-versa. It defines messages, equipment state and scenarios to enable factory software to control and monitor production equipment.

SEMI E10 is an established standard that provides a means for evaluating the operational status of production equipment.

SEMI E79 provides critical equipment time-in-state information used in equipment productivity metrics.

Real-time data denotes information that is delivered immediately after collection. There is no delay in the timeliness of the information provided.

Theoretical Framework is a conceptual model of how the researcher theories or makes logical sense of the relationships among the several factors that have been identified as important to the problem. The theoretical framework may be referred to as a conceptual framework or as the research model.

Hypothesis is a tentative statement about the relationship between two or more variables. A hypothesis is a specific, testable prediction about what is expected to happen in the study. Also note: a hypothesis does not have to be correct, hypothesis predicts what the researchers expect to see, the goal of research is to determine whether this guess is right or wrong.

Panel Data (time series cross-sectional data) is a dataset in which the behaviours of entities are observed across time. It contains observations of multiple phenomena obtained over multiple time periods for the same company or individuals.

Multicollinearity refers to a situation when the independent variables are highly correlated with one another.

Equipment Maintenance is the necessary support and repair of equipment. In a broad term it describes the various processes that are deployed to keep equipment in proper working order. Some examples of maintenance include cleaning, inspection, set-up, alignment, adjustment and replacing parts.

Production Equipment (Machine) that resides on the production floor of a manufacturing company and its purpose is to manufacture products (units). In this study it has been used interchangeably with Production Equipment or Equipment or Machine.

Labour utilisation, in this study refers to direct labour (operators) and indirect labour (technicians) hours incurred in production.

Material Cost, in this study refers to the sum of cost of all raw material used in manufacturing the unit or product.

Overhead Cost, in this study refers to the overall manufacturing overhead (administrative salaries, insurance, legal, rent, depreciation and facilities) cost incurred during the production period.

Green Manufacturing Practices (GMP), are practices that do not harm the environment during any part of the manufacturing process. It emphasises the use of processes that do not pollute the environment or harm consumers, employees, or other members of the community.

1.11 Summary

In summary, this chapter has provided an introductory overview of the research study in ECM companies. The significance of the problem and its underlying causes were presented which has led to defining the problem statement. From the problem statement, we identified the research questions and objectives of the study. Also, the significance and scope of the study were discussed. Operational definitions of key terms were presented so that the readers have a better understanding of the terms used in this study.

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APPENDIX A1

Company A: Operational Data from 2011 to 2013

CODE	Company	Period	Time	Output	OverheadCost	APOEE	PMHrs	AMHrs	SECSGEM	DLabHrs	InLabHrs	MatCost
1	Company A	Jan-11	1	5832	45000	49.87	191.8	67.5	1	24084	1505	50000
1	Company A	Feb-11	2	6137	45000	55.98	209.1	54.9	1	24515	1532	50000
1	Company A	Mar-11	3	3556	45000	41.55	226.4	71.5	1	24300	1519	50000
1	Company A	Apr-11	4	3665	45000	40.66	231.5	75.7	1	23869	1492	51000
1	Company A	May-11	5	6224	45000	56.00	194.1	76.1	1	24084	1505	51000
1	Company A	Jun-11	6	3664	45000	42.55	242.5	63.1	1	24084	1505	51000
1	Company A	Jul-11	7	4614	45000	45.88	232.4	51.5	1	24515	1532	52000
1	Company A	Aug-11	8	4000	45000	43.77	230.4	54.5	1	24945	1559	52000
1	Company A	Sep-11	9	6764	45000	56.77	192.4	73.0	1	25375	1586	52000
1	Company A	Oct-11	10	5787	45000	50.77	223.7	76.0	1	25805	1613	51000
1	Company A	Nov-11	11	8030	45000	55.88	206.9	75.2	1	25590	1599	51000
1	Company A	Dec-11	12	8081	45000	55.45	207.8	73.9	1	25375	1586	51000
1	Company A	Jan-12	13	7258	50000	56.77	172.8	95.0	1	23654	1478	52000
1	Company A	Feb-12	14	7463	50000	55.99	191.3	77.3	1	23869	1492	52000
1	Company A	Mar-12	15	7568	50000	54.89	210.2	69.1	1	23869	1492	52000
1	Company A	Apr-12	16	7890	50000	58.77	190.0	58.4	1	24084	1505	52000
1	Company A	May-12	17	7234	50000	54.76	199.2	81.7	1	24300	1519	52000
1	Company A	Jun-12	18	7358	50000	54.99	201.3	73.7	1	24084	1505	52000
1	Company A	Jul-12	19	7567	50000	56.88	190.2	87.9	1	24084	1505	54000
1	Company A	Aug-12	20	7968	50000	59.00	189.2	66.2	1	23654	1478	54000
1	Company A	Sep-12	21	8099	50000	60.54	168.0	70.3	1	24084	1505	54000
1	Company A	Oct-12	22	8109	50000	61.00	175.9	72.1	1	24084	1505	54000
1	Company A	Nov-12	23	8009	50000	60.99	157.1	71.0	1	24084	1505	54000
1	Company A	Dec-12	24	8150	50000	61.55	163.8	70.5	1	24084	1505	54000
1	Company A	Jan-13	25	8200	48000	61.55	143.1	83.3	1	17418	1452	50000
1	Company A	Feb-13	26	8309	48000	60.99	145.8	72.0	1	17580	1465	50000
1	Company A	Mar-13	27	8310	48000	60.09	148.6	67.9	1	17741	1478	50000
1	Company A	Apr-13	28	8150	48000	61.00	147.5	64.0	1	17741	1478	50000
1	Company A	May-13	29	8450	48000	62.55	156.0	67.0	1	17580	1465	50000
1	Company A	Jun-13	30	8400	48000	62.77	145.6	68.0	1	17580	1465	50000
1	Company A	Jul-13	31	8512	48000	63.45	153.0	72.5	1	17902	1492	49000
1	Company A	Aug-13	32	8733	48000	65.56	139.0	61.0	1	18063	1505	49000
1	Company A	Sep-13	33	8678	48000	64.00	138.5	67.0	1	18063	1505	49000
1	Company A	Oct-13	34	8599	48000	64.99	138.0	65.0	1	18386	1532	49000
1	Company A	Nov-13	35	8778	48000	65.00	134.8	70.6	1	18386	1532	49000
1	Company A	Dec-13	36	8978	48000	66.00	120.8	69.0	1	18386	1532	49000

APPENDIX A2

Company B: Operational Data from 2011 to 2013

CODE	Company	Period	Time	Output	OverheadCost	APOEE	PMHrs	AMHrs	SECSGEM	DLabHrs	InLabHrs	MatCost
2	Company B	Jan-11	1	4165	45000	45.67	235.8	0	0	25805	1613	50000
2	Company B	Feb-11	2	4832	45000	47.88	221.4	0	0	25590	1599	50000
2	Company B	Mar-11	3	4614	45000	46.88	246.8	0	0	25805	1613	50000
2	Company B	Apr-11	4	4887	45000	48.67	242.4	0	0	25590	1599	51000
2	Company B	May-11	5	4986	45000	50.66	214.2	0	0	25590	1599	51000
2	Company B	Jun-11	6	4766	45000	48.00	209.9	0	0	25160	1572	51000
2	Company B	Jul-11	7	4660	45000	46.00	222.3	0	0	25375	1586	52000
2	Company B	Aug-11	8	4599	45000	47.99	227.5	0	0	25375	1586	52000
2	Company B	Sep-11	9	4678	45000	47.00	215.6	0	0	25805	1613	52000
2	Company B	Oct-11	10	4867	45000	47.55	233.5	0	0	25805	1613	51000
2	Company B	Nov-11	11	4900	45000	50.01	233.1	0	0	25375	1586	51000
2	Company B	Dec-11	12	4876	45000	49.44	221.1	0	0	25375	1586	51000
2	Company B	Jan-12	13	4164	50000	44.88	256.7	0	0	25375	1586	50000
2	Company B	Feb-12	14	4831	50000	48.88	209.9	0	0	25375	1586	50000
2	Company B	Mar-12	15	4549	50000	46.78	237.0	0	0	25805	1613	50000
2	Company B	Apr-12	16	4565	50000	46.00	237.4	0	0	25805	1613	49000
2	Company B	May-12	17	4832	50000	49.99	224.6	0	0	25805	1613	49000
2	Company B	Jun-12	18	4499	50000	45.88	233.0	0	0	25590	1599	49000
2	Company B	Jul-12	19	4966	50000	49.98	245.4	0	0	25375	1586	50500
2	Company B	Aug-12	20	4833	50000	48.76	256.5	0	0	25375	1586	50500
2	Company B	Sep-12	21	4500	50000	47.88	223.7	0	0	25805	1613	50500
2	Company B	Oct-12	22	4867	50000	49.78	233.4	0	0	25805	1613	51000
2	Company B	Nov-12	23	4834	50000	49.56	212.5	0	0	25805	1613	51000
2	Company B	Dec-12	24	4890	50000	48.55	207.6	0	0	25590	1599	51000
2	Company B	Jan-13	25	4834	48000	48.95	237.3	0	0	24945	1559	50000
2	Company B	Feb-13	26	4890	48000	49.00	213.9	0	0	24945	1559	50000
2	Company B	Mar-13	27	4946	48000	48.90	245.9	0	0	24730	1546	50000
2	Company B	Apr-13	28	4845	48000	49.88	249.0	0	0	25160	1572	50000
2	Company B	May-13	29	5009	48000	50.23	224.5	0	0	24515	1532	50000
2	Company B	Jun-13	30	5050	48000	50.55	223.2	0	0	24515	1532	50000
2	Company B	Jul-13	31	4950	48000	50.00	233.4	0	0	24945	1559	50500
2	Company B	Aug-13	32	4978	48000	50.10	244.6	0	0	24945	1559	50500
2	Company B	Sep-13	33	5110	48000	52.66	228.4	0	0	25590	1599	50500
2	Company B	Oct-13	34	5010	48000	51.77	226.3	0	0	25590	1599	50500
2	Company B	Nov-13	35	4977	48000	48.99	217.0	0	0	25375	1586	50500
2	Company B	Dec-13	36	4990	48000	49.77	211.6	0	0	25375	1586	50500

APPENDIX A3

Company C: Operational Data from 2011 to 2013

CODE	Company	Period	Time	Output	OverheadCost	APOEE	PMHrs	AMHrs	SECSGEM	DLabHrs	InLabHrs	MatCost
3	Company C	Jan-11	1	12350	34000	57.70	167.8	103.1	1	12943	1079	25000
3	Company C	Feb-11	2	12076	34000	56.79	155.3	111.9	1	12822	1068	25000
3	Company C	Mar-11	3	12470	34000	58.00	162.5	107.3	1	13064	1089	25000
3	Company C	Apr-11	4	13456	34000	59.78	160.1	94.9	1	13306	1109	26000
3	Company C	May-11	5	10223	34000	47.00	195.7	121.8	1	13064	1089	24000
3	Company C	Jun-11	6	12345	34000	57.89	175.6	91.8	1	13185	1099	25000
3	Company C	Jul-11	7	11134	34000	56.78	176.6	103.3	1	13064	1089	25000
3	Company C	Aug-11	8	10345	34000	48.56	204.1	109.7	1	13064	1089	24000
3	Company C	Sep-11	9	11123	34000	55.89	175.5	110.1	1	13185	1099	24000
3	Company C	Oct-11	10	9950	34000	45.90	201.2	121.5	1	12459	1038	22000
3	Company C	Nov-11	11	8905	34000	44.90	233.9	113.1	1	12459	1038	22000
3	Company C	Dec-11	12	10134	34000	48.89	196.4	125.3	1	13064	1089	24000
3	Company C	Jan-12	13	13340	38000	49.99	184.8	118.9	1	11290	1058	27000
3	Company C	Feb-12	14	13078	38000	49.12	200.1	101.1	1	11397	1068	27000
3	Company C	Mar-12	15	12970	38000	50.12	193.3	118.5	1	11612	1089	27000
3	Company C	Apr-12	16	13300	38000	50.99	181.0	117.7	1	11827	1109	26600
3	Company C	May-12	17	13100	38000	52.10	193.7	102.6	1	11827	1109	26600
3	Company C	Jun-12	18	13129	38000	51.90	165.0	118.9	1	11397	1068	26600
3	Company C	Jul-12	19	12854	38000	53.99	169.2	119.3	1	11290	1058	25000
3	Company C	Aug-12	20	12235	38000	55.45	157.9	120.8	1	11505	1079	25000
3	Company C	Sep-12	21	12003	38000	54.99	171.4	107.5	1	11720	1099	25000
3	Company C	Oct-12	22	12300	38000	56.78	178.2	90.4	1	11290	1058	24500
3	Company C	Nov-12	23	11023	38000	57.54	173.5	88.2	1	11397	1068	24500
3	Company C	Dec-12	24	11254	38000	58.60	169.4	84.7	1	11290	1058	24500
3	Company C	Jan-13	25	14330	39679	59.99	175.0	76.4	1	11505	863	30000
3	Company C	Feb-13	26	13377	39673	59.00	168.0	86.3	1	11720	879	30000
3	Company C	Mar-13	27	14566	39667	60.50	168.5	77.3	1	11935	895	30000
3	Company C	Apr-13	28	13997	39673	60.78	153.3	85.2	1	11720	879	30000
3	Company C	May-13	29	14200	39676	62.55	140.0	82.3	1	11612	871	30000
3	Company C	Jun-13	30	14100	39685	61.09	145.3	78.7	1	11290	847	30000
3	Company C	Jul-13	31	13990	39682	63.99	141.3	76.1	1	11397	855	32000
3	Company C	Aug-13	32	13950	39676	64.00	138.2	74.3	1	11612	871	32000
3	Company C	Sep-13	33	14004	39670	64.55	145.4	71.0	1	11827	887	32000
3	Company C	Oct-13	34	14500	39691	64.99	130.5	77.2	1	11075	831	32000
3	Company C	Nov-13	35	13960	39688	63.55	138.0	78.4	1	11182	839	32000
3	Company C	Dec-13	36	13500	39676	63.90	140.8	79.3	1	11612	871	32000

APPENDIX A4

Company D: Operational Data from 2011 to 2013

CODE	Company	Period	Time	Output	OverheadCost	APOEE	PMHrs	AMHrs	SECSGEM	DLabHrs	InLabHrs	MatCost
4	Company D	Jan-11	1	11355	34000	48.38	203.1	0	0	13548	1129	32000
4	Company D	Feb-11	2	12007	34000	49.46	204.8	0	0	13789	1149	32000
4	Company D	Mar-11	3	11447	34000	48.02	201.3	0	0	14515	1210	32000
4	Company D	Apr-11	4	11140	34000	48.09	210.8	0	0	14273	1189	35000
4	Company D	May-11	5	11999	34000	48.01	215.8	0	0	14031	1169	32000
4	Company D	Jun-11	6	11130	34000	47.34	215.6	0	0	13185	1099	32000
4	Company D	Jul-11	7	11023	34000	46.00	236.6	0	0	13548	1129	32000
4	Company D	Aug-11	8	11032	34000	45.12	234.1	0	0	13668	1139	32000
4	Company D	Sep-11	9	11112	34000	49.44	188.4	0	0	13427	1119	31000
4	Company D	Oct-11	10	10245	34000	42.25	223.3	0	0	13910	1159	32000
4	Company D	Nov-11	11	10101	34000	43.45	233.9	0	0	14031	1169	32000
4	Company D	Dec-11	12	11513	34000	49.12	218.8	0	0	14394	1200	32000
4	Company D	Jan-12	13	11001	38000	49.35	213.0	0	0	13910	1159	34000
4	Company D	Feb-12	14	11107	38000	49.44	212.0	0	0	14031	1169	34000
4	Company D	Mar-12	15	12007	38000	50.18	182.2	0	0	14273	1189	34000
4	Company D	Apr-12	16	12141	38000	50.26	202.2	0	0	14152	1179	33000
4	Company D	May-12	17	12021	38000	51.45	200.4	0	0	13789	1149	33000
4	Company D	Jun-12	18	11130	38000	49.17	202.2	0	0	13548	1129	33000
4	Company D	Jul-12	19	11045	38000	48.39	221.0	0	0	14031	1169	33000
4	Company D	Aug-12	20	12011	38000	50.44	211.2	0	0	14273	1189	34000
4	Company D	Sep-12	21	11023	38000	48.40	211.9	0	0	14394	1200	34000
4	Company D	Oct-12	22	11241	38000	48.19	197.0	0	0	13548	1129	34000
4	Company D	Nov-12	23	11451	38000	49.10	188.4	0	0	13789	1149	34000
4	Company D	Dec-12	24	11014	38000	49.00	223.0	0	0	14031	1169	34000
4	Company D	Jan-13	25	12101	39160	50.22	202.1	0	0	13548	1129	33000
4	Company D	Feb-13	26	12103	39160	51.48	203.5	0	0	13548	1129	33000
4	Company D	Mar-13	27	12223	39145	51.29	199.9	0	0	13789	1149	33000
4	Company D	Apr-13	28	11143	39138	49.33	201.2	0	0	13910	1159	32500
4	Company D	May-13	29	11221	39168	50.30	214.7	0	0	13427	1119	32500
4	Company D	Jun-13	30	12132	39168	51.33	211.1	0	0	13427	1119	32500
4	Company D	Jul-13	31	12044	39145	50.06	199.3	0	0	13789	1149	32500
4	Company D	Aug-13	32	11214	39123	49.45	204.1	0	0	14152	1179	32500
4	Company D	Sep-13	33	12104	39115	51.37	206.1	0	0	14273	1189	35000
4	Company D	Oct-13	34	11143	39100	49.33	217.9	0	0	14515	1210	35000
4	Company D	Nov-13	35	11045	39160	49.46	204.6	0	0	13548	1129	35000
4	Company D	Dec-13	36	12112	39168	51.22	195.0	0	0	13427	1119	35000

APPENDIX A5

Company E: Operational Data from 2011 to 2013

CODE	Company	Period	Time	Output	OverheadCost	APOEE	PMHrs	AMHrs	SECSGEM	DLabHrs	InLabHrs	MatCost
5	Company E	Jan-11	1	7346	23000	59.60	157.2	89.8	1	18708	1559	18000
5	Company E	Feb-11	2	6191	23000	53.03	158.9	113.5	1	18386	1532	18000
5	Company E	Mar-11	3	6019	23000	52.21	161.0	105.9	1	19031	1586	18000
5	Company E	Apr-11	4	7906	23000	61.22	158.4	75.6	1	18708	1559	18500
5	Company E	May-11	5	7383	23000	57.71	115.7	100.8	1	19354	1613	18500
5	Company E	Jun-11	6	5992	23000	45.01	215.3	93.9	1	19192	1599	18500
5	Company E	Jul-11	7	7701	23000	57.45	128.1	122.6	1	19676	1640	18500
5	Company E	Aug-11	8	9085	23000	64.57	114.2	71.7	1	19515	1626	18500
5	Company E	Sep-11	9	9844	23000	63.23	112.9	71.6	1	19676	1640	17500
5	Company E	Oct-11	10	7200	23000	45.61	180.7	83.6	1	18708	1559	18000
5	Company E	Nov-11	11	6500	23000	46.70	189.1	121.7	1	18386	1532	17500
5	Company E	Dec-11	12	6600	23000	45.78	205.3	110.1	1	18386	1532	17500
5	Company E	Jan-12	13	6970	27000	58.99	147.8	101.7	1	15053	1505	21000
5	Company E	Feb-12	14	6800	27000	59.14	152.5	110.8	1	14784	1478	21000
5	Company E	Mar-12	15	6567	27000	54.99	191.2	99.3	1	14784	1478	21000
5	Company E	Apr-12	16	5900	27000	52.33	170.4	125.2	1	14918	1492	19800
5	Company E	May-12	17	7210	27000	63.90	139.2	81.1	1	15053	1505	19800
5	Company E	Jun-12	18	7020	27000	62.77	145.4	83.8	1	15053	1505	19800
5	Company E	Jul-12	19	7700	27000	65.40	138.1	82.0	1	14784	1478	19800
5	Company E	Aug-12	20	7690	27000	64.22	143.3	79.1	1	14784	1478	19800
5	Company E	Sep-12	21	7545	27000	63.99	140.5	82.5	1	15322	1532	19800
5	Company E	Oct-12	22	6933	27000	59.34	166.8	96.8	1	15322	1532	20000
5	Company E	Nov-12	23	6788	27000	58.99	160.2	97.8	1	15053	1505	20000
5	Company E	Dec-12	24	6209	27000	53.66	178.6	104.5	1	15053	1505	20000
5	Company E	Jan-13	25	6900	28000	59.99	156.8	83.6	1	11612	1089	22000
5	Company E	Feb-13	26	6990	28000	60.99	146.1	105.6	1	11827	1109	22000
5	Company E	Mar-13	27	7005	28000	62.99	146.4	83.5	1	12150	1139	22000
5	Company E	Apr-13	28	7100	28000	63.78	152.5	79.7	1	12042	1129	22000
5	Company E	May-13	29	7245	28000	64.88	135.5	81.2	1	12365	1159	22000
5	Company E	Jun-13	30	7009	28000	63.77	145.1	78.8	1	12472	1169	22000
5	Company E	Jul-13	31	7090	28000	62.44	144.0	82.7	1	11612	1089	21500
5	Company E	Aug-13	32	7235	28000	62.77	150.1	77.5	1	11720	1099	21500
5	Company E	Sep-13	33	7300	28000	64.55	140.6	72.3	1	11612	1089	21500
5	Company E	Oct-13	34	7300	28000	65.77	145.5	75.0	1	11827	1109	21500
5	Company E	Nov-13	35	6998	28000	60.12	162.0	94.5	1	12257	1149	21500
5	Company E	Dec-13	36	7002	28000	60.55	151.3	91.0	1	12472	1169	21500

APPENDIX A6

Company F: Operational Data from 2011 to 2013

CODE	Company	Period	Time	Output	OverheadCost	APOEE	PMHrs	AMHrs	SECSGEM	DLabHrs	InLabHrs	MatCost
6	Company F	Jan-11	1	5400	23000	49.67	214.1	0	0	19354	1613	21000
6	Company F	Feb-11	2	5678	23000	48.99	211.5	0	0	19515	1626	21000
6	Company F	Mar-11	3	6230	23000	51.22	212.0	0	0	19837	1653	21000
6	Company F	Apr-11	4	6100	23000	50.45	202.4	0	0	19999	1667	21000
6	Company F	May-11	5	4500	23000	42.00	267.0	0	0	19354	1613	19500
6	Company F	Jun-11	6	4400	23000	43.55	224.0	0	0	19192	1599	19500
6	Company F	Jul-11	7	5200	23000	47.00	234.2	0	0	19031	1586	19500
6	Company F	Aug-11	8	5100	23000	46.99	243.1	0	0	19676	1640	19500
6	Company F	Sep-11	9	5323	23000	46.78	223.3	0	0	19837	1653	19500
6	Company F	Oct-11	10	4956	23000	44.00	234.4	0	0	19999	1667	18000
6	Company F	Nov-11	11	4800	23000	45.00	248.0	0	0	19515	1626	18000
6	Company F	Dec-11	12	4600	23000	42.00	235.1	0	0	19515	1626	18000
6	Company F	Jan-12	13	5500	27000	48.66	234.8	0	0	19676	1640	22000
6	Company F	Feb-12	14	5400	27000	47.99	245.1	0	0	19837	1653	22000
6	Company F	Mar-12	15	5345	27000	49.64	226.8	0	0	19515	1626	22000
6	Company F	Apr-12	16	5900	27000	51.00	215.5	0	0	19676	1640	22000
6	Company F	May-12	17	6012	27000	52.99	213.5	0	0	19837	1653	22000
6	Company F	Jun-12	18	5914	27000	50.98	222.1	0	0	19999	1667	22000
6	Company F	Jul-12	19	5995	27000	51.00	224.8	0	0	20160	1680	21500
6	Company F	Aug-12	20	5450	27000	49.99	228.5	0	0	19999	1667	21500
6	Company F	Sep-12	21	5478	27000	48.96	203.3	0	0	19676	1640	21500
6	Company F	Oct-12	22	4956	27000	45.99	215.4	0	0	19837	1653	21500
6	Company F	Nov-12	23	4965	27000	43.77	215.4	0	0	19999	1667	21500
6	Company F	Dec-12	24	4945	27000	44.90	213.8	0	0	20160	1680	21500
6	Company F	Jan-13	25	4500	28000	45.88	224.6	0	0	19031	1586	23000
6	Company F	Feb-13	26	4800	28000	47.99	245.8	0	0	18708	1559	23000
6	Company F	Mar-13	27	4978	28000	46.99	255.1	0	0	19031	1586	23000
6	Company F	Apr-13	28	4990	28000	49.99	234.1	0	0	19192	1599	24000
6	Company F	May-13	29	5002	28000	50.25	227.7	0	0	18870	1572	24000
6	Company F	Jun-13	30	5100	28000	51.00	227.5	0	0	19515	1626	24000
6	Company F	Jul-13	31	5090	28000	51.34	213.2	0	0	19515	1626	23000
6	Company F	Aug-13	32	5200	28000	50.78	191.8	0	0	19676	1640	23000
6	Company F	Sep-13	33	5309	28000	52.66	200.8	0	0	19837	1653	23000
6	Company F	Oct-13	34	5045	28000	51.34	208.3	0	0	19031	1586	23000
6	Company F	Nov-13	35	5045	28000	51.09	195.0	0	0	19999	1667	23000
6	Company F	Dec-13	36	5080	28000	50.55	204.1	0	0	19999	1667	23000

APPENDIX A7

Company G: Operational Data from 2011 to 2013

CODE	Company	Period	Time	Output	OverheadCost	APOEE	PMHrs	AMHrs	SECSGEM	DLabHrs	InLabHrs	MatCost
7	Company G	Jan-11	1	210677	30000	62.44	121.2	85.6	1	49795	2845	7772876
7	Company G	Feb-11	2	221445	30000	63.56	109.0	93.4	1	50232	2870	7728761
7	Company G	Mar-11	3	221345	30000	63.22	110.7	94.7	1	50669	2895	7832704
7	Company G	Apr-11	4	210324	30000	61.23	109.9	98.9	1	51542	2945	7636024
7	Company G	May-11	5	209905	30000	60.10	119.1	96.2	1	49358	2820	7983216
7	Company G	Jun-11	6	201134	30000	60.67	112.7	99.8	1	54600	3120	7642192
7	Company G	Jul-11	7	229889	30000	64.55	108.6	89.7	1	53726	3070	7874348
7	Company G	Aug-11	8	198704	30000	59.55	116.6	98.9	1	54163	3095	7159275
7	Company G	Sep-11	9	210089	30000	62.34	120.4	93.2	1	52853	3020	7375088
7	Company G	Oct-11	10	200563	30000	60.99	108.9	97.1	1	53290	3045	7840418
7	Company G	Nov-11	11	219045	30000	62.00	115.1	94.5	1	52853	3020	7925861
7	Company G	Dec-11	12	201094	30000	60.12	117.7	91.8	1	51979	2970	7428721
7	Company G	Jan-12	13	220014	30000	63.45	112.2	78.7	1	48048	2746	7872876
7	Company G	Feb-12	14	218005	30000	61.40	122.8	77.3	1	47611	2721	7828761
7	Company G	Mar-12	15	219005	30000	62.33	111.9	96.7	1	48922	2796	7932704
7	Company G	Apr-12	16	210045	30000	62.56	107.6	101.7	1	49795	2845	7236024
7	Company G	May-12	17	220144	30000	64.78	108.5	85.7	1	49358	2820	7783216
7	Company G	Jun-12	18	220133	30000	65.54	95.7	77.1	1	52416	2995	7542192
7	Company G	Jul-12	19	220456	30000	63.45	109.0	82.2	1	51106	2920	7774348
7	Company G	Aug-12	20	229567	30000	63.48	110.3	87.6	1	51542	2945	6959275
7	Company G	Sep-12	21	228123	30000	62.98	110.1	88.5	1	48485	2771	6975088
7	Company G	Oct-12	22	227893	30000	63.77	109.3	82.3	1	47174	2696	8840418
7	Company G	Nov-12	23	218678	30000	62.00	119.6	82.7	1	50669	2895	7625861
7	Company G	Dec-12	24	219453	30000	61.34	126.9	86.1	1	50232	2870	6428721
7	Company G	Jan-13	25	247000	32000	79.56	43.0	67.5	1	41184	2059	8892000
7	Company G	Feb-13	26	241524	32000	78.50	40.8	67.8	1	41558	2078	7728761
7	Company G	Mar-13	27	230140	32000	70.65	62.2	93.8	1	41933	2097	7732704
7	Company G	Apr-13	28	233751	32000	75.60	50.3	83.0	1	44928	2246	7106024
7	Company G	May-13	29	227232	32000	75.78	67.1	63.2	1	44554	2228	7453216
7	Company G	Jun-13	30	190180	32000	65.66	98.8	89.2	1	44179	2209	6542192
7	Company G	Jul-13	31	279843	32000	80.12	37.3	70.1	1	43805	2190	10074348
7	Company G	Aug-13	32	222345	32000	65.78	95.5	91.8	1	43430	2172	6759275
7	Company G	Sep-13	33	248962	32000	75.98	45.1	78.6	1	43056	2153	5975088
7	Company G	Oct-13	34	271524	32000	78.40	35.9	75.9	1	42682	2134	9340418
7	Company G	Nov-13	35	198990	32000	60.89	108.7	106.7	1	42307	2115	6285861
7	Company G	Dec-13	36	201345	32000	61.58	108.8	109.4	1	43430	2172	6428721

APPENDIX A8

Company H: Operational Data from 2011 to 2013

CODE	Company	Period	Time	Output	OverheadCost	APOEE	PMHrs	AMHrs	SECSGEM	DLabHrs	InLabHrs	MatCost
8	Company H	Jan-11	1	188950	30000	51.23	191.0	0	0	62899	4717	7000000
8	Company H	Feb-11	2	188775	30000	51.27	200.6	0	0	61402	4605	7000000
8	Company H	Mar-11	3	199805	30000	53.45	163.5	0	0	60902	4568	7000000
8	Company H	Apr-11	4	199886	30000	53.78	174.5	0	0	62400	4680	7000000
8	Company H	May-11	5	189456	30000	51.22	194.0	0	0	63898	4792	7000000
8	Company H	Jun-11	6	178665	30000	49.78	208.7	0	0	62899	4717	7000000
8	Company H	Jul-11	7	177845	30000	49.55	197.1	0	0	61901	4643	7200000
8	Company H	Aug-11	8	176904	30000	49.90	190.4	0	0	60902	4568	7200000
8	Company H	Sep-11	9	189775	30000	50.55	161.7	0	0	64397	4830	7200000
8	Company H	Oct-11	10	188094	30000	51.78	193.1	0	0	61901	4643	7200000
8	Company H	Nov-11	11	179845	30000	49.98	194.1	0	0	63398	4755	7200000
8	Company H	Dec-11	12	189123	30000	51.34	190.3	0	0	63898	4792	7200000
8	Company H	Jan-12	13	199004	30000	53.44	190.3	0	0	61901	4643	6700000
8	Company H	Feb-12	14	189003	30000	50.55	200.1	0	0	60902	4568	6700000
8	Company H	Mar-12	15	200678	30000	56.34	165.1	0	0	62400	4680	6700000
8	Company H	Apr-12	16	209345	30000	56.78	177.8	0	0	63398	4755	6700000
8	Company H	May-12	17	199034	30000	54.34	173.6	0	0	64397	4830	6700000
8	Company H	Jun-12	18	177904	30000	50.54	203.5	0	0	64896	4867	6700000
8	Company H	Jul-12	19	189004	30000	52.34	177.2	0	0	63898	4792	7000000
8	Company H	Aug-12	20	188904	30000	53.45	178.8	0	0	61402	4605	7000000
8	Company H	Sep-12	21	178904	30000	51.79	190.0	0	0	60403	4530	7000000
8	Company H	Oct-12	22	177845	30000	49.56	190.8	0	0	62899	4717	7000000
8	Company H	Nov-12	23	176890	30000	49.98	182.6	0	0	64397	4830	7000000
8	Company H	Dec-12	24	188009	30000	52.34	189.9	0	0	64896	4867	7000000
8	Company H	Jan-13	25	190122	32000	55.10	168.7	0	0	57907	4343	6500000
8	Company H	Feb-13	26	180034	32000	58.55	160.8	0	0	57408	4306	6500000
8	Company H	Mar-13	27	210004	32000	60.23	148.9	0	0	56909	4268	6500000
8	Company H	Apr-13	28	193455	32000	59.12	154.6	0	0	58406	4380	6500000
8	Company H	May-13	29	170456	32000	55.78	171.7	0	0	58906	4418	6500000
8	Company H	Jun-13	30	178000	32000	55.45	170.3	0	0	61402	4605	6500000
8	Company H	Jul-13	31	191234	32000	59.12	150.8	0	0	61901	4643	6500000
8	Company H	Aug-13	32	189034	32000	50.78	160.1	0	0	62400	4680	6500000
8	Company H	Sep-13	33	193453	32000	59.15	152.1	0	0	60902	4568	6500000
8	Company H	Oct-13	34	187900	32000	58.11	159.8	0	0	60403	4530	6500000
8	Company H	Nov-13	35	188456	32000	57.45	162.5	0	0	59904	4493	6500000
8	Company H	Dec-13	36	190055	32000	59.44	152.2	0	0	59405	4455	6500000

APPENDIX A9

Company I: Operational Data from 2011 to 2013

CODE	Company	Period	Time	Output	OverheadCost	APOEE	PMHrs	AMHrs	SECSGEM	DLabHrs	InLabHrs	MatCost
9	Company I	Jan-11	1	57556	40000	59.65	142.7	87.0	1	31300	1423	690000
9	Company I	Feb-11	2	58478	40000	60.87	142.4	83.7	1	30751	1398	690000
9	Company I	Mar-11	3	57798	40000	59.77	151.7	84.5	1	30476	1385	690000
9	Company I	Apr-11	4	57878	40000	59.97	147.6	83.0	1	30202	1373	690000
9	Company I	May-11	5	56012	40000	58.55	158.3	80.6	1	31025	1410	690000
9	Company I	Jun-11	6	55334	40000	58.69	145.5	87.3	1	31574	1435	690000
9	Company I	Jul-11	7	53212	40000	56.87	149.0	96.1	1	32947	1498	695000
9	Company I	Aug-11	8	58078	40000	60.54	143.9	82.0	1	33222	1510	695000
9	Company I	Sep-11	9	59789	40000	61.33	142.4	77.1	1	32398	1473	695000
9	Company I	Oct-11	10	58945	40000	61.67	128.9	87.5	1	31849	1448	695000
9	Company I	Nov-11	11	59923	40000	62.77	136.8	73.8	1	32673	1485	695000
9	Company I	Dec-11	12	58907	40000	61.87	131.6	77.8	1	32124	1460	695000
9	Company I	Jan-12	13	57456	48000	59.67	154.3	79.3	1	31300	1423	700500
9	Company I	Feb-12	14	57778	48000	59.55	149.3	77.8	1	32398	1473	700500
9	Company I	Mar-12	15	56798	48000	58.99	152.8	78.4	1	31574	1435	700500
9	Company I	Apr-12	16	59078	48000	62.88	146.4	64.2	1	31849	1448	710000
9	Company I	May-12	17	60012	48000	62.93	151.2	64.1	1	32124	1460	710000
9	Company I	Jun-12	18	60334	48000	62.61	136.2	76.8	1	33496	1523	710000
9	Company I	Jul-12	19	61123	48000	63.54	136.0	75.7	1	33222	1510	700800
9	Company I	Aug-12	20	59078	48000	62.87	150.4	66.8	1	32947	1498	700800
9	Company I	Sep-12	21	58789	48000	61.64	146.3	66.7	1	33771	1535	700800
9	Company I	Oct-12	22	59945	48000	61.66	146.1	68.7	1	34045	1548	700800
9	Company I	Nov-12	23	60123	48000	61.89	142.7	81.5	1	32673	1485	700800
9	Company I	Dec-12	24	59907	48000	62.77	144.2	69.1	1	34320	1560	700800
9	Company I	Jan-13	25	55467	45000	58.99	151.9	73.9	1	28454	1423	600000
9	Company I	Feb-13	26	59674	45000	60.14	152.2	74.6	1	29453	1473	600000
9	Company I	Mar-13	27	53456	45000	58.33	152.2	68.8	1	28704	1435	600000
9	Company I	Apr-13	28	54388	45000	64.30	147.4	59.6	1	28954	1448	650000
9	Company I	May-13	29	55678	45000	64.56	141.2	59.9	1	29203	1460	650000
9	Company I	Jun-13	30	56784	45000	67.55	132.0	53.5	1	30451	1523	650000
9	Company I	Jul-13	31	60045	45000	72.33	100.0	49.6	1	30202	1510	700000
9	Company I	Aug-13	32	59089	45000	70.54	95.7	59.3	1	29952	1498	700000
9	Company I	Sep-13	33	54574	45000	60.55	152.6	65.4	1	30701	1535	700000
9	Company I	Oct-13	34	60234	45000	71.01	96.9	65.0	1	30950	1548	720000
9	Company I	Nov-13	35	59989	45000	70.23	94.7	62.4	1	29702	1485	720000
9	Company I	Dec-13	36	58890	45000	69.98	98.1	61.8	1	31200	1560	720000

APPENDIX A10

Company J: Operational Data from 2011 to 2013

CODE	Company	Period	Time	Output	OverheadCost	APOEE	PMHrs	AMHrs	SECSGEM	DLabHrs	InLabHrs	MatCost
10	Company J	Jan-11	1	37088	40000	57.88	156.9	0	0	47174	2359	500000
10	Company J	Feb-11	2	38756	40000	58.03	153.2	0	0	46800	2340	500000
10	Company J	Mar-11	3	38451	40000	58.45	153.6	0	0	46426	2321	500000
10	Company J	Apr-11	4	39936	40000	59.45	152.2	0	0	47549	2377	500000
10	Company J	May-11	5	39986	40000	59.85	146.1	0	0	48672	2434	500000
10	Company J	Jun-11	6	39867	40000	59.00	155.1	0	0	47923	2396	500000
10	Company J	Jul-11	7	39109	40000	59.66	146.7	0	0	48298	2415	520000
10	Company J	Aug-11	8	39004	40000	59.41	143.2	0	0	46051	2303	520000
10	Company J	Sep-11	9	39889	40000	59.09	146.8	0	0	45302	2265	520000
10	Company J	Oct-11	10	39867	40000	59.15	143.1	0	0	44554	2228	520000
10	Company J	Nov-11	11	39145	40000	59.66	141.9	0	0	44928	2246	520000
10	Company J	Dec-11	12	39012	40000	59.14	144.4	0	0	45677	2284	520000
10	Company J	Jan-12	13	38079	48000	58.23	153.4	0	0	44554	2228	550000
10	Company J	Feb-12	14	39856	48000	59.34	141.1	0	0	44928	2246	550000
10	Company J	Mar-12	15	39451	48000	59.01	149.7	0	0	46051	2303	550000
10	Company J	Apr-12	16	38936	48000	58.99	154.1	0	0	46800	2340	550000
10	Company J	May-12	17	39765	48000	59.98	143.8	0	0	48672	2434	550000
10	Company J	Jun-12	18	39867	48000	59.00	150.4	0	0	47549	2377	550000
10	Company J	Jul-12	19	39909	48000	60.01	146.9	0	0	48298	2415	540000
10	Company J	Aug-12	20	40004	48000	60.22	146.1	0	0	47923	2396	540000
10	Company J	Sep-12	21	40123	48000	60.55	143.4	0	0	47174	2359	540000
10	Company J	Oct-12	22	39889	48000	59.88	149.7	0	0	46426	2321	540000
10	Company J	Nov-12	23	40181	48000	60.44	141.4	0	0	45302	2265	540000
10	Company J	Dec-12	24	40001	48000	60.00	145.7	0	0	45677	2284	540000
10	Company J	Jan-13	25	32456	45000	55.34	180.9	0	0	41583	2228	550000
10	Company J	Feb-13	26	33456	45000	56.78	161.9	0	0	41933	2246	550000
10	Company J	Mar-13	27	32451	45000	55.12	178.8	0	0	42981	2303	550000
10	Company J	Apr-13	28	34236	45000	56.78	167.8	0	0	43680	2340	550000
10	Company J	May-13	29	38765	45000	59.45	156.8	0	0	45427	2434	550000
10	Company J	Jun-13	30	39867	45000	58.79	152.3	0	0	44379	2377	550000
10	Company J	Jul-13	31	38079	45000	57.69	164.2	0	0	45078	2415	540000
10	Company J	Aug-13	32	40212	45000	59.97	151.7	0	0	44728	2396	540000
10	Company J	Sep-13	33	40012	45000	58.23	160.2	0	0	44029	2359	540000
10	Company J	Oct-13	34	39904	45000	58.23	165.3	0	0	43331	2321	540000
10	Company J	Nov-13	35	39781	45000	57.88	160.1	0	0	42282	2265	540000
10	Company J	Dec-13	36	40012	45000	57.99	161.5	0	0	42632	2284	540000

APPENDIX B1

Pre-Interview Questions

The below list of questionnaires is for assessing the level of awareness of Autonomous Maintenance and SECS/GEM standard in ECM companies.

1. Are you familiar with Autonomous Maintenance (A.M.)?

Yes / No

2. Are you familiar with SECS/GEM standard?

Yes / No

3. To which extent you are able to appreciate the essence and importance of SECS/GEM standard?

1	2	3	4	5	6	7	8	9	10

1 = Strongly Disagree and 10 = Strongly Agree

4. To which extent you believe that SECS/GEM standard could be implemented in companies?

1	2	3	4	5	6	7	8	9	10

1 = Strongly Disagree and 10 = Strongly Agree

5. To which extent you appreciate that SECS/GEM standard integration with Autonomous Maintenance will result in maintenance improvement?

1	2	3	4	5	6	7	8	9	10

1 = Strongly Disagree and 10 = Strongly Agree

APPENDIX B2

Interview Guide

The below are the list of questionnaires which were asked and discussed during the semi-structured interviews with managers, supervisors, engineers, technicians and operators.

1. How is the top management understanding, commitment and involvement in Autonomous Maintenance and SECS/GEM standard?
2. As managers, how is your understanding in Autonomous Maintenance activities?
3. As Supervisors and Engineers, how is your understanding in Autonomous Maintenance roles and activities?
4. What type of daily routine maintenance work does the operator carry out?
5. What type of planned maintenance work is being carried out by technicians?
6. As operators and technicians, how is your understanding on Autonomous Maintenance activities?
7. What is your understanding on SECS/GEM standard?
8. Do you have any knowledge on SECS/GEM standard's application and benefits?
9. Will the management support future direction on SECS/GEM standard?
10. Overall, implementing Autonomous Maintenance activities with SECS/GEM standard, do you think it will have impact to productivity?