A DECISION SUPPORT SYSTEM FOR ERP PROJECTS IN MAKE -TO-ORDER MANUFACTURING SMEs

SREEJIT PILLAI

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE UNIVERSITY OF GREENWICH FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

APRIL 2015

Declaration

I certify that this work has not been accepted in substance for any degree, and is not concurrently submitted for any degree other than that of Doctor of Philosophy (PhD) being studied at the University of Greenwich. I also declare that this work is the result of my own investigations except where otherwise identified by references and that I have not plagiarised the work of others.

Signed…………………………………………………………….Date………………………
Sreejit Pillai
(Student)

Signed…………………………………………………………….Date………………………
Dr. Raj Bhatti
(1st Supervisor)

Signed…………………………………………………………….Date………………………
Dr. Alan Arokiam
(2nd Supervisor)

Check List for PhD Thesis

"A decision support system for ERP projects in make-to-order manufacturing SMEs"

Sr. No.	Title	Status(✓ or X)
1	Front sheet Declaration	✓
2	Declaration	✓
3	Abstract	✓
4	Contents	✓
5	Acknowledgements	✓
6	Aims/Objectives	✓
7	Chapters – Each starting on a new page	✓
8	Sub division of chapters	✓
9	Discussion	✓
10	Conclusion	✓
11	Future work	✓
12	References	✓
13	Appendices	✓

ABSTRACT

Almost 40 to 57% of Enterprise Resource Planning (ERP) projects fail to realise any benefit, run over budget or time. Only a few published works explicitly focus on ERP Critical Success Factors (CSFs) in Make-to-Order (MTO) manufacturing small and medium size enterprises (SMEs).

A dynamic Decision Support System (DSS) is developed for selecting and managing CSFs including production strategy and their interrelationships during and after completion of ERP projects in MTO SMEs. The research work carried out was based on a 30 month Knowledge Transfer Partnership (KTP) ERP implementation project. Based on the research objectives and the characteristics of the challenges facing the case company, action research method was assessed to be the most appropriate.

Two Discrete Event (DE) simulation based DSS were developed. The first DSS studies the interrelationships of over thirty CSFs as an ERP system is being implemented. Users can determine the attributes of the CSF from real-time data and visualise the interrelationships of CSFs during phases of the ERP project. After the ERP system was implemented, a three stage DSS was developed to manage production strategy to realise benefits of ERP system. A prototype production planning and scheduling system (PPSS) using Microsoft Excel formed an ERP linkage for manufacturing lead-time analysis, Customer Relationship Management (CRM) activities and planning. The final stage involved managing the job release decisions based on Work Load Control (WLC) logic in purely manual assembly lines requiring high skill levels.

This research contributes to limited research data available on managing ERP related CSFs in Make-to-Order (MTO) manufacturing firms. Also, a unified approach has ensured that a number of strategies that are not currently synchronised can be implemented successfully. The proposed methodology will enable small and medium size enterprises (SMEs) realise ERP benefits by focussing on CSFs during and after ERP implementation.

Keywords: *Enterprise Resource Planning, Make-to-Order, Small and Medium Size Enterprises, Discrete Event Simulation, Decision Support System, Critical Success Factors* (CSFs), *Work Load Control*

Contents

List of Figures

List of Tables

LIST OF ABBREVIATIONS

Below is the list for the abbreviations used in the thesis.

Abbreviation	Stands For
APS	Advance Planning and Scheduling
APT	Additional Processing Time
ASCII	American Standard Code for Information Interchange
ATO	Assemble-to-Order
BPR	Business Process Engineering
BTO	Build-to-Order
CNC	Computer Numerical Control
CPFR	Collaborative Planning and Forecasting and Replenishment
CR	Crystal Report
CRM	Customer Relationship Management
CSF	Critical Success Factors
CSF/ CSFs	Critical Success Factor/Critical Success Factors
CSV	Comma Separated Value
CTO	Configure-to-Order
DD	Due Dates
DE	Discrete Event
DSS	Decision Support System
DTO	Design-to-Order
ERP	Enterprise Resource Planning System
ERP2	Extensions of ERP
ETO	Engineer-to-Order
FIFO	First In First Out
FTO	Finish-to-Order
IDEF0	Integrated Definition Functional Modelling
IS	Information System
IT	Information Technology
KPI’s	Key Performance Indicators
KTP	Knowledge Transfer Partnership
LE	Large Enterprises
LEs	Large Enterprises
MC	Mass Customisation
ME	Medium Enterprises
MIG	Metal Inert Gas Welding
MIS	Management Information Systems
MPS	Master Production Schedule

Abbreviation	**Stands For**
MRP or MRP I	Material Resource Planning System
MRP II	Manufacturing Resource Planning
MS Excel	Microsoft Excel
MTO	Make-to-Order
MTS	Make-to-Stock
NF	Neutral Factor
OCD	Operation Completion Date
OP	Operational
OR	Organisational
PCO	Product Configuration
PERT	Program Evaluation and Review Technique
PESTLE	Political, Economic, Social, Technology, Legal and Environmental
PLM	Product Lifecycle Management
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PPC	Production Planning and Control
PPSS	Prototype Planning and Scheduling System
PRD	Planned Release Date
PT	Processing Time
PWL	Planned Workload
RCCP	Rough Cut Capacity Planning
ROI	Return of Investment
RSM	Response Surface Methodology
RWL	Release Workload Control
SaaS	Software as a Service
SaS	Software As Service
SCM	Supply Chain Management
SDOM	Standard Deviation of the Mean
SE	Small Enterprises
SME	Small and Medium Scale Enterprises
SMEs	Small and medium-sized enterprises
TCO	Total Cost of Ownership
TIG	Tungsten Inert Gas Welding
TNORMAL	Truncated Normal
TQM	Total Quality Management
TWL	Total Workload
VBA	Visual Basics
WIP	Work-in-progress
WLC	Work Load Control

DEDICATION

Dedicated

to my parents

Ratnam and Mukundan Pillai

ACKNOWLEDGEMENTS

This research work was one of the most important phases in my educational journey and without the support and guidance of the following people it would not have been completed. I owe my deepest gratitude to all of them.

I first thank my PhD academic supervisors Dr Raj Singh Bhatti and Dr Alan Arokiam. Dr Raj for his three "R's" and one "M" rule - Reflect , Rehearse, Revise and Monitor, which he mentioned during the first day of my postgraduate studies at the UoG in 2008. It has been something I have tried to follow quite religiously in my academic and professional career ever since. I thank Dr Raj for all the opportunities and advice he gave me.

I thank Dr Alan for his passion for new technologies and simulation. His high standards of work were always a source of inspiration. I also thank him for his time and continuous encouragement. I greatly appreciate those Skype calls and Social media tools he used to guide my research. It may be a research topic in itself! This saved me lot of commuting time to Medway from London.

Many thanks to MD and Manufacturing Director at Company 'A' for the support and faith they showed in me during the ERP project, as well as being flexible with my PhD commitments. I thank the Manufacturing Director further for his constant encouragement, timely advice and interest in my PhD. I could not have asked for a better working relationship. I thank the KTP office including Dr Linda Hyder and Dr Terry Corner for being such a wonderful project team and supporting my work during the KTP.

I thank Manufacturing Director and MD at Company 'A', Dr Raj and Dr Alan for making extraordinary efforts to get my fees paid for the year 2013-2014 after my KTP project was over. I also take this opportunity to thank Tony Rice and Lanner Group for their tutorials, training, resources and guidance on Microsoft Excel, Planning & Scheduling systems and simulation respectively. I also thank Caroline Smith and Nigel Beviit-Smith for proof reading my thesis and helping me improve my written and spoken English.

Finally, this project would not have been accomplished without the priceless support, love and constant encouragement from my family and friends. Among my friends I would like to take this opportunity to thank Gaby, Ranjit, Hari Cheta and Mathias for their support and advice; Mathias especially for ‘being there’ when needed, for always answering all my questions and doubts related to a PhD and university procedures, Gaby for her kindness, encouragement and advice, Ranjit for his interest in my work and Hari Cheta for his constructive criticism and intellectual thoughts.

Within my family, I thank my father and mother for always having been a source of great inspiration and strength to me. I thank my sister Hema, Satish Cheta and my niece Kimaya for their keen desire to see me get a PhD. My parents and sister never made it to any of my past educational award ceremonies so far and they had promised me they will make it for my PhD convocation. This was a great source of motivation for me to do this PhD. I thank my wife Karthi for her love and affection, her lovely meals and cups of tea. You have been so kind to me.

I also thank the University of Greenwich. I got everything from this institution and hope to repay the favour some point in my life.

Finally, I thank the almighty God for all the love, failures, opportunities and successes in life.

Sreejit Pillai
April, 2015

PUBLICATIONS

Part of the contents of this report has been published or has been submitted for publication. The publications to date are listed below:

a) Pillai, S., Arokiam, A., Bhatti, R. and Collins, A. (2011), "Make to Order Manufacturing and Operational Management Strategies – A Case Study at Company 'A' ", *Proceeding of the 18th International Annual EurOMA Conference, June 3-6, University of Cambridge, UK*

b) Pillai, S., Arokiam, A. and Bhatti, R. (2013), "Linking simulation, critical success factors and enterprise resource planning in small and medium size enterprises", *International Journal of Information Systems and Change Management*, Vol.6 No.3, pp. 266-290.

Chapter 1: Introduction

1.1 Chapter Introduction:

This chapter outlines the reasoning and the scope for the research, as well as justification for the case study to underpin the academic theory. Within this chapter, background information of the research is also given.

1.2 Research Background

Small and medium-sized enterprises (SMEs) represent 57.1% of the UK's manufacturing sector (Department of Business Innovation and Skills, 2011). They are the major contributors to the UK's economy. Enterprise Resource Planning (ERP) systems have become the most widespread Information Technology (IT) solution for organisations these days.

A global study conducted in the year 2010, consisting of 1600 ERP implementation projects across various sectors showed, that more than 57% projects went on for longer than expected, 54% went over budget and 41% failed to realise the benefits (Zach & Olsen, 2011).. Further, ERP implementation in SMEs is challenging due to their limited knowledge of IT and lack of IT infrastructure (Ali & Xie, 2011). The need for further research is imperative. There are three main streams of ERP research (Grabski *et al.*, 2011):

(1) ERP system Critical Success Factors (CSFs)

(2) ERP organisational impact research

(3) The economic impact of ERP systems

Critical Success Factors (CSFs) are subjective and change with every ERP project and stage (Ahmad & Cuenca, 2013; Zach & Olsen, 2011). Merely identifying possible CSFs is not sufficient to help with ERP success. Further investigation is required to establish the criticalness of the proposed CSFs before managerial time is devoted to them (Ram & Corkindale, 2014). Very little published literature explicitly focuses on CSFs in Make-to-Order (MTO) manufacturing SMEs. Further, the dynamic interrelationships between CSFs during the various phases of an ERP project are not clear. Less explored, but a key CSF in MTO SMEs is their unique production strategy (Zach & Olsen, 2011).

ERP systems are based on technological foundations of Material Resource Planning (MRP or MRP I) and Manufacturing Resource Planning (MRP II) systems. The functionality of

ERP systems has continued to grow due to the development of various analytical extensions also known as 'Extended ERP' or ERP II.

Workload Control (WLC) logic is proposed as an extension or decision-making tool that can improve Production Planning and Control (PPC) practices in MTO. It is based on Little's Law, i.e. mean throughput times can be decreased by reducing the mean work-in-progress (WIP) (Kirchhof *et al.*, 2008). However, WLC technology is often overlooked in MTOs. By integrating Discrete Event (DE) simulation and traditional production planning methods, it is possible to forecast required workloads from given input values (Montonen *et al.*, 2010). Within the SME context, there are limited examples of use of simulation tools in the operational planning of manufacturing. Computer simulations have been augmented by results from other DE simulation studies such as ERP education simulation.

Computer simulation studies have a number of advantages:

- They offer complete control of the simulation environment properties, such as the subjective nature of CSFs and unique environment of ERP projects in MTO SMEs. Ahmad & Cuenca, 2013; Zach & Olsen, 2011).
- They explore unknown territories for which SMEs have limited infrastructure and knowledge (Ali & Xie, 2011).
- Good simulation before and during actual implementation of a phase can effectively narrow down the possibilities to be investigated, thereby lowering implementation costs and focusing efforts into the most relevant possibility (Arokiam, 2004).
- They aid in reducing the cost of implementing ERP projects by providing cheaper, near real time and faster studies of CSFs

Despite these advantages there are a number of disadvantages that one needs to be aware of:

- Many of the simulation results are not directly applicable to real life conditions (Arokiam, 2004)
- Acceleration procedures for speeding up the simulation and approximations to simplify the simulation have to be taken into account (Arokiam, 2004).
- CSF simulations are dependent on fundamental data such as interactions and interrelationships of CSFs during various ERP phases and are subjective, which can be inaccurate. (Ahmad & Cuenca, 2013, Ram & Corkindale, 2014).

- Due to simplifications and assumptions to make simulations possible, simulations best describe processes and explain phenomena rather than giving exact numbers (Arokiam, 2004).

The above mentioned factors highlight the advantages of computer simulation, and the scientific and economic reasons for its choice, but it is also important to note that the work contained in this research should be applied in a more general manner. Despite the fact that it is carried out for the CSFs in ERP projects in SMEs, the results presented should be treated in a more general sense and could be applied to other systems with similar physical properties. The research work carried out involved literature review, field data collection and analysis and simulation modelling using WITNESS software, based on a 30 month Knowledge Transfer Partnership (KTP) ERP implementation project. A DE simulation based Decision Support System (DSS) has been developed to study the interrelationships of more than 30 CSFs. Attributes like sequence, time, cost, and resources such as team were simulated. Users can determine the attributes of the CSF from real-time data and visualise the interrelationships of CSFs during various phases of the ERP project. In this work, CSFs and their interactions in ERP project phases such as *Initialisation, Adoption, Adaption, Routine* and *Retirement* processes were studied using DE computer simulation.

As an output of the ERP system, a three stage DSS was developed. A prototype production planning and scheduling system (PPSS) using Microsoft Excel was developed to ensure effective planning and scheduling of MTO production activities. In particular, capacity management was used to manage a number of future periods with confirmed orders. The data for the PPSS comes from the ERP that is then linked to the DE simulation model. A DE simulation model formed the PPSS-ERP linkage for manufacturing lead-time analysis in MTO environment. The model allows the user to determine and edit priority, material, routing, labour and cycle time for customer orders. Using random and antithetic random numbers, ten experimental runs were conducted to prove the repeatability and reliability of the models.

The final stage involved managing the job release decisions in purely manual assembly lines requiring high skill levels. Work Load Control (WLC) logic was incorporated into the DSS, considering dynamic parameters such as key workers as work centres and unbalanced distributions of skills and set-up characteristics. This can augment the task of planners and schedulers to run production more efficiently in MTO SME environment and improve the percentages of firms who realise the benefits of ERP implementations. Trial runs for DSS system were carried out at Company ‘A’ and feedback received on the demonstration and the recommendations has been positive.

1.3 Collaborator Company

In fields like hospitals, drink and food processing, laboratories, microbiology, veterinary science, the need to sterilize equipment before their use is fundamental. Company ‘A’, based in UK, provides an answer to this issue since 1988 by manufacturing and selling Autoclaves globally. During the last two decades, the company has emerged as one of the UK’s leading manufacturers of laboratory Autoclaves. The company also manufactures low-pressure Autoclaves and climatic cabinets for use in the electronics, packaging and plastic industries.

- **Product Family**

Company ‘A’, a MTO firm manufactures various models of laboratory Autoclaves, low-pressure Autoclaves and climatic cabinets.

Figure 1-1 : Front Loading Rectangular Autoclave (Source: Company ‘A’)

All Autoclaves manufactured belong to one of the following three product families - Compact and Standard Autoclaves, Standard Autoclaves and Large Chamber Autoclaves. Further customisation would depend on various factors such as loading option - front or top, heating system - electrical or steam, capacity - 40 to 2000 litres, door mechanism - swing or power door, door type - single or double and vacuum option - pre-cycle or post-cycle. All Autoclave models have a Tactrol control system that provides a simple and reliable method to control the operating parameters.

- **Manufacturing Processes and Flow**

Company 'A' is a typical example of a MTO manufacturing facility with average production quantities ranging from 15 to 20 Autoclaves a month. As a direct result of mass customisation, Company 'A' manufactures up to 90 different types of Autoclave models and there are over 100 components which go into an average Autoclave. However, it is still possible to identify the manufacturing flow at Company 'A'. It has two manufacturing units located adjacent to each other. The first manufacturing unit contains the machine shop and the sheet metal shop while the second unit consists of the electrical and fitting shop. Majority of the MTO job shops have a process-oriented layout (Yeh, 2000). Largely this is true at Company 'A' too. Autoclaves manufactured at Company 'A' have two main sub-assemblies. The first one is the frame work made out of mild steel and 316 grade stainless steel. The other important sub-assembly is the pressure vessel, which is made of 316-grade stainless steel. Among the four shops, the sheet metal shop manufactures the frames and pressure vessels for the Autoclaves. The common manufacturing processes involved in the sheet metal shop for frame skeleton and frame panels are cutting, deburring, drilling, and MIG welding. Additional the frame panel work involves processes like punching and bending. Apart from the processes indentified above, the vessel making involves additional processes like punching, rolling and TIG welding. Except MIG welding, all processes need machine operation.

The machine shop provides critical sub-assemblies to the sheet metal and fitting shops. CNC machine tools are used for this purpose. Processes like cutting, turning, milling, and drilling are common to this shop. The electrical shop provides electrical chassis for the Autoclaves. The fitting shop carries out the pressure vessel testing, pipe work and final assembly of an Autoclave. These processes are manual. Almost all the machine tools in the factory are located either in the sheet metal shop, or in the machine shop. Periodic maintenance and replacement of worn-out tools are necessary for these machine tools. Most often tool parts are locally sourced. Company 'A''s pressure vessel manufacturing and design processes are approved and scrutinised by BS EN ISO 9001 Quality System and Zurich Insurance. This manufacturing policy has helped the company emerge as a key Autoclave manufacturer in the UK.

1.4 Problem Statement

Almost 40% of firms implementing an ERP system fail to realise any benefits (Zach *et al.*, 2011). It is anticipated that this research and methodology creation, would enable Make-to-Order (MTO) SME firms to realise ERP benefits by introducing techniques that are suitable and support the ERP system even after implementation. The research will highlight how effectively managing the Critical Success Factors (CSFs) for EPR systems in dynamic environments like MTO SMEs enable to increase their effectiveness. In this research ERP system in MTO SMEs are being analysed from a multiple perspective i.e. from a strategic, operational and continuous view. ERP implementation is an ongoing process of integration and transformation of the business using an ERP system. However, there is a further need to understand the post-implementation utility, benefits and the challenges behind its successful adaptation.

1.5 Research Questions

From the discussion in sections 1.2, 1.3 and 1.4, specific research questions emerged and were investigated in this work. The key questions are as follows.

- Which CSFs and Make-to-Order (MTO) characteristics affect which ERP implementation stage in MTO SMEs?
- Is there a dynamic relationship between CSFs during the various ERP implementation stages in MTO SMEs?
- Can Workload Control (WLC) release decisions in purely manual skill based assembly lines be managed by Discrete Event (DE) simulation?
- Post ERP implementation can Material Resource Planning (MRP), Workload Control (WLC), ERP and Discrete Event (DE) simulation enable formulating a Decision Support System (DSS) for MTO environment?

1.6 Research Aim

The aim of this research work is to develop a methodology using a dynamic Decision Support System (DSS) for selecting and managing Critical Success Factors (CSFs) including production strategy and their interrelationships during and after completion of ERP projects in MTO SMEs, using continuous development approach.

1.7 Research Objectives

The objectives of this work were to:

1. Identify CSFs and their interrelationships during various ERP project phases in MTO SMEs
    a. Implement an ERP system in a MTO SME environment
    b. Develop a dynamic decision support tool for CSFs to enable implementation using phases within ERP project along with iterative tools like Delphi analysis
    c. Develop a Plan-Do-Act-Check cycle to monitor a continuous development strategy
2. Study the effects of production strategy as a CSF and develop DSS for day-to-day running of production activities based on data from ERP system
    a. Develop planning and scheduling system based on Microsoft Excel platform linking traditional tools such as MRP I, MRP II and ERP
    b. Investigate and incorporate CRM activities post ERP projects
    c. Investigate and incorporate WLC logic as a production strategy in MTO SMEs

1.8 Research Philosophy

The research topics discussed and the objectives stated are defined throughout this thesis. All of the topics are fully researched from varying sources of information. This enabled an understanding of previous research and it allowed it be developed further though this study. Having completed this research, a detailed methodology of the approach was written and justified through an actual implementation of an ERP system in an MTO SME. The results found were demonstrated in graphs, figures and tables depending upon the requirement. The results were discussed and analysed enabling future research to be identified.

1.9 Layout of the thesis

The thesis is laid out in eight chapters. This is shown in Figure1-2. Chapter 2 introduces the subject of study, various definitions of technical terms, theoretical knowledge and simulation techniques; optimisation methods and compromises taken are explained in detail. Chapter 3 reviews the various methodologies used in this research. Chapter 4

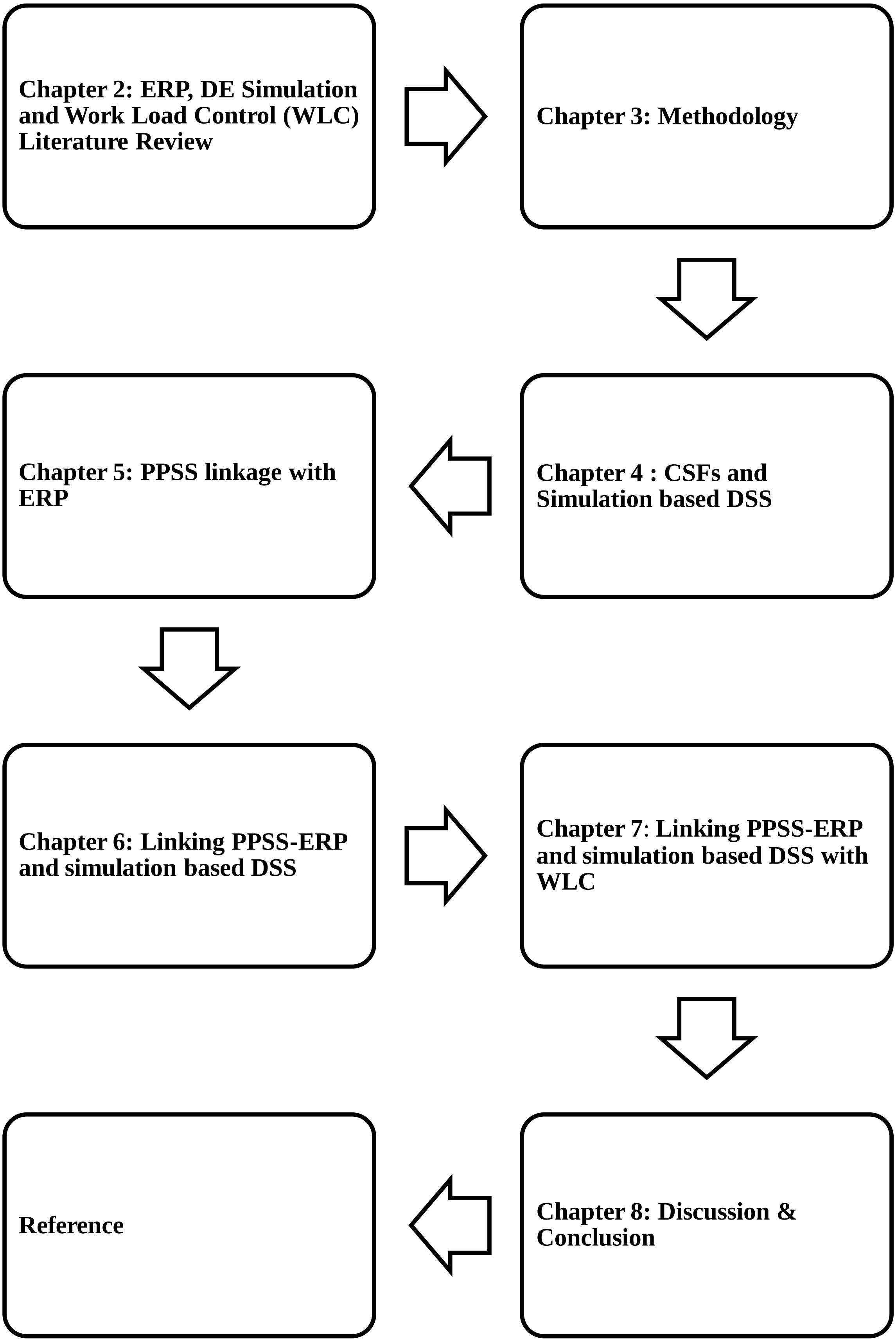


Figure 1-2: Layout of Thesis

discusses the results of study of CSFs and interrelationships using a DE simulation. Chapter 5 presents results from the study of production strategy using a prototype planning and scheduling system (PPSS). Chapter 6 presents and discusses the results of study of production strategy using a DE simulation. Chapter 7 presents and discusses the results of study on release decisions based on Work Load Control (WLC) for production orders in a skill based manual assembly lines using DE simulation. Chapter 8 presents a discussion on the research carried out, draws a conclusions to the whole work carried out and suggests a plan for future work.

Chapter 2: Literature Review

2.1 Introduction

The overall scope of ERP related literature is quite broad (Grabski *et al*, 2011). Many research studies have clearly suggested that ERP implementations are neither standard projects nor they are only Information Technology (IT) projects. Despite the awareness of such information, majority of ERP projects fail to realise their benefits. This work will use data from CSFs, ERP, MTO SME environments, production strategies, simulations and analytical computations to understand some issues underlying ERP projects in MTO SMEs. A large amount of published work in these fields exists and here an attempt is made to consolidate the most relevant information required to understand the phenomena that will be discussed in the forthcoming chapters. Chapter 1 is intended to introduce the reader to the research project. This chapter will focus on the relevant research literature for ERP projects in MTO manufacturing SMEs.

The purposes of this literature survey were identified as: to gain insights into the variety and complexity of implementing ERP systems in MTO manufacturing SMEs; and to understand the development, concepts, and use of various tools required for ERP projects in MTO manufacturing SMEs. The literature review consists of three main sections: Section 2.2 looks at ERP research related to this study, Section 2.3 looks at Discrete Event (DE) simulation studies, and Section 2.4 discusses relevant Workload Control (WLC) research.

2.2 Enterprise Resource Planning (ERP)

In this section the valid theories related to Enterprise Resource Planning (ERP) is reviewed.

2.2.1 UK Private Sector and SMEs

This work is related to SMEs and it is important to understand their share in the UK private sector. There are around 4.5 million private sector enterprises in the UK (Department of Business Innovation and Skills, 2011). Depending upon the staff levels, they can be classified into Large Enterprises (LE), Medium Enterprises (ME) and Small Enterprises (SE). Their respective contributions to the UK private sector economy are shown in Table 2-1. At the start of 2011, SMEs employed an estimated 13.8 million people, and had an estimated combined annual turnover of 1,500,000 million GBP. Further, they accounted for 58.8% of the private sector employment and 48.8% of the turnover. Small enterprises alone (0 to 49 employees) accounted for 46.2% of private sector employment and 34.94% of private sector turnover.

Enterprise Type	**Staff Size**	**UK Enterprise %**	**UK Turnover %**	**UK Employment %**
LE	Over 250	0.20	51.21	41.17
ME	50 to 249	0.70	13.84	12.64
SE	0 to 49	99.20	34.94	46.20

LE=Large Enterprise, ME=Medium Enterprise, SE=Small Enterprise

Table 2-1 : UK Private Sector Enterprises (Adapted from DBI -UK's 2011 annual business population estimate)

Within the UK manufacturing sector, SMEs had a share of 57.1% (Department of Business Innovation and Skills, 2011). These are interesting statistics that highlight the crucial role SMEs play in the performance of the UK economy.

Small and medium size enterprises (SMEs) are major employers and contributors to the growth of market economy. SMEs often drive innovation and change. Under the present circumstances, SMEs are seen as decisive for the future prosperity of the EU. This was actualised in the phenomenal growth of China, led by SMEs (Nisula & Pekkola, 2012).

2.2.2 Characteristics of modern ERP system

Organisations have a functional structure supported by various functional units. These functional units support the organisational goals and require a systemic view. ERP systems provide cross organisation integration of information through embedded business processes. This integration process and functions enable organisations to improve efficiency. Often the success of a company depends on decision-making based on timely information on internal and external processes being available to the right person at the right time (Nazemi *et al.*, 2012).

Enterprise Resource Planning (ERP) systems, a name coined by Gartner Group, were systems originally conceived for large organisations with the idea to provide the business with a single software product to support the main business functions in a company (Ahmad & Cuenca, 2013; Aslan *et al.*, 2012). The following definition of ERP is valid: "*ERP software is a suite of application modules that can link back-office operations to front office operations as well as internal and external supply chains. It conjoins function* *areas and business process in an integrated environment that provides a broad scope of applicability for organisations"* (Verville *et al.*, 2005; Pricewaterhouse Coopers, 1998).

Present day ERP systems were conceived from Material Resource Planning (MRP I) and Manufacturing Resource Planning (MRP II) systems. The functionality of ERP systems has continued to grow and has extended from internal processes (transactional activity, internal planning) to analytical systems encompassing external processes. This extension is often referred as 'Extended ERP' or ERP II. Various extensions to ERP have emerged such as:

Supply Chain Management (SCM): SCM software can facilitate information integration with supply chain partners. Firms focus on their core competencies, outsourcing other operations to firms in the supply chain. The main role of supply chain information is in cost reduction and improved efficiency, service and relationships with customers.

Advanced Planning and Scheduling (APS): ERP systems focus on process management and transactional activities and do not resolve planning issues. APS addresses planning issues and has similarities with the planning and scheduling in MRP II in terms of hierarchical planning and capacity-constrained structure, but also tries to address the decision support insufficiency of ERP. It has features like Available-to-Promise (ATP) and Capable-to-Promise (CTP) functionality incorporated in the APS system.

Customer Relationship Management (CRM): It is a business strategy based on the concept of one-to-one marketing and is a business practice centred on customer needs. CRM can be an independent enterprise-wide IT system or supported by the ERP to compile and analyse data on customers in order to be able to sell more goods or services.

Collaborative Planning and Forecasting and Replenishment (CPFR): CPFR is both a strategy and a supply chain solution and is mainly used in the retail sector for fast moving consumer goods.

Customer Enquiry Management (CEM): Used for due date and price estimation. It can be used for automating order entry, processing customer orders and tracking order status.

Product Configuration (PCO): This is usually provided over the internet and is an add-on that provides an interface between the end customer and supplier. The customer selects the components or specifications and the supplier receives the order in real time.

Product Lifecycle Management (PLM): This incorporates product design support, cost estimation, product development and prototyping data management, enabling a company to manage product-related information more effectively throughout the lifecycle of a product.

Literature exploring the extensions of ERP with SCM, APS and CRM have been published. However, more research is required, which combines ERP with various add-ons and in relation to particular sectors.

Aslan *et al.* (2012) further suggested that there is an influence of pre-configured sector and industry specific packages to minimise implementation cycle time. However, this is limited for MTO manufacturing and academia has an important role to play in the future development of ERP systems and frameworks through case studies, Delphi studies, theoretical work and surveys.

2.2.3 Organisation size and ERP

Organisation size and type play an important role in relation to ERP implementation (Aslan *et al.*, 2012; Zach & Olsen, 2011). Company size affects ERP adoption and at present the fit between them is inconclusive. ERP implementation for SMEs (size factor) in MTO (type factor) manufacturing (producers of bespoke and high variety low/high volume products) presents another challenge. This is primarily due to the demand pattern and complex manufacturing operations (Aslan *et al.*, 2012; Zach & Olsen, 2011).

In recent years, many manufacturers have switched to MTO type production. Almost all MTO companies are SMEs (Zach & Olsen, 2011). Low production volume, wide product variety and unstable production schedules are the characteristics of MTO manufacturing. The requirements of MTO are different from a typical ‘Make-to-Stock’ (MTS) manufacturer. The core competency of MTO companies comes with managing volume flexibility and product customisation. Often, when implementing a standard solution as an ERP system, this core competitiveness may be threatened. The standardised ERP systems embed standard business processes and do not necessarily align with the distinctive processes of MTO SMEs. Given these factors, ERP implementation in SMEs may become more vulnerable to failure (Zach & Olsen, 2011).

Zach & Olsen (2011) conducted a unique exploratory empirical study on EPR projects. They suggested that a possible way to improve the implementation of ERP systems was to focus on specific organisational issues based on size and type, especially manufacturing strategy. There is a need for empirical studies exploring MTO sector and industry specific issues for ERP system adoption.

Aslan *et al.* (2012) revealed the gap between the requirements of a MTO SME and ERP systems. This research suggested the need for empirical studies exploring MTO sector specific issues of ERP system adoption. It highlighted that order penetration point has a substantial impact on planning at the firm and supply chain levels, but this has been ignored by the academia. Deep *et al.* (2008) developed a framework for ERP system selection for MTO SMEs, however this covered only the selection phase.

Research on ERP implementation technique within SMEs is still limited (Ahmad & Cuenca, 2013; Ali & Xie, 2011; Aslan *et al.*, 2012; Sun *et al.*,2005; Zach & Olsen, 2011). Most of the ERP literature is based on large organisations and SMEs are not miniature versions of large organisations (Leyh, 2012; Zach & Olsen, 2011). SMEs may have advantages such as a simplified organisational structure; however, there is a lack of defined structure and procedures formalisation and a shortage of resources and funds.

Further, ERP implementation of SMEs is challenging due to their limited knowledge of IT and lack of IT infrastructure (Ali & Xie, 2011). Recent research studies have reported that enterprises are encountering difficulties to achieve the benefits of implementing an ERP system (Ahmad & Cuenca, 2013). Lately the benefits and disadvantages of implementing an ERP system have been studied, most of them in the Management Information Systems (MIS) field. A large number of investigations have been focussed on the identification of main critical factors and methodologies for implementation of ERP systems and recommended a project like approach, where an ERP project is an IT project and has a start and end time. But Ahmad *et al.* (2012) have suggested the need to think of ERP implementation as a dynamic and continuous process aligning management techniques and organisational culture. This alignment involves a large number of factors that interact and influence among themselves.

These factors, known as CSFs, have received wide attention in the literature, but the dynamic interactions of these CSFs among themselves and with the ERP implementation phases have not been investigated in a MTO SME environment.

The contribution of the ERP system to organisations' strategic value creation depends on many CSFs, the right implementation and effective management of its operational performance during its lifecycle (Nazemi *et al.*, 2012). CSFs underpin ERP implementation projects, and have been studied extensively by academia for ERP projects in large organisations. However, there exists a research gap in this field from an SME perspective (Ahmad & Cuenca, 2013; Leyh, 2012; Zach & Olsen, 2011). There also exists a research gap in establishing the interrelationships between the CSFs and the stages of ERP project (Ahmad & Cuenca, 2013).

The total cost of ownership (TCO) of the ERP system is high, generally between GBP 0.2 to 150 million (Nazemi *et al.*, 2012). Therefore, ERP implementation projects are often one of the biggest single projects that an enterprise has ever launched in its lifetime (Moon *et al.*, 2005). ERP implementations are known to be complex, cumbersome and costly and very often exceed the initial estimated resources. The cost associated with implementation of ERP systems and difficulties found in achieving management expectations are the most significant reasons hindering SMEs from adopting ERP systems. However, usage of ERP systems in SMEs has increased (Ahmad & Cuenca, 2013). Enterprise Resource Systems (ERS) or Enterprise Resource Planning (ERP) systems have become the most widespread Information Technology (IT) solution in organisations (Zach & Olsen, 2011). ERP is an information system (IS) concept used by organisations either to reduce cost or to add value to their operations (Levy *et al.*, 2001; Kulonda & Arif, 2009).

ERP systems have developed from traditional Material Requirement Planning (MRP) and Manufacturing Resource Planning (MRP II) systems of the past, but have a wider scope and improved platform (Aslan *et al.*, 2012). ERP projects are often the most resource intensive and a costly IT project a firm undertakes (Moon *et al.*, 2005). This becomes very critical within an SME perspective, considering the limited resource, lower IT expertise and lack of structured IS management compared to larger firms.

According to the 2012 Gartner® Inc white paper on ERP systems, the projected global spending on ERP projects is expected to be a total of £59.2 billion in 2012, a 4.5% increase from 2011 spending of £56.5 billion. Further, the SME ERP market is expected to grow to £15 billion by 2014.

A study consisting of 1600 ERP implementation projects showed that more than 57% of projects went on for longer than expected, 54% went over budget and 41% failed to realise the benefits (Zach *et al.*, 2011). The need for further research is imperative.

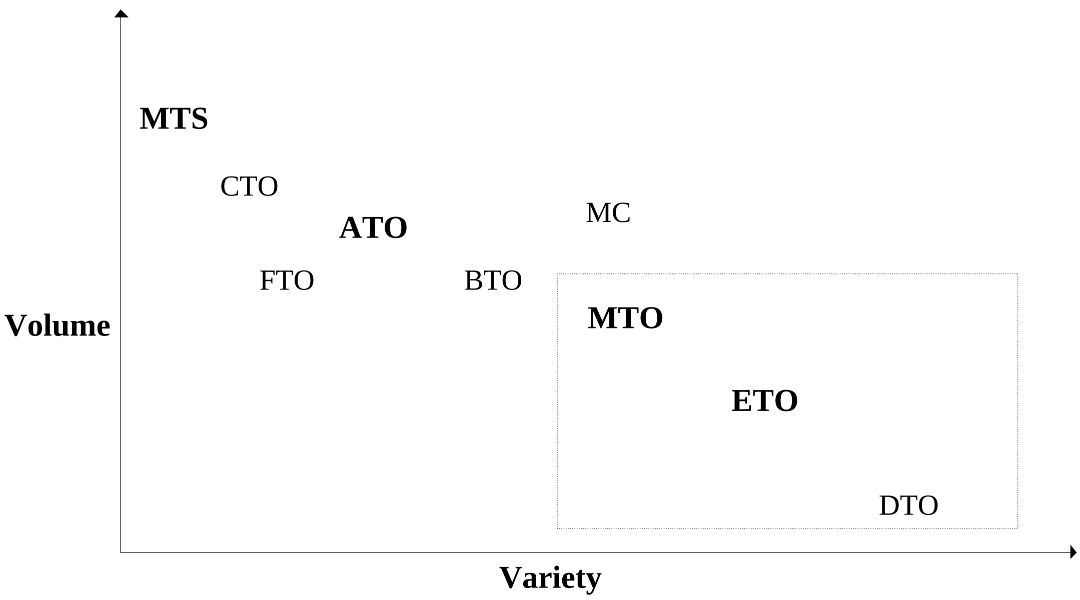
Since the mid 2000s,due to factors like increasing IT use in SMEs coupled with the saturating market for ERP in large organisations, ERP vendors have been actively developing and implementing scaled down and pre-configured low cost versions of their products to suit SMEs (Ahmad & Cuenca, 2013; Aslan *et al.*, 2012; Zach & Olsen, 2011). Growth can be attributed to the fact that SMEs have realised the advantages of integrating the information pertaining to all business processes into one system. Further, large organisations have totally integrated manufacturing to their supply chains, and SMEs, which often are suppliers to these organisations, are propelled towards adopting these systems (Zach & Olsen, 2011).

2.2.4 Make-to-order Perspective/Characteristics of MTO System

Various production strategies exist and there is a dynamic relationship between volume and variety among these strategies. Strategies such as Make-to-Stock (MTS), Assemble-to-Order (ATO), MTO and Engineer-to-Order (ETO) are the most common. In MTS and ATO settings, finished goods are manufactured and stocked in anticipation of demand (Aslan *et al.*, 2012). In MTO and ETO strategies, design and production activities take place only on acceptance of customer orders and production is typically done in an exclusive job shop environment. There exist other ‘to-order’ based sub-strategies such as Design-to-Order (DTO), Build-to-Order (BTO), Configure-to-Order (CTO) and Finish-to-Order (FTO). Also, under the ATO strategy, a Mass Customisation (MC) strategy based on mid-volume and mid-variety can be identified (Aslan *et al.*, 2012).

Further, MTO can be generalised as an umbrella term for DTO and ETO strategies. It applies to firms producing bespoke and customised products in order to meet the requirement of a particular customer but not repeated on a regular basis. Figure 2-1 shows the various production strategies in a volume and variety plot. Customer driven manufacturing is the key concept in MTO scenario. Aslan *et al.* (2012) further classified the characteristics and requirements of MTO firms as planning and control stage, shop floor configuration, supply chain, product customisation, company size and market characteristics.

Analysing these variables in a MTO environment implies a low volume, low standardisation, and high product variety of production. The most significant feature of this type of manufacturing environment is that the products are more or less engineered to customer order. To give customers a responsive service and to ensure a reliable delivery date for orders, MTO firms require detailed, realistic, and flexible operations plans and schedules, along with a control mechanism for easy track of production status of customer orders (Yeh, 2000).



ATO = Assemble-to-order, BTO = Build -to-order, CTO = Configure-to-order
DTO = Design-to-order, ETO = Engineer-to-order, FTO = Finish-to-order
MC = Mass Customisation, MTO = Make-to-order, MTS = Make-to-stock

Figure 2-1: Production Strategies Volume and Variety Interfaces – (Adapted from Aslan et al., 2012)

In order to better realise the most suitable approach to planning and scheduling, a firm needs to identify and understand its key business processes, both currently in force and the ones that are likely to be required because of any strategic changes in business direction (Porter *et al.*, 1999). Consequently, the business processes can be characterised by a number of variables related to the product, the demand and the manufacturing process respectively. Some of the important variables considered critical to understand what constitutes a suitable approach to planning and scheduling have been identified as product-related, demand-related and manufacturing-related (Jonsson *et al.*, 2003).

Product-related variables: They can be identified as bill of materials complexity, product variety, degree of value added at order entry and proportion of customer specific orders, etc.

Demand-related variables: It constitutes variables such as product lead-time, delivery lead-time ratio, volume and frequency ratio of a product, demand type - forecast or customer order, etc.

Manufacturing-related variables: They include variables such as manufacturing mix, shop floor layout - process or cellular, batch size, throughput time, number of operations, sequencing dependency, etc.

The batch sizes are typically small, often equivalent to customer orders. Products are complex and the bill of materials is deep and wide. In addition, manufacturing throughput times and the delivery lead times are long. Layout of the shop floor is a process oriented one.

Planning and scheduling activities in MTO companies are more difficult as compared to make to stock companies, because it is not possible to forecast future demand. A major issue for MTO firms is determining due dates (DD) for firm orders. In MTO production environments, the assignment of DD can be done either by the customers or by the manufacturers themselves (Saad *et al.,* 2004).

In the former case, customers have their own DD, which are passed to the manufacturers along with the production orders. The manufacturers then make a decision as to whether or not it is possible to accept the orders and deliver them as required. In the latter case, manufacturers decide their own DD. The customers then decide if they can accept the delivery time and confirm or cancel their orders accordingly. However, in both scenarios the manufacturer has to determine the DD, whether to offer a DD to their customer or to make their own decision regarding the feasibility of the customer DD (Saad *et al.,* 2004).

Further, it has been observed that for low-volume and high-mix shops, analytical and algorithmic aids have limited benefit and appropriate use of computer technology as an important tool in addressing scheduling issues (McKay *et al.*, 2007). In such an environment, the human scheduler requires a production planning system to manage the situation, wherein the production planning system is a specialised form of DS system. Jonsson *et al.* (2003) suggested that MRP logic-based production planning systems are the most applicable planning method and it functions well in complex customer based production. However, Stevenson *et al.* (2005) argued that MRP despite capacity features like Rough Cut Capacity Planning (RCCP) and Capacity Requirements Planning (CRP) does not provide sufficient support to manage customer enquiries in a MTO context.

Aslan *et al.* (2012) suggested that for the MTO sector, a system must be able to provide support through most of the production planning and control stages and be suitable for job shop. Such a system should be able to support stages such as Customer Enquiry, Design and Engineering, Job Entry and Release and Shop Floor Dispatching. It proposed Workload Control (WLC) as a good fit to integrate with ERP systems and linked with the work of McKay *et al.* (2007). They argued that if the ERP system can handle most of the other needs of the MTO firm, then WLC embedded in ERP can improve the functionality of the ERP system.

2.2.5 ERP Extensions and MTO Production Strategy

Jacobs & Bendoly (2003) encouraged research in hybridisation of supply chain, MRP and other functional models. They also suggested ERP extensions would gain prominence and encouraged strong interest in integrating the functionalities of these system extensions to the ERP. MTO business features such as design input, position in supply chain, rush orders, repeat business customers, repeat orders, due date and price determination interact with ERP extensions. The dynamic relation between these business features in a MTO sector with ERP extensions such as SCM, APS, Product Configuration and PLM require attention.

Rush Orders (RO) can be common, considering the limited advantage of MTO firms due to its position in the supply chain. This could also be a case in dealings with Repeat Business Customers (RBC). Such requests require responsive supply chain practices and hence aligning the core functionality of the ERP with extensions such as SCM is beneficial. This requires further research. Further, CRM applications can help convert a new customer into a RBC. RBCs may require constant negotiations of contracts and MTOs have to maintain a flexible approach. Aslan *et al.* (2012) argued that CRM utilisations in the MTO sector need to be explored further. Like production strategy this could be an important CSF for a firm’s successful ERP implementation.

Deep *et al.* (2008) studied the use of a ‘Product Configurator’ extension for repeat orders. However a significant proportion of the orders have high level of customisation or design needs hence a ‘Product Configurator’ may not provide an effective solution for the full range of finished goods. In addition, it is unclear if the use of PLM as an extension would add value where product life cycles are short (Aslan *et al.*, 2012). Deep *et al.* (2008) suggested APS to be relevant in the MTO sector due to functionalities such as capacity management and analytical planning. However, Aslan *et al.* (2012) argued that APS appears to lack adequate support for due date, price determinations and design and engineering stage. This needs further research.

Aslan *et al.* (2012) and Zach & Olsen (2011) argued that traditional MRP modules were not appropriate for MTO sector and suggested that APS systems may yield enough manufacturing flexibility and be appropriate for MTOs. However, the case company did not implement MRP module during ERP implementation and it could not conclude that MRP would not work. Further research is needed to explore this issue. Zach & Olsen (2011) suggested that research on ERP in manufacturing SMEs should consider production strategy as a key influencing strategy. The study could not effectively conclude that the traditional MRP strategies had limited applicability for MTO SMEs and there was a need for research to explore this issue. Aslan *et al.* (2012) questioned the feasibility of MTO manufacturing in ERP and they proposed that strategies like WLC needed to be explored. To summarise the above discussion, extensions of ERP have received limited attention. MTO specific solutions do not exist in the ERP market. The fit between the needs of a MTO firm and the functionality of ERP and these extensions is limited in some and not clear in others (Aslan *et al.*, 2012).

2.2.6 Organisational Culture and SMEs

Ball & Bititci (2000) tried to demonstrate the influence of organisational personalities and culture on planning and implementation of a successful ERP project. This study was conducted in two SMEs and one Large Enterprise (LE). A selection and implementation methodology was applied to three similar companies and a wide variation in outcome was observed. The underlying reasons for the variations in success can be specifically attributed to organisational personalities and culture. The methodology was developed based on Oliver Wight's methodology comprising of seven phases; *Vision and Commitment, Business Process Engineering, Statement of Requirements and Invitation-to-Tender, Systems Selection and Contract Negotiation, Implementation Planning, Implementation, Post Implementation Review and Fine Tuning.*

Amongst the three case studies introduced, there were varying degrees of success in using this methodology despite having similar process characteristics. Many of the factors that contributed to success are the conditions under which the methodology is executed, such as attention to detail, stability of team membership and ERP/IT skills.

2.2.7 Why firms undertake ERP project and Process redesign

Nazemi *et al.* (2012) reviewed 326 papers in major scholarly journals and academic conferences and identified five reasons why firms undertake ERP projects.

- To standardise and speed up processes
- To standardise HR information
- To integrate financial information
- To integrate customer order information
- To reduce inventory

ERP system contribution should be aligned with the ways a firm conducts business before implementation and deployment. If a firm realises that there is no linkage between the benefits of an ERP system and their ways of doing business then they can make one of two choices. They can customise the system to accommodate the process or they can change the business process to accommodate the system. Any redesign and changes of a business process should not be carried out with the intent of supporting the planned system. Rather, any process redesign should involve the implementation of best practices that are supported by the planned system so that they provide improvements in the performance of the process.

Nazemi *et al.* (2012) suggested the most common causes for ERP budget overrun are training, integration and testing, customisation, change management, transaction cost economics, data conversion, data analysis, consultants, losing talented staff, nonstop constant software updates, waiting for Return of Investment (ROI) and post ERP depression. The research concluded that ERP research primarily focuses on the implementation phase. This may be because most of the firms are in the implementation phase or in other phases such as acquisition; there is high level of intervention by consultants making it difficult in gaining information.

Nazemi *et al.* (2012) concluded that CSFs are not well covered and only a few studies provide ERP CSF definition. Case studies constituted the largest category of publication, however there was no explanation of research methodology and the available data was not enough to interpret some of the results presented. Further, most of these studies lacked assumptions or hypotheses for future studies. The number of studies was not sufficient to create a body of knowledge in the area; therefore more effort should be put into the definition and subsequent validation of CSFs.

Zach (2011) conducted a multiple case study in the Czech Republic to contribute to the scarce literature on evaluation of ERP system outcomes in SMEs. The study was based on two research questions: (1) What are the ERP system outcomes perceived by SMEs? (2) How does the SME context affect the ERP system outcomes? Four SMEs operating within the private sector in the Czech Republic were studied. The case companies differed in terms of organisational characteristics (e.g., size, business type, industry) as well as ERP project characteristics (e.g., brand of ERP system, number of implemented modules). Personal interviews were utilised as the primary data collection technique. In total 33 interviews were done in a semi-structured and face-to-face manner, following Myers & Newman's (2007) guidelines for conducting qualitative interviews.

The findings showed the main reason for implementing an ERP system was to replace the legacy system, rather than for using it as a business strategy. Further, the ERP systems offer far higher functionality compared to the legacy systems. They also require more work to provide sufficient data. In terms of organisational impact, the dynamic environment of SMEs may impede evaluation of ERP system organisational impact. A strategic approach will enable SMEs to gain organisational outcomes from the ERP implementation.

2.2.8 Business process re-engineering and ERP

Al-Mashari (2003) reviewed several dimensions related to ERP adoption, technical aspects of ERP and ERP in Information System (IS) curricula. Business Process Re-engineering (BPR) and ERP are linked. ERP is often considered as a driving force for BPR. During adoption, a balance between standardisation and flexibility of the ERP should be considered, based on careful determination of industrial and organisation demands. Further, during the preparation stage of ERP implementation, factors such as infrastructure resource planning, local support, computing hardware, human resource planning, education on ERP, training facilities, top management commitment, commitment to release the right people and manuals need to be included. The review suggested that future research in ERP deployment should focus on conducting a series of cases and empirical studies related to specific stages of implementation using a CSF approach. The other research themes proposed were ERP influence on IT and human resource infrastructure, strategic alignment, competitive advantage, knowledge management and organisational learning. The technical aspect of the review stated that ERP vendors were committed to include internet-based applications. From the academic viewpoint, the review proposed local universities capitalising on their own expertise, and the establishment of collaborative curriculum development teams across various institutions.

2.2.9 Implementation Issues & ERP

Jacobs & Bendoly (2003) reviewed two streams of ERP success. The first stream focused on fundamental corporate capabilities driving ERP as a strategic concept. The second stream focused on the details associated with implementing information systems and relative success and cost. They suggested that issues with implementation would cease to be a problem, as individuals with real experience emerge to guide companies. However, in a recent review Zach & Olsen (2011) showed over 50% of ERP projects failing.

2.2.10 Research Streams & ERP

Grabski *et al.* (2011) suggested there are three main streams of ERP research; (1) ERP system CSFs, (2) ERP organisational impact research, (3) the economic impact of ERP systems. This is shown in Figure 2-2. There have been evolutionary changes in ERP related to integrating systems like SCM leading to an integrated supply chain. The review suggested that the research into inter-organisation benefits of ERP systems was in its infancy. It suggested that the following research questions needed to be addressed: what are the factors that lead to successful inter-organisation cooperation? How do we measure ERP costs and benefits across the inter-organisational value chain? Is it possible to isolate the benefits of ERP systems if they are intertwined with other processes or systems?

Grabski *et al.* (2011) suggested the need for a theory, as a large number of papers on CSFs have been survey-based. It suggested that unless an article is following the design science methodology proposed by Henver *et al*. (2004), theoretical framework needs to be utilised to understand the mix and interaction of CSFs in different types of implementation especially related to ERP upgrades and conversions to different ERP systems.

In order to advance the concept of ERP fit to the organisations theories such as contingency theory, social capital theory, social exchange theory and actor network theory could be used. Grabski *et al.* (2011) further suggested that ERP is now available as ‘Software as a Service’ (SaaS) and research needs to address the implementation, use, and risks and controls in the new environment.

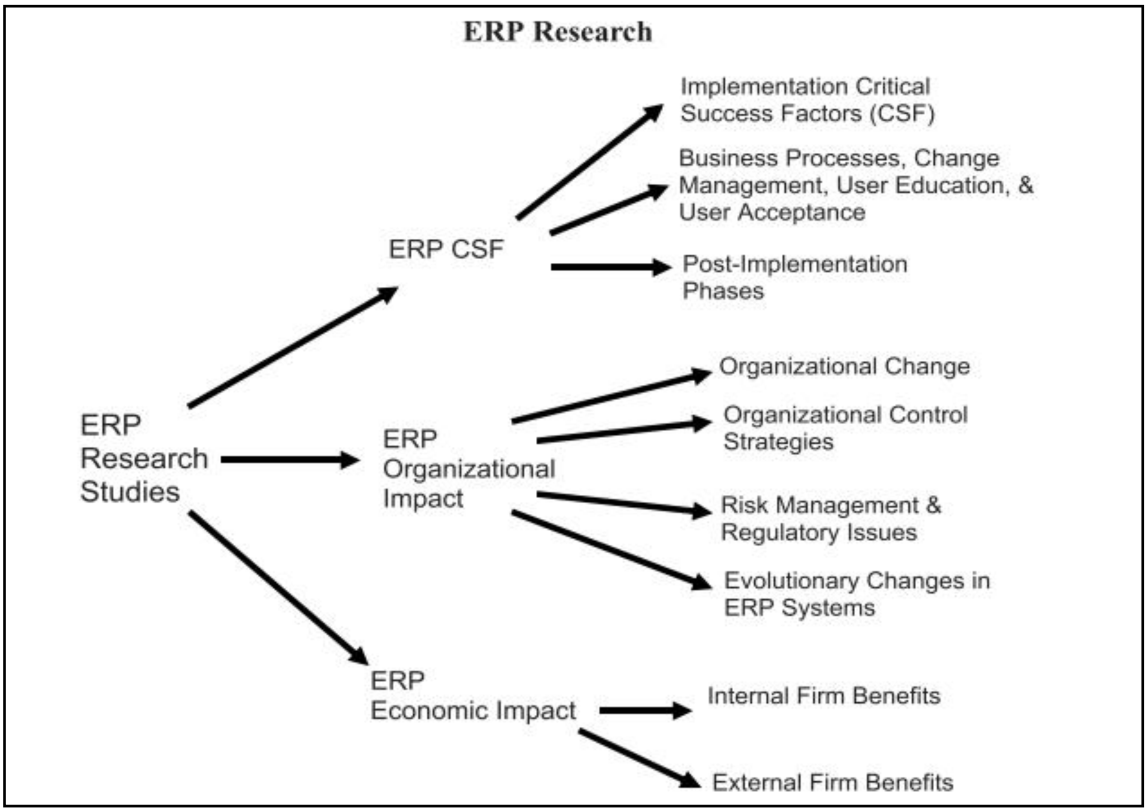


Figure 2-2: ERP Research Areas (Adapted from Grabski *et al.*, 2011)

The review identified that there is a need to;

- understand the mix and interaction of CSFs in different types of implementation especially related to ERP upgrades and conversions to different ERP systems
- understand the individual, team, and organisational heuristics that result in successful implementation
- understand the inter-organisation benefits
- propose theories to understand the relationship between ERP systems and organisational culture and organisation change.

2.2.11 ERP Systems – Three Phases and Success Metrics

Markus *et al.* (2000) presented a study conducted on 16 organisations undergoing ERP implementation under sponsorship of an ERP vendor. The study tried to address research questions such as – How successful are companies at different points in time in their ERP experience? How are different measures of success related to each other? What problems do ERP adopters encounter as they implement and deploy ERP and how are these problems related to outcomes? They conceptualised the ERP experience cycle into three distinct phases and defined success metrics to it. This is shown in Table 2-2.

Phase	**Phase Action**	**Success Metrics**
Project	The ERP software is configured and rolled out to the organisation	• Project cost relative to budget • Project completion time relative to schedule • Completed and installed system functionality relative to original project scope.
Shakedown	Company makes transaction from 'go live' to 'normal operations'	• A short-term change occurring after system 'go-live' in key business performance indicators such as operating labour cost • Length of time before key performance indicators achieve normal or expected results • Short-time impacts on the organisation adopters, suppliers and customers such as average time on hold when placing a telephone call
Onward and Upward	Company captures the majority of business benefits from the ERP system	• Achievement of business results expected from the ERP such as reduced IT operating cost or reduced inventory cost • Ongoing improvements in business results after the expected results have been achieved • Ease in adopting new ERP releases, other IT programs, improved business practices and decision making

Table 2-2: ERP experience cycle (Adapted from Markus et al., 2000)

The success metrics are indicators of human and organisational learning. It is not only important how well the ERP system itself performs, but also how well people in the organisation know to how use, maintain and upgrade the ERP system and how well the business improves its performance with the ERP system.

Markus *et al.* (2000) concluded that connections between starting conditions, issues encountered and outcomes in ERP experiences are not deterministic. This requires further research to understand problem recognition and resolution behaviour. Another area that was identified and requires research is the charter phase of an ERP project, especially how companies make or avoid making decisions.

2.2.12 ERP Systems – Critical Success Factors (CSFs)

Rockart (1982) defined CSFs as "the limited number of areas in which results if they are satisfactory will ensure successful competitive performance of the organisation. There are a few areas where things must go right for business to flourish. If results in these areas are not adequate, then the organisation's efforts for the period will be less than desired".

Ahmad & Cuenca (2013) carried out an intensive survey using four academics experienced in ERP implementation and 16 managers involved in ERP implementation in SMEs to address three questions related to CSFs. First, what are the main CSFs? Second, how do these factors interact throughout the implementation process? Third, which factors have their highest impact and in what stages?

Thirty-three CSFs were identified after the literature survey and were classified in three categories. The list of CSFs identified and their IDs is presented in **Table 2-3** with their frequency of occurrence mean. The CSFs were classified as organisational and cultural factors as *organisational* CSFs; operational and technical factors as *operational* CSFs; and *neutral* CSFs, which cannot clearly be defined as organisational or operational factors. These factors were then ranked by panels of four academic experts and 16 ERP industry practitioners.

The results obtained underwent a cross-reference analysis with eight ERP managers involved in ERP implementation using a questionnaire-based survey in North East England, UK. CSFs were then classified as *basic, critical and dependent*. The *basic* factors included in this category were those which influence other CSFs, but others do not significantly influence them. It included CSFs such as project team skills, experienced project manager, resources, and data analysis.

The *critical* factors included in this category were those CSFs that were impacted by the basic factors and had a notable impact from others such as cultural change, use of consultants and management support. The *dependent* factors were those factors which were highly impacted by other CSFs such as cooperation, evaluation progress, and communication. Further research needs to be carried out to study the stages in which each CSF might have its critical role and their overall impact. CSFs among the different stages of the implementation would provide a better approach of identifying KPIs for measuring the implementation.

ID	CSF	Occurrence
ID1	Good project scope management	26.32
ID2	Management expectations	21.05
ID3	Formalised project plan/schedule	63.16
ID4	Project management	68.42
ID5	Steering committee	26.32
ID6	Legacy systems	36.84
ID7	Cultural change/political issues	57.89
ID8	Business process reengineering (BPR)	78.95
ID9	Experienced project manager-leadership	63.16
ID10	Project champion's role	47.37
ID11	Adequate resources	42.11
ID12	Trust between partners	15.79
ID13	Interdepartmental communication	84.21
ID14	Interdepartmental cooperation	73.68
ID15	Project team composition/team skills	78.95
ID16	Empowered decision makers	15.79
ID17	Management support and commitment	100
ID18	Monitoring and evaluation progress	68.42
ID19	Appropriate use of consultants	57.89
ID20	Vendor's tool	21.05
ID21	Managing consultants	21.05
ID22	Software customisation	36.84
ID23	Software configuration	31.58
ID24	Appropriate technology	26.32
ID25	Reduced trouble shooting-project risk	42.11
ID26	Training on software	52.63
ID27	Education on new business processes	42.11
ID28	Vendor support	26.32
ID29	Data analysis and conversion	15.79
ID30	Formal methodology-ERP implementation strategy	63.16
ID31	Carefully defined information and system requirements	52.63
ID32	Adequate ERP software selection	52.63
ID33	Clear goals and objectives	68.42

Table 2-3: List of CSFs (Adapted from Ahmad & Cuenca, 2013)

2.2.13 Implementing ERP Systems – ERP Selection Framework

Deep *et al.* (2008) presented a framework for the selection of ERP system for MTO SMEs by considering the unique needs to the SME sector and then MTO production. The research tried to address the following – What are the reasons for ERP adoption? What are the unique features of SME MTO sector? How will these features translate into sound selection procedure?”. The point where a product becomes unique to a customer order, known as Customer Order Decoupling Point (CODP) or Order Penetration Point (OPP), was used to differentiate the various production systems such as MTO, MTS, ETO and ATO. The survey involved interviewing 30 key users and findings were analysed as common trends.

Various features such as incalculable demand pattern, production lead time, pulled strategy, multiple models of replenishment, overlap of different functions, high degree of management control, lack of defined procedures, routings and standardised times, little control over suppliers, late product changes into manufacturing either by customer action or design changes and lack of engineering skills were identified. They were specific to the sales, design/bill-of-material (BOM), production and despatch and finance stages of operation in the MTO environment.

The selection process framework was conducted through semi-structured interviews with 17 members comprising the end-users and management. The selection features included better integration between different systems such as MRP, financial system, CRM, need for effective planning system such as APS; rule based product configuration, structured BOM maintenance, flexibility to integrate with add-ons, ease of use, and automated quotation system.

A PLAN-IDENTIFY-EVALUATE-SELECT methodology for ERP selection was proposed. Deep *et al.* (2008) concluded the following –

- ERP selection began and ended with a realistic estimate of what was a value-adding process
- ERP selection should be a team decision and it should involve as many end users as possible
- Change management was a unique scenario and required educating people who had little experience on such systems
- Reference visits to companies who had implemented ERP systems was important
- Use of Pareto’s 80-20 rule to define process paths to overcome the inherent difficulty in SMEs for defining process paths
- Cost considerations should not be explicitly used to eliminate a vendor

2.2.14 Implementing ERP Systems – ERP Selection Framework limited to Large Enterprises (LEs)

Verville & Bernadas (2005) suggested ten CSFs in acquiring an ERP system using a multiple-case design in three Large Enterprises (LEs). These factors were related to the process of acquisition and people within the process.

Acquisition CSFs identified were – planned and structured process, rigorous process, definition of all requirements, establishment of selection and evaluation criteria and accurate information. People-related CSFs identified were – clear and unambiguous authority, careful selection of acquisition team, partnership approach, user participation, and user buy-in.

The study concluded that future researchers should compare CSFs in implementation stage to the acquisition stage. This will address questions such as "are they comparable or do they complement each other?"

2.2.15 Implementing ERP Systems – Profile of manufacturing SMEs

Raymond & Uwizeyemungu (2007) provided a framework for analysis that can help SME owner-managers to better position their firm before contemplating the implementation of an ERP system. The study provided *environmental*, *organisational* and *technological* contexts that influence the profile of SMEs adopting ERP. A cluster analysis of secondary questionnaire data obtained from a database of 356 Canadian manufacturing SMEs was performed. The *environmental* factors included were – commercial dependencies, network intensity related to design, research and development, marketing and distribution partnerships. The *organisational* factors involved administrative intensity, types of production, innovative capability, quality, capacity and flexibility. Finally *technological* context involved Computer Integrated Manufacturing (CIM) tools like Computer Aided Design and Manufacturing (CAD /CAM) and Flexible Manufacturing Systems (FMS).

The above contexts were used to classify firms as internally predisposed, externally predisposed and unfavourably predisposed towards ERP implementation. SME owners-managers by closely observing the current level of assimilation of their manufacturing systems (technological) with organisational and environmental context will be able to determine to what extent the SMEs manufacturing systems are in phase with their competitive environment, strategy and resources.

2.2.16 Implementing ERP Systems – CSFs in Large Enterprises and SMEs

Doom *et al.* (2010) conducted a study on CSFs in four Belgian SMEs. The results showed that most of the success factors found in the literature apply to SMEs. By merging over 40 CSFs, five groups of CSFs were formed, i.e. – (a) vision, scope, and goals; (b) culture, communication and support; (c) infrastructure; (d) approach; (e) project management. The study concluded that most of the CSFs of ERP implementations in LEs also occur in SMEs. This holds true for the list of the most important CSFs in SMEs. However, this study showed that there were a few CSFs of ERP implementations found in LEs that were notoriously absent in the SMEs.

The explicit limitation of the scope and a dedicated IT infrastructure appears to be no issue for SMEs. Possibly, this could be explained by the high level of top management involvement. Moreover, monitoring by the senior management prevents projects from running out of control. The IT infrastructure of SMEs is usually far less complex than the infrastructure of LE and generally does not cause an issue. In terms of external expertise and change management factors, the study showed that there was a relatively high reliance on the input of consultants. In addition, Belgium had an economy that was rather small and open in nature; hence change management was not an issue there. It concluded that future research should focus on each of these differences and study them to discover the mechanisms behind them. Moreover, similar studies should be executed in different countries to gain a better understanding of the impact of culture on critical success factors for ERP implementations in SMEs. This links to Aslan *et al.* (2012) conclusion that a UK sector-specific ERP survey should be carried out.

Snider *et al.* (2009) explored CSFs for ERP system implementation in five SME manufacturers from Canada. The study identified factors that may distinguish between the successful and unsuccessful ERP implementations in SMEs. Secondly, it explained how and why specific factors might apply in particular to SMEs. The study did not directly compare the CSFs identified in previous studies based on LEs. CSFs identified in this study were for SMEs. It concluded future research could involve a survey study that includes both LEs and SMEs for a statistically valid comparison of CSFs between both types of organisations.

Leyh (2012) conducted a study of 185 relevant journal papers on CSFs and concluded that only 12 papers explicitly focused on SMEs. This represented a lack of research and links to the outcome of the study by Snider *et al.* (2009). The review derived 31 CSFs and identified top management support and involvement, project management and user training as the top three important CSFs.

2.2.17 Implementing ERP Systems – HR Benefits, Gable's ESS model & evaluation

As per the study conducted by Zach (2011) in the Czech Republic, SMEs did not realise any HR cost reduction. None of the four organisations reported any HR layoffs because of the ERP system. This may be related to the nature of work positions in SMEs. In SMEs, since there were no precisely defined employees' roles and responsibilities, ERP system implementations were not expected to bring significant HR cost reduction. Further, no evaluation of the ERP outcomes had been conducted by any of the companies. This could be due to reasons like the ownership style of these SMEs. Often the Chief Executive Officer (CEO) is the owner and they were actively involved in the operation of the business. Thus, they were in contact with the system on a daily basis and got regular feedback on this all the time. Therefore, they were able to perceive the effect of the ERP system and recognise ERP outcomes based on the practice. Another reason for the lack of evaluation may be the incomparable nature of legacy systems. They were functionally limited and insufficient; hence the logic of 'everything' was improved by implementing an ERP system.

SMEs had been found to be constrained by limited resources and limited IS competence. Since the evaluation of ERP requires resources, this would lead to taking resources away from the primary business activities. This generally is not approved by SMEs. Future research should involve understanding why not all the ERP system outcomes matched the Gable's Enterprise Systems Success (ESS) model parameters for IS success measurement. Another study could be to relate the ERP system outcomes to different stages in the ERP implementation in SMEs.

2.2.18 ERP and Customisation, Flexible Business Process and System Flexibility

Teittinen *et al.* (2012) conducted a study on implications of management control when companies implement ERP systems. It argued that ERP systems were homogeneous systems, which were used in a heterogeneous and very inconsistent way in organisations. The study showed that heterogeneous use of ERP might lead to problems in management control, particularly in the form of incorrect data. This is primarily due to lack of personnel resources in SMEs and partly due to structural inadequacy of the ERP.

Zach & Olsen (2011) suggested that one of the key differences in implementing ERP systems in MTO sector was the requirement for a high level of customisation. Olsen & Saetre (2007) argued that the monolithic structure of ERP systems was often insufficient to mould the idiosyncratic business process of MTO sector. Further, it suggested the use of proprietary in-house developed software for niche companies with idiosyncratic processes. However, this cannot be a solution for all SMEs due to lack of in-house software development expertise coupled with resource constraints associated with developing and maintaining such departments (Ahmad & Cuenca, 2013; Zach & Olsen, 2011).

Deep *et al.* (2008) suggested that one of the features that underpin the success of an ERP project was the degree to which the business process and the ERP system were reconfigurable. MTO firms often work in an environment of untold demand pattern. Further, product changes may happen late in the manufacturing stage, either by customer action or by design changes. The management in MTO SMEs exercise a high degree of involvement and communication in the daily functioning of processes. As communication is more visible, business processes are more flexible. This needs to be reflected in the ERP system too and it should be possible to perform system modifications quickly and efficiently, such as the possibility to provide add-ons when needed at later stages (Zach & Olsen, 2011).

2.2.19 Post Implementation System Development and Team & External Events

Zach & Olsen (2011) suggested that the system development competence within the MTO SME was crucial to further maintain and develop the system. Such firms should compensate any vulnerability of staff turnover by training more employees or hiring new IT staff. Zach & Olsen (2011) suggested that poorly described business processes in SMEs lead to imprecise definition of employee roles and responsibilities. Often implementation team members deal with ERP system implementation and routine work duties. Resulting work overload and lack of time can affect the quality of requirements identification and analysis. Thus, clear responsibilities and tasks need to be granted at the very beginning of the implementation project. They further suggested that ERP implementation projects get affected by external economic macro events primarily because of their position in the supply chain.

2.2.20 ERP and System Outcomes Evaluation

Compared to other IS, the outcome evaluation of ERP systems requires a complex approach. This is primarily because ERP systems are organisation wide systems encompassing processes from the organisation as a whole. Further, the dynamic MTO environment implies an additional constraint. Zach & Olsen (2011) argued that as MTO conditions changed quickly, ERP outcome evaluation was difficult to perform. Further research is needed to explore this issue.

Earlier, Sun *et al.* (2005) demonstrated a simulation model for cost versus time and achievement versus time for various CSFs. There is a need to explore this study further. Daneva & Wieringa (2008) suggested developing an integrated approach to effort, size and cost and then using the models to manage cross-organisational ERP customisation related risks. Hustad & Olsen (2011) presented a costs list to help SMEs to predict the costs they might face or include within their budget allocation. This research was limited to Egyptian SMEs and there is a need to explore this further. Daneva (2010) suggested a three-way approach to determine the uncertainty of ERP projects from an effort estimation perspective. The work tried to address the issue of considering competing bids at request-for-proposal. It demonstrated an empirical approach that leveraged the complementary application of three techniques; an algorithmic estimation model, Monte Carlo simulation, and portfolio management.

2.2.21 Summary

In this section, relevant results from various researchers have been reviewed, and the important information gleaned from their work.

Some of the important points are summarised as follows:

- ERP projects are more than IT projects and are continuous projects
- ERP systems are made from traditional MRP systems
- ERP markets in LE have saturated
- ERP vendors since the mid-2000’s have modified their products to suit SMEs
- SMEs are different from LE’s in terms of ERP system needs
- There is a generalisation issue in ERP packages made for SMEs
- Almost 40 to 57% of ERP projects fail to realise any benefit or run-over budget or overtime
- CSFs are not well defined for ERP projects in SMEs

- Interrelations between CSFs and ERP project phases are not clear in published literature
- MTO SMEs have different requirements from ERP projects than MTS SMEs
- Production strategy is an important CSF in MTO environments
- ERP project system evaluation and achievement are complex functions and need further research

From the discussion in this section, certain questions emerge that are not understood and are investigated in this work. The key ones are as follows.

- Do characteristics of MTO SMEs and CSFs for ERP projects interact?
- Which MTO characteristic affects which ERP implementation stage?
- Which CSFs affect which ERP implementation stage in MTO SMEs?
- Is there a dynamic relationship between CSFs during the various ERP implementation stages in MTO SMEs?

2.3 Simulation

In this section the valid theories related to Discrete Event (DE) simulation is reviewed.

2.3.1 Simulation Theory

ERP systems are based on technological foundations of MRP and MRP II systems. As a result, ERP systems inherit a number of shortcomings associated with the MRP system. The shortcomings inherent in the MRP approach are fixed lead-time, the assumption of infinite resources and fixed routings. However, simulation can often capture and describe complex interactions within a manufacturing system where analytical methods fail.

Pegden *et al.* (1995) defined simulation as '*the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system'*.

After modelling, simulation has been recognised as the second most widely used technique in the field of operations management (Jahangirian *et al.*, 2010). Jahangirian *et al.* (2010) conducted a review with the purpose of having a wider coverage of the simulation literature, broader scope of simulation and focus on real-world application. Two hundred and eighty one papers were reviewed and it was found that in terms of application area, scheduling had the most number of references. This was mainly attributed to the fact that this area was well defined with known variables. The difficulty was usually in finding a reliable analytical model.

As a technique, Discrete Event (DE) simulation had been used in over 40% of the papers. This was followed by System Dynamics (SD), which accounted for 15% of the reviews. The review stated that a growing area of research was the use of hybrid simulation. This technique brings together various simulation techniques to solve an issue. Example of this type of integration is 'Enterprise Modelling and Simulation', where the impact of production decisions evaluated using DE simulation is investigated on enterprise level using SD technique. Although DE simulation technique has the highest number of real problem-solving papers, only half of them used real data. As the data gathering process takes a longer time, this may cause stakeholders to lose their interest. The review called for further studies about the successes and failures of simulation being applied in new domains.

2.3.2 Simulation Process

O'Kane (2004) presented a cross-case study on DE simulation usage in LE and SMEs. It suggested that the measure of manufacturing productivity was highly relevant to manufacturing organisations. The study considered resources such as machines and workers as performance measures. LE and SMEs have different organisational approaches to choice and usage of simulation. The SE used in this study was a MTS type whereas the ME and LE employed more than 500 people, hence not applicable to this study.

O'Kane suggested that the standard steps in simulation study were as follows:

- Problem definition
- Preliminary analysis and project planning
- Data collection
- Model building
- Model verification
- Model validation
- Experimental design
- Simulation runs and output analysis
- Documentation of model and implementation

In this study of DE simulation system, WITNESS was used. Initial models called *baseline models* were developed to understand the behaviour of existing systems. Further models were developed to simulate alternate solutions or 'what if' scenarios. Average simulation runs were between five and ten runs. Warm up periods were between three to twenty four hours. While the entire simulation model developed for the individual case studies proved to be an aid in achieving performance measure goals, the approach and expectations were different. The results indicated that SMEs tended to let the model development and results dictate the direction of the study at times. This was because owners/managers in SMEs knew a lot about their process, but not about simulation. O'Kane suggested simulation like most technologies needs a champion to support its cause. The study concluded by suggesting the following:

- Do not perceive simulation as a solution or only aid to decision making
- Ensure that there is a company champion for simulation
- From the onset, identify main or salient features and ignore irrelevant aspects
- Emphasise the need for good data accuracy
- Data collection needs to be disciplined
- Understand the processes thoroughly before trying to mimic them
- Design good data connections to speed up data input to the model
- It is important to build a baseline model to build confidence in the modelling
- Effective reporting and communication with appropriate staff
- Realistic and relevant run times
- Involve company personnel in model building
- Develop good graphic user interfaces to explore experiments and alternate scenarios
- Not to rely heavily on animation, to get insights into problems use reporting /analysis tools as well

2.3.3 Simulation and ERP

DeFee (2011) suggested that change management is the single biggest hurdle in successful ERP implementation. Further stated, technology should not drive the business, rather it should support and enable efficiencies in the business. Simulation models can be used to communicate to stakeholders how ERP will be configured to support processes. It further stated that a 'narrow down' approach is adequate. Typically, 20 to 30% of the processes are critical processes and hence will likely need full simulation to mitigate risk.

2.3.4 Simulation and ERP Achievement Assessment

Sun *et al.* (2005) presented a framework to help SMEs identify the key requirements and measurements that determine achievement of ERP implementation. Using realistic data, CSFs were converted into quantitative information to reflect measurement including cost, schedule, and goal achievement that must be addressed during implementation. Using simulation a good balance was reached amongst cost, schedule and achievement level. It demonstrated that as the implementation schedule increases, the cost increases; while the achievement increases to some point beyond which there is no significant achievement benefit. Implementation strategies may be developed and evaluated using simulation to ensure that pre-defined goals set by the company are satisfied in an acceptable manner. It concluded that future work is needed to indentify and prioritise attributes of CSFs which contribute the most to ERP success. It proposed developing a stochastic model for giving SMEs the ability to model and monitor ongoing changes to CSF parameters during implementation.

2.3.5 Simulation and Interrelationships between CSFs in ERP Projects

Ali & Xie (2011) studied the role of CSFs and the relationship between CSFs in ERP implementation. It reviewed models proposed to study CSFs, but concluded that most of them were theoretical and lacked practicality. It proposed a simulation model for ERP implementation in SMEs to overcome this deficiency.

The proposed model would involve the CSFs and its attributes. It is based on the idea that CSF performance during implementation process is drawn from a number of key attributes and level of focus given during implementation. Further, each CSF has its related cost, time and performance that contribute to overall results. This is linked to the study conducted by Sun *et al.* (2005).

2.3.6 Simulation and BPR in SMEs

O'Kane *et al.* (2007) presented a study of a family owned SME implementing a simulation model to gauge the potential improvements for production facilities while implementing Total Quality Management (TQM) and Business Process Engineering (BPR). Change management decision making in manufacturing organisations is usually related to either radical changes such as new operations systems or improvements to existing production systems. TQM and BPR are considered as two completely different improvement programmes mainly because of the pace, time required and initiatives for change.

The study suggested that there had been a recent increase in SMEs pursuing joint TQM/BPR programmes. Simulation can be a reliable scientific method to assist in the re-engineering process and make a significant contribution to continuous improvement of quality management systems. However, simulation technology is often overlooked in SMEs primarily due to cost and expertise required to develop a credible simulation model.

Using DE system WITNESS, the study modelled the existing manufacturing process for three types of filters most commonly made by the SME. It then identified potential improvements, conducted what-if simulation analysis and demonstrated that SMEs can benefit from simulation as a decision-making tool. Appropriate run-time and warm-up period were selected and four experiments were conducted to test various operational scenarios. These experiments contribute to the process of continuous improvement. The research concluded that more exploratory studies were required to validate their findings of use of simulation to SMEs and that the future studies should incorporate both manufacturing and service sectors.

2.3.7 Simulation and ERP – MRP Logic Shortcomings

Moon & Phatak (2005) investigated the possibility of addressing the ERP system's inability to handle uncertainties and unexpected events using simulation. ERP systems are mainly designed for transaction bookkeeping purposes and are not meant for decision-making processes. To get real-time data, ERP systems require external systems such as Manufacturing Execution System and SCM system.

The model uses probability and statistics to consider the effect of uncertainties. The benefits are bi-directional with the simulation model addressing the uncertainties of the ERP and ERP addressing the inherent challenges of the simulation model. The ERP system provides real-time data to the simulation model. The architecture of the model involved three steps:

- Feeding data from the ERP system to the pre-built model
- Incorporation of real-time shop floor status into the simulation model
- Simulation scenario runs: Optimal model was selected using optimisation tool within the model, and expertise of production manager

An example of determining realistic lead-time was demonstrated. A manual feedback was created to update the lead-time in the ERP system for a manufactured item. It suggested that a similar method should be applied to address other specific issues caused by MRP's non-stochastic assumption. Future research should explore automatic data collection process to update the simulation model.

2.3.8 Simulation and Workload Control Logic (WLC) in MTOs

Stevenson *et al.* (2010) conducted a study on data collected from 41 MTO SMEs to gather evidence on the characteristics of MTO organisations that affect WLC implementation. The requirement identified from the study was a research agenda for refining WLC concepts to improve alignment between theory and practice. The study concluded that WLC had potential to improve Production Planning and Control (PPC) practices in MTO. It proposed developing more realistic simulation models using MTO SMEs characteristics such as company size, and PPC activities. Field research should apply and extend the initial implementation strategy.

Kirchhof *et al.* (2008) presented a case study on the applicability of WLC for an automobile supply industry to address poor delivery reliability and reduced inventory times. WLC is a load oriented production control policy intended to establish short and precisely predictable lead times in order to improve delivery reliability. It is based on Little's Law, i.e. mean throughput times can be decreased by reducing the mean WIP. The idea is to create short, stable and predictable queues in the production process in order to minimise throughput time. The main instrument to control WIP is the release decision transferring an order to the set of orders admissible for production. The decision is based on the level of workload at each workstation that the order has to pass through during its outing sequence. These levels of workloads are measured in units of processing time and compared to workload norms.

The processing time and routings were adopted directly from the firm's EPR system. The statistical distribution of the inter-arrival times, order quantities and percentage of urgent orders were derived from historical data. The robustness and simplicity of the model were dependent on parameters such as workload norms, release period length, release method and priority dispatching. Various simulation runs were performed and a sensitivity analysis was done to gauge the effect of changing the input data with a +/- 30% tolerance. The study concluded that such a technique allowed deep understanding of the system dynamics.

2.3.9 Simulation in Mass Customisation Environment

Stump & Badurdeen (2009) presented a Mass Customisation (MC) boat manufacturer's case study in applying lean principles and integrated strategies such as quick response manufacturing, job shop lean, flexible manufacturing system and theory of constraints in MC environment. A simulation model was developed to check the potential impact of system design changes. The results from the simulation showed a significant reduction in lead-time. The study concluded that it was not a complete representation of all cases, but more of an attempt to combine the existing findings into a comprehensive framework to aid in further research.

2.3.10 Simulation and Service operation in SMEs

Ahmed and Latif (2010) presented a case study of product return procedure in two retail SMEs. The research study used DE simulation to model the effects of product returns in SMEs. WITNESS simulation software was used to develop the base model and what-if scenarios were conducted to find inefficiencies. Once the *baseline* model identified the issues, the study resulted in the construction of three RMA simulation models. The final model selected provided an efficiency of 99% with reduced staff levels and costs.

2.3.11 Simulation and Lean Strategies in SMEs

Stone (2012) presented a review of scholarly lean literature spanning four decades. Five themes evolved from the analysis starting with discovery, dissemination, implementation, enterprise and performance. After reviewing nearly 200 papers, the study suggested that most of them centred on 'how to do' lean principles and critiques of the consequences. The research gap identified by Stone (2012) can be summarised as follows:

- Void between lean thinking and aspects of planned organisational change. Organisational change such as revolutionary versus evolutionary, and discontinuous versus continuous were areas which needed to be explored with lean thinking
- Lack of connections between 'human' factors such as human resource management, labour retention and lean thinking

Mahfouz *et al.* (2011) presented the results of a case study in a food and packaging SME, where four lean factors were defined and examined against three response functions. The system was comprehensively modelled using Integrated Definition for Functional Modelling (IDEF0) language. Then a DE simulation was developed to analyse the selected factors. Finally, a Response Surface Methodology (RSM) was used to optimise the response function.

A simulation based optimisation model was developed to optimise a set of parameters (demand management, preventative maintenance, labour capacity and product flow) of lean SMEs against three performances measures – cycle time, WIP and workforce utilisation. IDEF0 was used as a modelling approach to conceptualise the business process at the company. IDEF0 indicates the sequences of activities, inputs, outputs and the controls. The simulation model evaluated lean principles by changing various parameters or adding resources. Verification of the model was done by decomposition (analysis of small blocks) and built-in debugging in the simulation software. The simulation model was validated using two techniques; face-to-face validation that was performed by interviewing managers and manufacturing teams to validate results and 'comparison testing' by comparing the model output with the system output under identical input conditions.

During the analysis stage, three goals were pursued: (i) develop a valid relationship between the indentified lean factors and response variables, (ii) identify CSFs that have significant influence on response functions, (iii) optimise the settings of the critical parameters for each response. The Taguchi method was used to identify the main and interaction effects of the studied lean factors. Response Surface Methodology (RSM) was employed to establish optimal results. The study concluded that further research should be carried out to develop decision-making models that could optimise the contradicted response functions simultaneously.

2.3.12 Lean – System Dynamics to Manage Lean Manufacturing Systems

Deif (2010) suggested that a difference existed between lean manufacturing and a manufacturing system that just applied lean techniques. The study suggested that there were many attempts in literature to describe how to implement lean manufacturing or how lean manufacturing would improve the performance of manufacturing systems. However, there are fewer attempts to explore the lean manufacturing dynamics.

A system dynamic approach was used to explore the impact of applying lean policy on traditional inventory based production system. To get full benefits of the lean manufacturing theory, systems should undergo substantial change in terms of culture and infrastructure. Applying Just-in-Time (JIT) systems to traditional production and inventory control will not guarantee improvement levels. The model demonstrated how JIT brought responsiveness in traditional systems by setting the inventory adjustment time to equal or greater than cycle time and shipment time. A trade off decision was required to balance the benefit of quick response to market and the costs associated with that to stabilize production. It concluded that the presented dynamic analysis should be extended to multiple stage production, and that the role of parametric modelling should be investigated.

2.3.13 Discrete Event Simulation and Lean

Detty & Yingling (2000) presented a case study to check whether DE simulation was a tool able to assist organisations with decisions to implement lean principles. The case study focussed on not only the manufacturing system but also warehouse, inventory control, transportation and scheduling systems. The case study used a high volume assembly process for electronic assembly with 80 components in MTS environment. These parts were mostly sourced and assembled in identical cells. The study showed how simulation could be an aid in analysing, designing and improving specific parameters of a system. It enabled quantifying the impact of the system improvements to some extent, but could not provide monetary value gained due to reduction in order lead-time and levelled demand on suppliers.

Sharma and Yadava (2011) suggested that the role of maintenance in modern manufacturing systems was becoming even more important with companies adopting maintenance as a profit generating business. The study proposed that for best operating performance, maintenance optimisation model, maintenance policy, maintenance cost and reliability measures should be considered simultaneously. One of the methods used was simulation-based optimisation method. The study concluded that there was scarcity of DSS type optimisation models. It suggested that there was a need to carry out a study of optimising maintenance cost for different combinations of maintenance activity using simulation.

Bergmann & Strassburger (2010) suggested that future challenges of modelling and simulation included reduction in time and effort for simulation studies. It suggested that the entire simulation technology was interdisciplinary and required expertise in different knowledge areas such as computer science and economic science as well as mechanical and industrial engineering. This often caused issues within the SME context. *Automatic models* are generated from external data sources, using interfaces of the simulator and algorithms. They are not created using modelling tools of the simulator. The challenges to create such simulation models are incomplete data in external systems, handling missing details regarding the dynamic behaviour of the system and model reuse issues. The proposed work to overcome these issues involves simulation model generation based on close integration of simulation with the IT landscape of the company.

Waller & Ladbrook (2002) suggested the use of virtual reality and 3D views. Although they offered little or nothing to the solution of the mathematical simulation, they suggested that the benefits lie in understanding the layout under discussion. It is easier to discuss the real issues if the basic layout of the model is self-evident. This is a different view to the one suggested by O'Kane (2004).

2.3.14 Reconfigurable Simulation Systems

Lee & Choi (2011) suggested that *business rule* approach was becoming popular for office-level domains such as ERP systems. This has seen the evolution of reconfigurable information systems. ERP vendors have adopted this trend and are putting their efforts into minimising software implementation and maintenance costs by reconfiguring various pre-defined services according to the business process of a client company.

McKay & Gary (2007) reviewed the purpose of planning and scheduling systems (PSS) taking manufacturing requirements, matching them with a model of the factory and using various algorithms and technology to create a work schedule automatically or with manual intervention. Pinedo (2002) further suggested that the PSS should be implemented as reconfigurable. It should consist of software components that must be modularised in form to accommodate changes in the managerial business process caused by market fluctuation. Koren *et al.* (1999) suggested that manufacturing systems had evolved into flexible and reconfigurable manufacturing systems; but PPS were still far away from the agile information trends Lee & Choi (2011).

Lee & Choi (2011) suggested that the above drawback came from the structural limitation of PSS introduced so far. They adopted analytic algorithm approaches based on combinatorial optimisation. Wu (1994) and Pinedo (2002) suggested that in such cases it was not easy for the users to understand and modify those analytic models based on algorithms. Lee & Choi (2011) suggested that sometimes it was impractical to have a high degree of modular structure in a software system implementing various mathematical models. Plug-in modules provided were hard to modify and they were costly. To overcome the weakness of analytic algorithmic approaches, many studies related to simulation-based scheduling had been presented. This approach focuses on applying simulation to support a cyclical decision-making approach during planning and scheduling.

Lee & Choi (2011) presented a simulation model which was similar to the existing usage of simulation, but additionally allowed users variables to adjust simulation parameters or decision variables like dispatching rule until an acceptable plan or schedule was acquired. The simulation algorithm used was a capacity-filtering algorithm that was a core part of the capacity-filtering system. Experiments were conducted with a planning horizon of eight days, in a multi-chip package assembly line. The system was designed for non-professional users to reconfigure easily. Inputs to the model were initial time, initial status of jobs and resources, capacity and loading priority among candidate's jobs or resources. The outputs were completion time and update status of jobs and resources.

2.3.15 ERP – Decision Support for Customer-Driven Manufacturing

Montonen *et al.* (2010) suggested that there were limited examples of the use of simulation tools in the operational planning of manufacturing. They proposed a simulation based Decision Support System (DSS) to augment the task of planners and schedulers to run production more efficiently. This model was tested in two large customer-driven manufacturing organisations, Sandvik Mining and Construction and Raute Cooperation.

In MTO, customer order initiates material purchases, component and module manufacturing and assembly of the product. Manufacturing is performed based on customer orders. Each order can be unique, consisting of different components and varying batch sizes. A new order is a disturbance in the current situation in production. This creates a dynamic bottleneck, depending on the status of production resources, equipment, materials, and human operators. The accuracy of order date delivery promises is a key element in customer satisfaction. Simulation analysis with real data provides forecasts for feasible and optimised finite scheduling based on the given input values, but the human factor in the loop will make the final decision.

The benefits of implementing an operational simulation scheduling system are less effort required to plan day-to-day scheduling, customer order due date conformance, synchronisation of flow, minimisation of set-ups/changeovers, and 'what-if' scenario analysis of capacity planning. The main challenges identified are data integration, automated simulation model creation, and visualisation of results for interactive decision-making.

ERP and MRP systems are usually based on static resources with unlimited capacity and this is a limitation. At present, manufacturing systems cannot be effectively studied with the ERP system. By integrating DE simulation and traditional production planning methods, it is possible to forecast required workloads within given input values. The simulation model and the developed graphic user interface make it possible to visualise potential bottlenecks. The load data for simulation indicates the product, its parameters as well as required quantities and delivery dates from the ERP.

Another factor that could limit the use of this technology is the cost of data integration between the simulation model, the manufacturing system and ERP. ASCII text files were used in this case study. The research encouraged the use of XML data for future development. Further, it identified a need for real time data coupling from the factory floor and encouraged use of a hybrid method that involved simulation, optimisation and other manufacturing information systems in an integrated application. It suggested that future developments should evaluate energy consumption and other environmental aspects in the system design phase.

Further, the dynamic MTO environment implies an additional constraint. Zach & Olsen (2011) argued that as MTO conditions change quickly, ERP outcome evaluation is difficult to perform. Further research needs to explore this issue. Earlier, Sun *et al.* (2005) demonstrated a simulation model for cost versus time and achievement versus time for various CSFs. There is a need to explore this study further. Daneva & Wieringa (2008) suggested developing an integrated approach to effort, size and cost and then using the models to manage cross-organisational ERP customisation related risks. Hustad (2011) presented a list to help SMEs to predict the costs they might face or include within their budget allocation. This research was limited to Egyptian SMEs and there is a need to explore this further.

2.3.16 Decision Support System Overview

The concept of a decision support system (DSS) is extremely broad and their definition varies.DSS can take many different forms and can be used in many different ways. Finlay (1994) defined DSS as “a computer-based system that aids the process of decision making". Turban (1995) defined DSS as "an interactive, flexible, and adaptable computer-based information system, especially developed for supporting the solution of a non-structured management problem for improved decision making. It utilises data, provides an easy-to-use interface, and allows for the decision maker's own insights".

According to Power (1997), the term Decision Support System remains a useful and inclusive term for many types of information based decision-making system that:

- Supports decision makers instead of replacing them
- Uses data and models
- Solves problems with different structures
- Focuses on effectiveness rather than efficiency in the decision processes

DSS supports technological and managerial decision making by assisting in the organisation of knowledge about ill-structured, semi-structured, or unstructured issues. A structured issue has a framework comprising elements and relations between elements are known.

Evolution of DSS

The concept of decision support has evolved from two main areas of research: the theoretical studies of organisational decision making done at the Carnegie Institute of Technology during the late 1950s and the technical work on interactive computer systems, mainly carried out at the Massachusetts Institute of Technology in the 1960s. The concept of DSS became an area of research of its own in the middle of the 1970s, before gaining in intensity during the 1980s. This was followed by evolution of Executive Information Systems (EIS), Group Decision Support Systems (GDSS), and Organizational Decision Support Systems (ODSS) from the single user and model oriented DSS. Commencing in about 1990, data warehousing and On-Line Analytical Processing (OLAP) began broadening the realm of DSS. As the millennium approached, new Web-based analytical applications were introduced (Power, 2002).

Classification of DSS

Decision Support Systems (DSS) applications are classified primarily at user, conceptual and technical levels.

User Level: Power (2002) differentiates DSS as passive, active and cooperative at the user level.

- A passive DSS is a system that supports the process of decision making, but cannot bring out clear decision suggestions.
- An active DSS can bring out clear decision suggestions
- A cooperative DSS allows optimisation. It allows the decision maker to refine the decision suggestions provided by the system and sending them back to the system for validation. The process can be iterative and the whole process then starts again, until a consolidated solution is generated.

Conceptual level:

Power (2002) differentiates DSS at a conceptual level as Communication-Driven DSS, Data-Driven DSS, Document-Driven DSS, Knowledge-Driven DSS, and Model-Driven DSS.

- A Communication-Driven DSS supports more multiple users working on a shared task
- A Model-Driven DSS use data and parameters provided by DSS users to aid decision makers in analysing a situation, but they are not necessarily data intensive
- Data-Driven DSS emphasise access to and manipulation of a of internal or external company data at time intervals.
- Document-Driven DSS manage, retrieve and manipulate unstructured information in a variety of electronic formats.
- Knowledge-Driven DSS provide specialised problem-solving expertise stored as facts, rules or procedures

Technical level:

Power (1997) differentiated DSS as enterprise-wide and desktop based DSS. Enterprise-wide DSS are linked to large data warehouses and serve many managers in a company. Desktop, single-user DSS are small systems that reside on an individual PC.

Architecture of DSS

Once again, different authors identify different components in a DSS.

Sprague and Carlson (1982) identify three fundamental components of DSS:

- database management system
- model-base management system
- dialogue generation and management system .

According to Power (2002), academics and practitioners have discussed building DSS in terms of four major components:

- user interface,
- database,
- model and analytical tools
- DSS architecture and network

Marakas (1999) proposes a generalised architecture made of five distinct parts:

- data management system
- model management system,
- knowledge engine,
- user interface,
- user(s)

Hardware, Networks, and Software

A DSS is a system for incorporating and integrating different data sources to better allow decision makers to access and compile data in a useful format. In general, most decision support systems will include the hardware, networking technologies, operating systems necessary, supporting databases and servers. It will also have a a user interface with mechanisms for accessing, manipulating, and transferring data. Finally there would be some type of repository for temporarily or permanently storing data. The important technical requirements focus on issues such as accessibility, processing and transfer speed, scalability, interoperability, cost effectiveness, and security ((Power, 2002; Marakas 1999).

Data Collection, Analysis and Reporting Tools

Data Collection: Data collection forms the foundation on which the decision system makes or derives its source of decision making. It is therefore essential on how data is captured at entry point. Once data has been captured it follows therefore that it has to be stored in a database (Power, 2002).

Analysis tools: An analysis tool is basically an instrument that applies business rules to data in order to derive meaning. This includes time series analysis, cost allocations, data mining, and other user-driven manipulation and investigation. Analysis tools are available in many software applications, including spreadsheets, databases, and other stand-alone programs. In a DSS environment, however, analysis tools are particularly powerful because they rely on On-Line Analytical Processing (OLAP) technologies. They permit users to browse, query, analyze, and summarize large amounts of data in an efficient, interactive, and dynamic way (Power, 2002).

Reporting tools: Robust reporting tools are a major element of any DSS. Presenting information in multiple formats example as text, tables, and graphics and in multiple dimensions, changing an axis to present information more clearly, sometimes further clarifies the meaning of the data. Unlike a date warehouse or database, which both focuses on data storage, a DSS often includes reporting tools that permit a user too (Power, 2002).

Use of DSS in SMEs

The use of DSS in SMEs is limited and tends to focus on operational rather than strategic decision making. SME users tend to think that DSS is more beneficial in dealing with operational tasks compared to complexity and changing environment involved in strategic decision-making. By far the most common way manufacturing SMEs implement a DSS is by procuring commercial packages. Bespoke or in-house DSS are rarely used in SMEs except for strategic decision-making Research in-house and user-developed DSS is scare in SMEs. There is a higher probability of success for implementing a DSS in a SME if it is user-developed or in-house built. There is also recognition by SME managers that DSS vendors provide good support on operational decision-making queries. The willingness of SMEs to buy commercial packages and the acknowledgment of good vendor-support suggests that SMEs provide a future market for DSS vendors.

Lin *et al.* (2013) discussed the conceptual design of a Global Decision Support System for a manufacturing SMES, which has global supplier base and actively participates in collaborative manufacturing. In order to implement the proposed concept, a Web Services based system architecture is proposed to offer maximum interoperability between all the distributed participants of a collaborative manufacturing network and their management information systems.

Ali & Cullinane (2014) evaluated the role simulation based modelling can play in assisting SMEs in ERP implementation. In this study key informants representing diverse backgrounds were interviewed to collect ERP implementation related data. The findings of the research show that key participants supported the idea of incorporating simulation based model during the implementation process since a simulation based approach make more sense since it will allow the implementation team to observe the implementation process and the role played by factors which are essential for the success of the implementation. However, this research did not consider production strategy as a CSF.

2.3.17 Summary

In this section, relevant results from various researchers have been reviewed, and the important information gleaned from their work was discussed. Some of the important points are summarised as follows:

- DE simulation is not a solution for all issues
- DE simulation is not only to aid decision making
- Hybrid models involving DE simulation and traditional technologies such as MRP can aid the human scheduler
- DE simulation case studies have been used in ERP project achievement evaluations
- DE simulation has been used to study lean strategies
- DE simulation usage in SMEs is limited
- Data integration with ERP or manufacturing system is key
- CSFs are not well defined in ERP projects in SMEs

From the discussion in this section, certain questions emerge that are not understood and they shall be investigated in this work. The key ones are as follows:

- Is there a dynamic relationship amongst production strategies as CSFs during the various ERP implementation stages in MTO SMEs?
- Do characteristics of MTO SMEs and MRP characteristics interact?
- Can MRP tools enable formulating a DSS for MTO environment?
- Can MRP, ERP and DE simulation enable formulation of a DSS for MTO environment?
- Which MRP characteristic can provide relevant data for simulation interaction?

2.4 Workload Control Review

In this section the valid theories related to Workload Control (WLC) simulation is reviewed.

2.4.1 WLC Concept

The successful implementation of Production Planning and Control (PPC) concept is affected by its suitability to a given production environment. Any approach developed needs to be dependent on key company characteristics such as production strategy (Thürer *et al.*, 2012). WLC is one such approach which is primarily designed for MTO SME sector often having job shop configurations. As a PPC concept, WLC has been primarily developed for high-variety and low-volume products produced on a MTO basis. It has been identified as particularly appropriate for SMEs with limited financial resources (Stevenson *et al*., 2005; Land & Gaalman, 2009).

2.4.2 WLC Three Tiers

WLC can be divided into three tiers i.e. lower, middle and higher level. The lower level of WLC is *dispatching* involving short term decisions. The medium level is *order release* which involves a pre-shop pool which decouples the shop floor from the upper planning level. WLC uses a pre-shop pool which decouples order entry from order release. Jobs are held back in a pre-shop pool and input to the shop floor is regulated in accordance with workload norms or limits. Finally, the highest level of control is *customer enquiry management* covering all activities from quotation to order confirmation. The most comprehensive WLC approaches incorporate control at the *customer enquiry* stage to stabilise the level of Work-in-Process (WIP) and lead times, enabling competitive prices and Due Dates (DD) to be quoted.

2.4.3 WLC Research Streams

Thürer (2012) classified the research themes in WLC into four main categories. These categories are explained below

Conceptual Research

Three decades of conceptual research has contributed to the development of two mature WLC systems: the Lancaster University approach called LUMS approach and Load Oriented Manufacturing Control i.e. LOMC approach. LUMS is a comprehensive PPC system which considers both shop and job information and incorporates a proportion of the workload of unconfirmed jobs in the total workload of the shop based on the probability of winning a tender. LOMC is a widely implemented solution for integrating a planning system with the shop floor. A need for web-functionality within a WLC DSS was also identified, either to improve accessibility for multiple users or to integrate supply chain partners. This can be considered a step towards integration into the wider supply chain and integration with other systems such as ERP systems which previous studies had not explicitly considered. Exploring how WLC can be incorporated into different ERP systems is a future research area (Thürer, 2012).

Analytical research

Almost all the early analytical research contributions that emerged were based on queuing theory. However, there have been several recent attempts. The research carried out can be divided into three groups: (1) analytical models applying queuing theory, (2) mathematical analysis of new release methods and (3) analytical tools to facilitate management decisions (Thürer, 2012).

Exploring how to develop simpler, yet effective, heuristics and models to support managers in making faster decisions in practice, including tools to support the process of setting appropriate WLC parameters is a future research area (Thürer, 2012).

Empirical Studies

A large body of literature on WLC has been produced in the last three decades. However, reports of successful implementation of WLC are limited (Silva et al., 2014). Part of the reason is that WLC is often coupled with a computer system to support decision-making and this adds to the complexity of implementation. However, simulation based DE modelling has been widely used. The WLC research streams can be categorised as shown below in Table 2-4.

Category	Description	Papers	Percentage
Conceptual research	Categorisation and development of WLC theory	24	28.6%
Analytical research	Development of approaches for modelling WLC, mainly based on queuing theory	9	10.7%
Simulation based research	Simulation studies to test the influence of various WLC characteristics on performance	41	48.8%
Empirical research	Case study analysis of WLC implementations in practice	10	11.9%

Table 2-4: WLC research (Adpated from Silva et al., 2014)

A brief review of the most relevant WLC empirical studies include papers by Wiendhal *et al.*(1992) and Bechte, (1994) which reviewed both before customer enquiry and order release stages of WLC methodology and its impact on performance measures like lead time and WIP. Fry & Smith *et al.* (2011) discussed the implementation of order release stage only where as Park *et al*. (1999) and Riezebos *et al*. (2003) discussed implementation cases from customer enquiry stage only. Stevenson and Silva (2008) documented the implementation of WLC in MTO SMEs in the UK and Portugal. These two authors then collaborated on a joint effort to compare the results of their case studies. Further, Hendry et al. (2008) identified seventeen WLC implementation issues related to market, primary manufacturing, WLC system, information flow and organisational embedding through a combined case study based in Netherlands and UK. Recently, Hendry *et al.* (2010) also reported a study which documented improved communication between staff members when working on quotations while implementing WLC.

Thürer *et al.* (2012) demonstrated an implementation of WLC in a MTO environment using Microsoft Excel spreadsheet. The main limitation of the study by Thürer *et al.,* 2011 was firstly the capacity was considered a constant and the material management was not considered. Silva *et al.* (2012) presented a case study from a practitioner-led implementation in a larger high volume MTO manufacturing environment where again Microsoft Excel spreadsheet was used. However, all the products were made from the same raw material and the raw material was considered to be always available. This may not be the actual case and often MTO SMEs make products which are made from different raw materials.

Also, research has failed to investigate the performance of the three tiers in combination. Moreover, it is either assumed that all orders require a DD to be set or all have given DD. This neglects the influence where DD settings may be a combination of being specified by both the customer and the manufacturer.

Simulation-based research

Simulation was the dominant approach in the WLC literature. Four groups of simulation-based research can be identified (Thürer, 2011):

- Testing the influence of WLC on performance to find the best fit between control stages. This involved evaluating different combinations of DD, order release and dispatching rules to determine the best combination.
- Developing new release methods and comparing performance. This compared and developed new order release rules, such as load balancing and load limiting.
- Studying the influence of environmental (external) parameters such as worker flexibility or sequence-dependent set-up times on the performance of combinations of DD, order release and dispatching rules
- Analysing the influence of WLC characteristics (internal) parameters on performance. It underlined the importance of testing the characteristics of release rules i.e. internal parameters iteratively.

An important factor missing in WLC simulation research is the 'human factor'. Bertrand & Van Ooijen (2002) concluded that the level of WIP influences worker productivity and thus processing times. They argued that an optimum WIP level can be found and that WLC can be an appropriate means of maintaining WIP at the optimal level. Incorporating such human factors like this within WLC research can only be achieved by combining simulation models with empirical experience.

2.4.4 WLC Summary

From the evolution of the field of WLC, the following conclusions could be drawn:

- The conceptual development of the LUMS Approach and LOMC has reached maturity; the focus since 2000 has shifted towards conceptual refinement.
- There has been a substantial increase in analytical modelling since 2000 while the focus of field research has shifted from observation, and reporting before or after implementation, to focusing on how WLC can be implemented through participation.
- Simulation based research has its focus shifted from finding the best fit between DD setting, release and dispatching rules to internal parameter setting and the influence of external parameters on the performance of order release rules, in many cases addressing issues encountered during empirical research.
- WLC research gaps identified include (Thürer,2011)
    a. **Conceptual Research:** the need to give far greater consideration to human factors in the design of PPC systems based on WLC; and the need to integrate WLC with ERP systems and the wider supply chain.
    b. **Analytical Research:** the need to develop tools that support managers in making fast and appropriate decisions
    c. **Empirical Research:** the need to conduct further action research into how WLC can be effectively implemented in practice and whether improvements can be sustained over time.
    d. Simulation Based Research : the need to further improve simulation models, including studying human factors that affect WLC; and, feeding back empirical findings to simulation-based WLC research to improve the applicability of WLC theory to real-life job shops.

2.5 Research Gap Analysis

CSFs SME focus: Research on ERP implementation technique within SMEs is still limited (Ahmad & Cuenca, 2013; Ali & Xie, 2011; Aslan et al., 2012; Sun et al., 2005; Zach & Olsen, 2011). Most of the ERP literature is based on large organisations and SMEs are not miniature versions of large organisations (Leyh, 2012; Zach & Olsen, 2011). CSFs have been studied extensively by academia for ERP projects in large organisations. However, there exists a research gap in this field from an SME perspective (Ahmad & Cuenca, 2013; Leyh, 2012; Zach & Olsen, 2011).

CSF interrelationships: Nazemi et al. (2012) concluded that CSFs are not well covered and only a few studies provide ERP CSF definition. There exists a research gap in establishing the interrelationships between the CSFs and the stages of ERP project (Ahmad et al., 2012). Further, the dynamic interrelationships between CSFs during the various phases of an ERP project are not clear. CSFs underpin ERP implementation projects. Large number of investigations have been focussed on the identification of main critical factors and methodologies for implementation of ERP systems and recommended a project like approach, whereas an ERP project is an IT project and has a start and end time. But Ahmad et al. (2012) have suggested the need to think of ERP implementation as a dynamic and continuous process aligning management technique and as an organisational culture. This alignment involves a large number of factors that interact and influence among themselves.

Production Strategy as a CSF: The contribution of the ERP system to organisations' strategic value creation depends on many CSFs, the right implementation and effective management of its operational performance during its lifecycle (Nazemi et al., 2012). Zach & Olsen (2011) suggested that a possible way to improve the implementation of ERP systems was to focus on specific organisational issues based on size and type, especially manufacturing strategy. Less explored, but a key CSF in MTO SMEs is their unique production strategy Zach & Olsen (2011).

CRM activities as CSF: Aslan et al. (2012) argued that CRM utilisations in MTO sector needs to be explored further. Like production strategy this could be an important CSF for a firm's successful ERP implementation. Aslan et al. (2012) suggested that for the MTO sector, a system must be able to provide support through most of the production planning and control stages and is suitable for job shop. It proposed Workload Control (WLC) as a good fit to integrate with ERP systems and linked with the work of McKay et al. (2007).

They argued that if the ERP system can handle most of the other needs of the MTO firm, then WLC embedded in ERP can improve the functionality of the ERP system.

2.6 Summary

To conclude the literature review has identified the need to develop a methodology within a MTO sector where CSFs and interrelationships are managed in a continuous manner. Production strategy as a CSF within an MTO manufacturing sector needs to be managed during and after ERP implementation. Workload Control (WLC) interfaced with ERP can improve the functionality of ERP system in production order release decisions and address lead time based CRM activities.

Chapter 3: Methodology

3.1 Introduction:

It is the research problem that dictates the approach and methods to be used in research (Kekäle, 2001). This is a collaborative research project between MTO SME and University of Greenwich. Therefore any work carried out must be relevant to an industrial setting. A research methodology that satisfies the demands of both academia and industry has been selected. The methodology was divided into four phases, each of which covers an area of the research. The research were supported by actual implementation of an ERP system, numerous site visits, stakeholder requirement identification, dynamic and static data collection activities, extensive literature survey, project and people management skills.

3.2 Research Paradigms

Research can be of various types of such as descriptive, exploratory, analytical, predictive, qualitative, quantitative, deductive, inductive, applied and basic research (Hussey & Hussey, 1997). The nature of the research selection depends on the methodologies and methods used in the research and the explanation of the choice. A research paradigm or philosophy defines how people study their world. It provides a method for people to look at the world, interpret it and validate the findings presented by the researcher. Further, it also suggests how research should be performed, by whom and with what level of involvement or disconnection (Rubin & Rubin, 1995; 2005). Paradigm is also a set of shared assumptions of thinking about some of the aspects of the world (Oates, 2006). There are diverse views about the nature of our world (ontology) and how knowledge can be acquired about it (epistemology) from different philosophical paradigms.

The three major research philosophical paradigms which have been developed are positivists, interpretive and critical (Myers, 2010; Neuman, 1994; Klein and Myers, 1999; Myers and Avison, 2002; Oates, 2006). The oldest research paradigm is positivism or scientific approach (Oates, 2006). Positivism paradigm assumes that the world is ordered and can be objectively studied. The positivists assume that reality is quantifiable and it is independent of the researcher and their tools. The positivist attempts to test theory in order to increase the predictive understanding of the phenomena (Myers, 2010).

The researchers in the critical paradigm assume that social reality is historically constituted and then it is produced and reproduced by people (Myers & Avison, 2002). Researchers recognize that although people can consciously act to change their social and economic circumstance but their ability to do so is limited by various forms of social, cultural and political domination such as natural laws and resource limitations.

Interpretivism is the second major philosophical paradigm. Interpretivist aims to understand and interpret how people create and sustain their social world. The assumption in this paradigm is that access to reality is through social construction such as language, consciousness and shared meaning (Myers& Avison, 2002). The interpretive research is about how people view an object, the meaning they attribute to it and obtaining consequential information from the various social interactions (Myers & Avison, 2002).

Rationale for interpretive paradigm

The interpretive paradigm has been adopted for this research and this lead to the selection of an appropriate research method. Myers, 1997 suggested the study of Information Systems (IS) research can take any of the three approaches discussed above. The Information Systems (IS) process of acquiring knowledge i.e. epistemology depends on social sciences because IS are basically more social rather than technical systems (Hirschheim, 1992). The most important principle of the interpretive research is that the researcher is a part of the process and not an independent observer. The positivist paradigm was rejected due to its limitations when dealing with people and capturing their social beliefs i.e. subjectivity. As this research was part of a KTP project hence adoption of the interpretive paradigm is justified. Within a Make-to-order (MTO) SME context the researcher is interested in understanding the implementation, impact of Critical Success Factors (CSFs), utilisation of ERP, benefits and challenges of ERP systems thus this research study is interpretive in nature (Myers, 1997)

3.3 Research Approaches

The study of research methodology provides the necessary training in choosing methods, materials, scientific tools and training in techniques relevant for the problem chosen. Many researchers define themselves as either quantitative or qualitative. This idea is linked to what are seen as the different underlying philosophies and world views of researchers in the two ‘paradigms’. According to this view, two primarily different world views lie beneath quantitative and qualitative research. The world view underlying quantitative view is described as being ‘realist’ or ‘positivist’, while that underlying qualitative research is viewed as being ‘subjectivist’.

Rationale for mixed approach

Due to the nature of the research questions and the case company implementing an ERP system, a combination of qualitative methods in a descriptive manner and as well as quantitative research methodology was used to answer our research questions. It provides an opportunity to look at the literature review with the additional data collected and understand ERP potential effect on users and companies while implementing an ERP system. The qualitative data gathered using continuous improvement workshops, informal discussions with staff during observations gave more understanding on Company 'A' requirements and the ERP project phases. It laid the path for identifying Critical Success Factors (CSFs). The quantitative data that was gathered from Delphi analysis allowed identifying and studying the effect of CSFs had on incorporating best practices while implementing an ERP phase. Also, critically it identified the need for production strategy to manage as a CSF. From a standpoint it showed the effect of CSFs in their natural setting (within a Make-to-Order SME firm) and how they influence the effectiveness or ineffectiveness of ERP systems in MTO context. This coupled with the results from the Delphi analysis demonstrated how CSFs influence the ERP implementation phase from an end user training and change management perspective.

3.4 Research Strategy: Action Research

Industrial research projects are about addressing real issues in real life situations. Based on the research objectives and the characteristics of the challenges facing the case company action research were assessed to be the most appropriate research strategy. It is one of the most common strategies used for Information Science (IS). The strategies being ethnography, grounded theory and the case study research (Myers, 2009; Oates, 2006).

Action research is a collection of approaches that aim to "contribute both to the practical concerns of people in an immediate problematic situation and to the goals of science by joint collaboration through a mutually acceptable ethical framework" (Rapoport, 1970; Middel et al., 2006). It has been used and developed productively as an approach to Information Systems (IS) research (Iversen et al., 2004). The primary focus of this research methodology is on solving real issues by emphasising on scientific study (O'Brien, 1998). Such a methodology enabled to focus on the practical concerns of solving real issues during various phases of the research.

Action research and case study research differ. In action research, researchers test and refine principles, tools and methodologies to address real-world problems. Thus, whereas case study research examines phenomena in their 'natural' environment with the researcher as an independent or separate observer, in action research the researcher ought to be participative as well as an observer.

Action research creates knowledge based on enquiries conducted within specific and often practical contexts. Action research is participatory in nature and involves a spiral of self-reflective cycles of (Kemmis & McTaggart, 2000)

- Planning a change
- Acting and observing the process and consequences of the change
- Reflecting on these processes and consequences. And then re-plan
- Acting and observing
- Reflecting
- Simultaneous contribution to knowledge and practice

Action research uses participatory methods as much as possible. As the researcher and practitioner modify the experiment parameters, they could reach different outcomes from what is being achieved as a result of the changes. In action research, even though there is a conceptual difference between 'action', 'research' and 'participation' involved, such differences begin to disappear as the research continues. The trademark of action research is that change does not happen at the end of the research project but throughout it.

Defining the unit of analysis:

The unit of analysis chosen for this study is the ERP project of Company 'A' within a Make-to-Order manufacturer context. The KTP project at Company 'A' provided this opportunity. Cases for study can be revelatory or unique or critical to test a theory. Also, case study choices should provide opportunities to replicate and generalise the study. The case chosen is "revelatory" as the researcher was personally involved in ERP as a KTP Associate. This provides some unusual opportunities for collecting data but within a participatory framework that KTP provides. Detailed notes of the events made by the researcher also helped in this process. In addition, there was access to a detailed post-completion audit done of ERP by the team. This provides an excellent learning perspective of the events prevailing, the problems encountered, and the results achieved. The approach also satisfies meeting the necessary conditions for the research questions and also provides an opportunity to test replicability of findings for questions like

- Can CSFs and Make-to-Order (MTO) characteristics affect ERP implementation stage in MTO SMEs?
- Can a unified approach involving Material Resource Planning (MRP), Workload Control (WLC), ERP and Discrete Event (DE) simulation enable formulating a Decision Support System (DSS) for MTO environment?

Data collection and analysis methods

This research used both quantitative and qualitative data. The different approaches require different types of data collection, hence require varying data analysis techniques. Further, various data collection methods which are often common to the qualitative research paradigm were used. They can be identified as - keeping a research journal, collection and documentation of static and dynamic data, analysis, stakeholder viewpoint and feedback, unstructured interviews, viewing and studying actual business processes and manufacturing activities, and referring case studies related to make-to-order manufacturing environments, etc. Quantitative data collection technique used was Delphi analysis, questionnaires and interviews (Straub et al., 2005) whereas qualitatively, researchers may gather data through observation, interviews, and audit-reports (Myers, 1997; Silverman 2006). As a data collection technique interviewing, can be either quantitative or qualitative. For quantitative data collection specific predetermined questions are asked by the researcher to find out facts (Silverman, 2006). However, qualitative data collection the interviewing technique is more open-ended (Silverman, 2006). The data for the case was gathered and analysed over a thirty month period as follows:

1. Study of journal notes made by the researcher who was a KTP Associate during the implementation of ERP.
2. Detailed discussions with the KTP project team to understand the scope of the project, project deliverables and constraints.
3. Study of the audit report on the 5 legacy systems that were used at Company ‘A’ prior to implementing the ERP system.
4. Face-to-face qualitative open-ended interviews with different user groups
    - Management and project team
    - Managers of various departments such sales, marketing, purchase, design, production, quality, service, accounts
    - Customer service staff
    - Shop floor staff

- ERP Vendor staff

5. Delphi analysis to identify CSFs with users representing three different user cohorts: management; departments; and technical (IT staff, database administrators) responded to a structured Delphi questionnaire. These scores were captured using a 5-point Likert scale which allows balancing the number of positive and negative options.
6. Data related to set-up and processing time for three product groups was collected either from the ERP or from the observations.
7. Program Evaluation and Review Technique (PERT) was used by the project team when there was no historic data or records
8. Study of post-completion audit report of ERP that was prepared by a cross-functional team. This report was exhaustive and made a very good causal analysis of the issues resulting in a failed implementation.

3.5 Research Framework

The literature review highlighted issues with ERP system implementations. Figure 3-1 shows the conceptual framework for the research and the Decision Support System (DSS). It shows the DSS derived from an in-depth review of the scientific and empirical literature. The ERP adoption process in a MTO SME is influenced by CSFs, their interrelationships and Production Strategy as a CSF. Two areas of study involving CSFs during an ERP system implementation were identified and examined using Discrete Event (DE) simulation to support benefit realisation. The four phases of the methodology are explained below.

Phase 1:

The first phase was to carry out a review of published literature, focusing on a number of different areas related to the ERP systems, critical success factors and discrete event simulation. It developed an in-depth understanding of the theories, tools, and techniques required to develop a dynamic DSS for a MTO SME manufacturing environment. Published literature was reviewed to identify any gaps in the knowledge for which further research is required. The literature review was also used to identify those issues that companies need to consider prior to making a decision on whether or not to integrate their systems. The resources and factors most likely to have an impact on the level of integration selected by a company have been identified. This phase was carried out using **a** computer search of databases of the published literature and conference proceedings using the University's Resources area.

Phase 2:

The second phase allowed to gain an overall understanding of the environment in which Company 'A' is operating and to identify its business and information system requirements. The primary focus was on their size and structure, business and operational processes, existing legacy IT systems, IT systems used within such industry and the business problems that have arisen as a result of the systems. Based on the relative strengths and weaknesses a combination of the structured and unstructured techniques has been employed to find these requirements. The details are as follows.

- **Delphi analysis - To check validity and interrelationships of CSFs:**

Chapter two concluded that most of the models proposed to study CSFs were theoretical and lacked practicality. CSFs are subjective and any such model should be able to reflect near real-time CSFs relationships. Delphi analysis was carried out to overcome the subjective nature of CSFs as well as to involve end users without any bias. Subject selection and time for conducting Delphi are two important factors. Regarding the criteria used to guide the selection of Delphi subjects, individuals invited to participate in a Delphi study must have some related backgrounds and experiences concerning the target issues (Hsu & Sandford, 2007). Another important aspect to take into account is the sample size. However, what constitutes an optimal number of subjects in a Delphi study never reaches a consensus in the literature.

Ten to fifteen subjects could be sufficient if the background of the Delphi subjects is homogeneous (Hsu & Sandford, 2007). There are many limitations of Delphi and they can be summarised as follows:

- Time consuming: Conducting Delphi can be time consuming.
- Data can be both quantitative and qualitative. The decision regarding the kind and type of criteria to use to both define and determine consensus in a Delphi study is subject to interpretation. The major statistics used in Delphi studies are the measure of central tendency (mean, median and mode) and level of dispersion. Generally, the uses of median and mode are favoured.

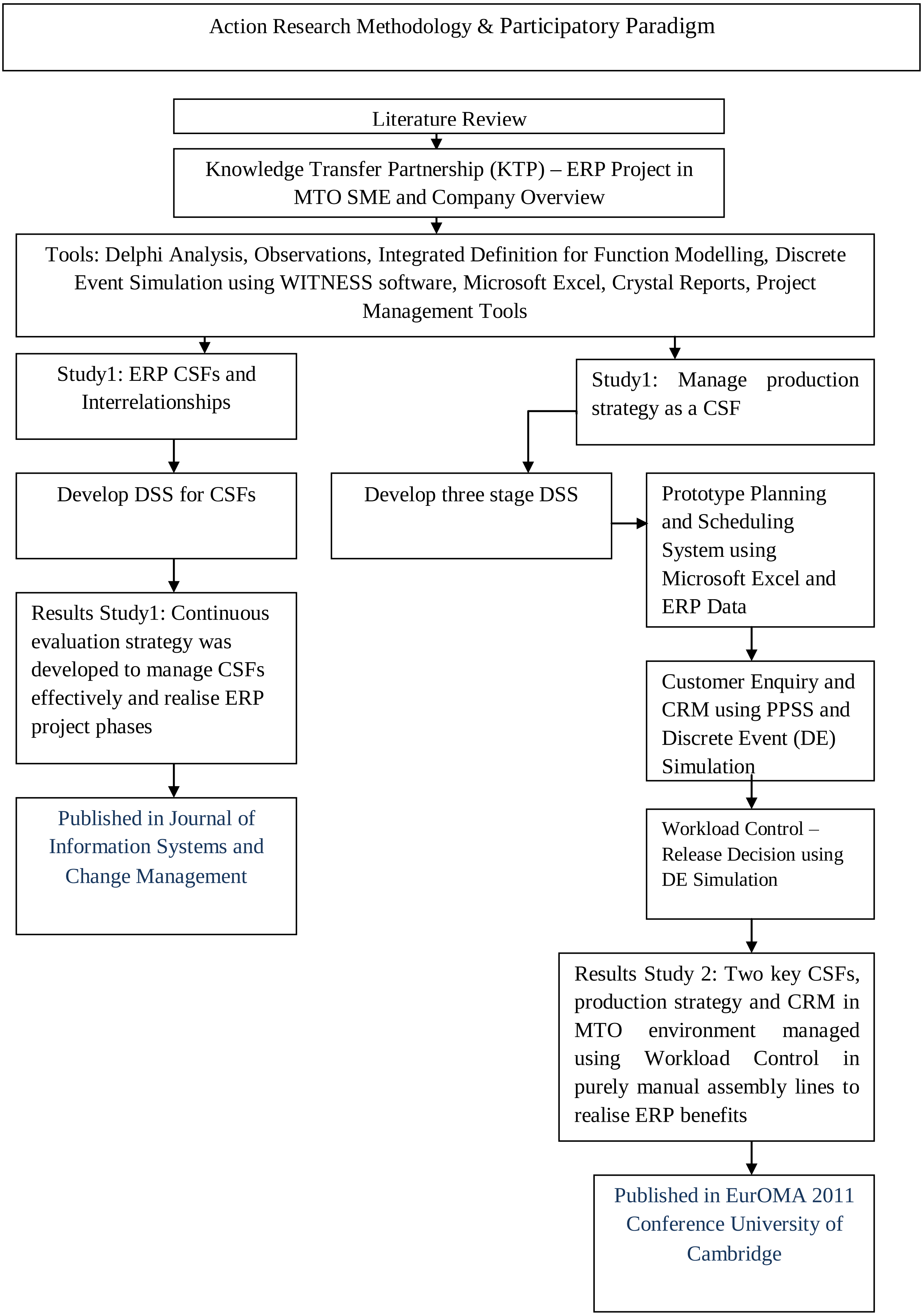


Figure 3-1 : The research framework

- Response rates: Potential low response rates are an issue.
- Investigators Moulding: Potential of investigators moulding opinions of the participant
- Risk of identifying general statements instead of specific topic related information. The assumption that Delphi participants are equivalent in knowledge and experience might not be true and this could lead to the inability of some of the participants to specify the most important statements.

- **Static and Dynamic Data – Observation Approach**

To develop a dynamic DSS, numerous sub-tasks were needed to be executed. One of them was collection of static and dynamic data for input system. As the company had no previous ERP system hence the first phase was to define the best practices to integrate the various processes in the company ranging from sales and marketing, design, purchasing, production, Customer Relationship Management (CRM), service and accounts. Later quantitative dynamic data like sales orders, finished inventory, bill of materials, material inventory, work-in-progress, production orders, shift calendar and purchase orders was mined from the ERP and analysed.

Considering at the beginning of the research, lack of work centre data and the author's own role, it was of high importance to involve the concerned operator's viewpoint, which in turn generated many hypothesis and assumptions. An important issue was how to gather such information from operators. An observational approach was adopted. Some of shop floor staff at Company 'A' had been employed for over 15 years and to a great extent they were set in their own ways. There have been occasions, where pre-arranged process viewings never started due to changing work priorities and led to numerous renegotiations.

Although, this process involved a great amount of time but it was possibly the only way to collect important work centre data, routings and sequence of operations. Appendix 'A' contains the developed work centre template, samples for work centre data and its analysis.

- One of the objectives was to design and develop a Prototype Planning and Scheduling System (PPSS) to support the task of planning to run production more efficiently at Company 'A'. The information was in the ERP system and it needed to be sourced and analysed. Work centre data was crucial for the production manager. Information related to all the production jobs since the ERP implementation in 2010 was entered in the ERP system. This needed to be retrieved and analysed. How can the due date settings, work centre data and cycle time for orders be integrated into the simulations? What is the lead-time offset hours? Which sequence can reduce set up times?

- The "to make" and "to procure" data can come from the ERP system. However, due to the nature of the MTO operations, the company does not use them. It follows a Kanban system for material procurement and the "to make" data involves a high level of human activity and lacks detail. Nevertheless, this is not a good strategy for scenario planning. Microsoft Excel based MRP I and MRP II logic was developed to determine "to make" and "to procure" data.

Phase 3:

The third phase involved specifying the requirements and architecture of a DSS. The specification was derived from information obtained by completing both the first and second phases. This was modelled using *Integrated Definition for Function Modelling* (IDEF0).

- **IDEF0 Modelling**

IDEF0 emerges as a powerful tool for modelling the complexities of a MTO environment (Mahfouz *et al*., 2011). The IDEF0 hierarchical modelling approach has four aspects i.e. input, control, mechanisms and outputs:

- Input : Input to the process
- Control: What controls or parameters would be used to govern the process
- Mechanisms: Agents that facilitate the process
- Outputs: The output of the process

- **DE Simulation**

One of the main tools used in this study is DE simulation. Simulation based research is typically applied if the model or problem is too complex to be solved by mathematical analysis (Bertrand & Fransoo, 2002) e.g. if multiple or interacting processes are involved or non-linear effects such as feedback loops and thresholds exist (Davis et al., 2007). It bridges the gap between analytical research which is restricted by mathematical tractability and empirical research which is often constrained by limited data. It is therefore one of the most important tools for Work Load Centre (WLC) research considering that non-linear effects, such as feedback from the shop floor, represent one of the core elements of the concept which makes analytical model building often unfeasible. Simulation modelling is proposed to overcome this deficiency. Simulation was used to route the CSF data to relevant ERP project phases. The data was provided by the ERP system and PPSS linkage. It was important to take into account the following questions:

- How can hybrid modelling involving DE simulation and PPSS aid the human scheduler? How can DE simulation support cyclical decision-making approach during planning and scheduling? How can the due date settings, work centre data and cycle time for orders be integrated into the simulation model?
- How availability of labour or staff can be modelled? How solutions from what-if scenarios are identified and implemented? How can the reliability and repeatability of the model be established?

In order to answer these questions, the following tools and techniques were used:

- Exploring the possibility of the DE simulation model, by getting data from ERP-PPSS linkage, using ASCII text files or Microsoft excel platforms.
- Incorporating real time shop floor status in ERP-PPSS and input files.
- Conducting work centre data analysis and further statistical analysis to determine distribution type and error calculations for data.
- Simulation of what-if analysis by conducting experimental runs with controlled parameters. This enables optimisation of the *baseline* model.
- Simulation to route the "to make" data supported by material availability, labour resources and priority to respective work centres.

- **Microsoft Excel Tools**

During initial phases of this research the management at Company 'A' expressed a preference on using Microsoft Excel as a platform for the PPSS as they are familiar to the end-users. Further, for interaction with DE simulation used for WLC and CSFs inter-relationships study needed creation of automatic simulation models from Excel files. This has a lot of potential as the end-user will just have to change parameters even if they do not have simulation skills. For this research various Excel features were used such as - dynamic named ranges, recording a paste-down macro, joining tables, pivot tables, working with dates, importing and exporting text files, linking workbooks, matrix to normalized table, multiple macros, exploding tables, stacking tables, advanced filter, pivot charts, and making a menu.

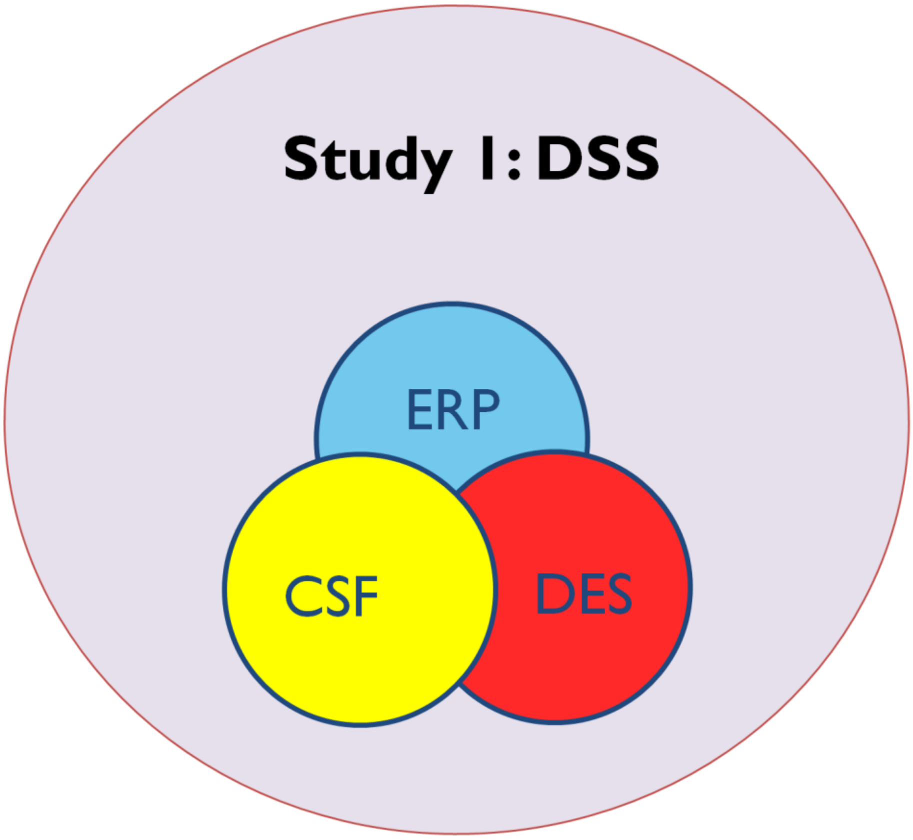
- **Phase 4:**

The fourth phase involved the development and evaluation of a DSS that can be used by SMEs operating within Company ‘A’. Two probabilistic DSS models were used to account for uncertainty in CSFs during ERP projects in MTO projects.

DSS 1: The stochastic technique of DE simulation is selected due to its capability of manipulating the variability and uncertainty of a system and CSF parameters. CSFs from an ERP project stage arrives in simulation model using American Standard Code for Information Interchange (ASCII) text files. Crystal Reports (CR) an industry standard report writer is used to create ASCII text files.

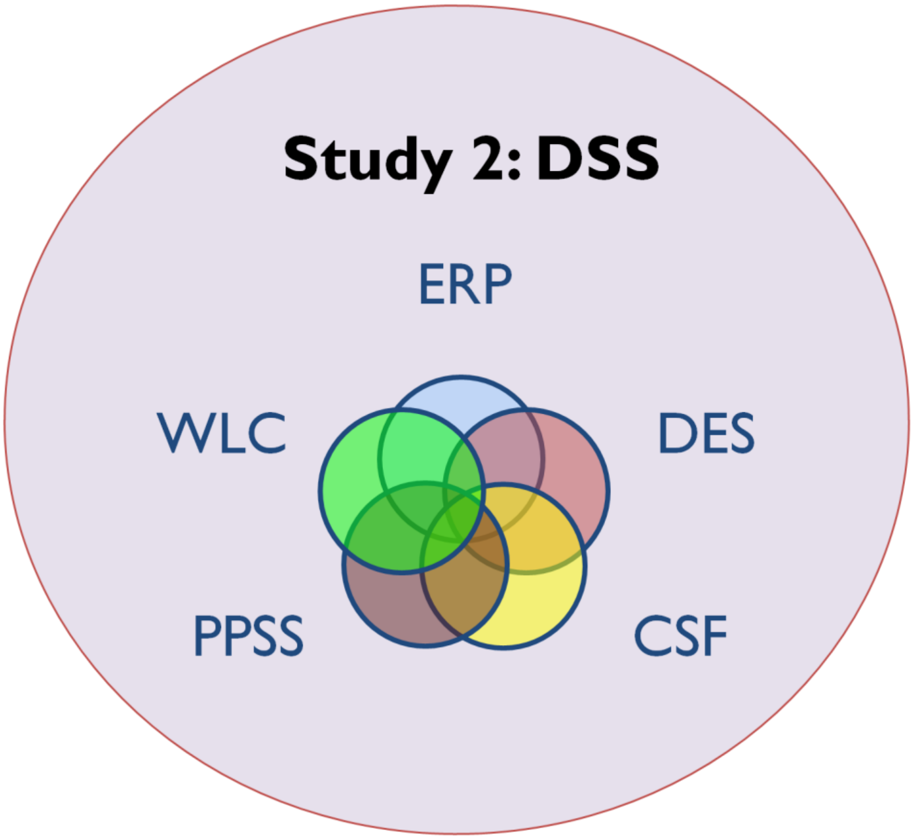
DSS 2: A three tier DSS was developed to study production strategy as a CSF on its own. First tier involves a production planning and scheduling system (PPSS) which is in-house extension or ERP 2. PPSS is a form of DSS research led to ‘MRP’ based ‘Capacity Driven’ logic. The second tier involved managing production strategy and Customer Relationship Management (CRM) activities. The ability to incorporate real-time shop floor status was key requirement. Orders from ERP-PPSS linkage arrives in simulation model using ASCII text files. Crystal Reports is used to create ASCII text files. Variable data cycle time and cost were analysed using statistical best-fit distribution. The third tier involved Workload Control (WLC) release decisions in purely manual assembly line is considered involving customer enquiry, order release and dispatching. Concept of ‘Key’ worker or walking worker is explored, in which a ‘Key’ worked would start and finish all the assembly line related stages for a particular job.

Both DSS systems have four stages i.e. input, process, output, feedback loop and optimisation. Within input stage the first input stage consists of the gathering the CSFs from ERP research, ERP software selected, MTO organisation, Delphi analysis, team configuration and transactional processes. The second input stage consists of the IDEF0 modelling, which then provides the input via text files to the simulation model. The process element consists of the simulation model creation, which is then optimised by feedback loop.



CSF= Critical Success Factors, DES = Discrete Event Simulation, DSS= Decision Support System, ERP= Enterprise Resource Planning

Figure 3-2: Decision Support System Study 1



CSF= Critical Success Factors, DES = Discrete Event Simulation, DSS= Decision Support System, ERP= Enterprise Resource Planning, PPSS= Prototype Planning and Scheduling System, WLC= Workload Control

Figure 3-3: Decision Support System Study 2

- **Feedback loop**

The feedback loop consists of the Project team, end user and Management. The input data is fed into the simulation generator to check the validity for current stage. Ideally, the results for a stage should be close to the stage estimates. If not, then changes are made to the parameter levels. This involves the concept of model optimisation where the model's parameters are changed to improve the model's performance. On the simulation screen, the project team and end-users can visualise how the various entities of the model interact to form the DSS. Different scenarios can be simulated manually by changing these parameters such as arrival time of a CSF or availability of a critical resource.

- **Developing Prototype Models and Future Integration**

The above tools were pooled to develop the logic to build the DSS. Both quantitative and qualitative data were used during the modelling stage. The cyclic execution of the phases of action research methodology i.e. planning, action, observation, and reflection was instrumental in developing the model. The DSS development process was iterative with changes made to accommodate the end-user needs after reviews. This approach helped in customising the system for Company 'A' rather than forcing a particular system onto them.

A demonstration was carried out to demonstrate the DSS, its operating procedure, and graphical interface of the system. This also was an opportunity to ascertain end-user satisfaction. This was given to ensure that the management at Company 'A' have a clear understanding of what needs to be done and in what order, for future integration and implementation of the dynamic DSS company wide. The author received encouraging response from the management at Company 'A' during the demonstration.

3.6 Summary

The research methodology mentioned above were critical to address the research gaps identified earlier. The effective use of the above framework made it possible to develop and implement a DE simulation based DSS.

Chapter 4: Development of DSS for ERP Critical Success Factors

4.1 Introduction

This chapter presents a Discrete Event (DE) simulation framework for studying relationships among Critical Success Factors (CSFs) using WITNESS software. The framework and concept are intended to improve the percentage of ERP projects realising their true benefits. SMEs represent 57.1% of the UK manufacturing sector. They attempt to implement ERP systems to improve efficiency. However, a recent global study conducted in 2010 consisting of 1600 ERP implementation projects across sectors showed that over 57% projects went longer than expected, 54% went over budget and 41% failed to realise the benefits (Zach & Olsen, 2011). ERP system Critical Success Factors (CSFs) are one of the important streams of research on success of implementation. In this work, the dynamic interrelationships between CSFs and various phases of an ERP project was studied during a 30-month ERP implementation at a Make-to-Order (MTO) SME using Discrete Event (DE) simulation.

There is a generalisation issue in ERP packages made for SMEs, hence a high failure rate among ERP projects. Further, CSFs as well as their interrelations with ERP project phases are not clear in published literature. ERP project system evaluation and achievement are complex functions and they need further research. In order to determine whether CSFs interact during different stages, a kind of prediction model is required to estimate their influences. A Decision Support System (DSS) based on DE simulation has been designed and developed to study interrelations between CSFs and ERP project phases, based on observations and Delphi based analysis of CSFs by the project team during the current ERP project at Company 'A'.

This chapter identifies CSFs in the implementation process through literature review and a 30-month ERP implementation project at a UK MTO SME. The interrelationships and impacts among the selected CSFs were analysed using a cross-reference analysis methodology and DE simulation.

4.2 DSS based on the simulation model

A probabilistic DSS model is required to account for uncertainty in CSFs during ERP projects in MTO projects. CSFs are subjective and this induces uncertainties. The implementation team may think a particular CSF may or may not be required in a particular ERP stage. Simulation can be used to verify and visualise both scenarios. The stochastic technique of DE simulation is selected due to its capability of manipulating the variability and uncertainty of a system and CSF parameters. The conceptual model is shown in Figure 4-1.

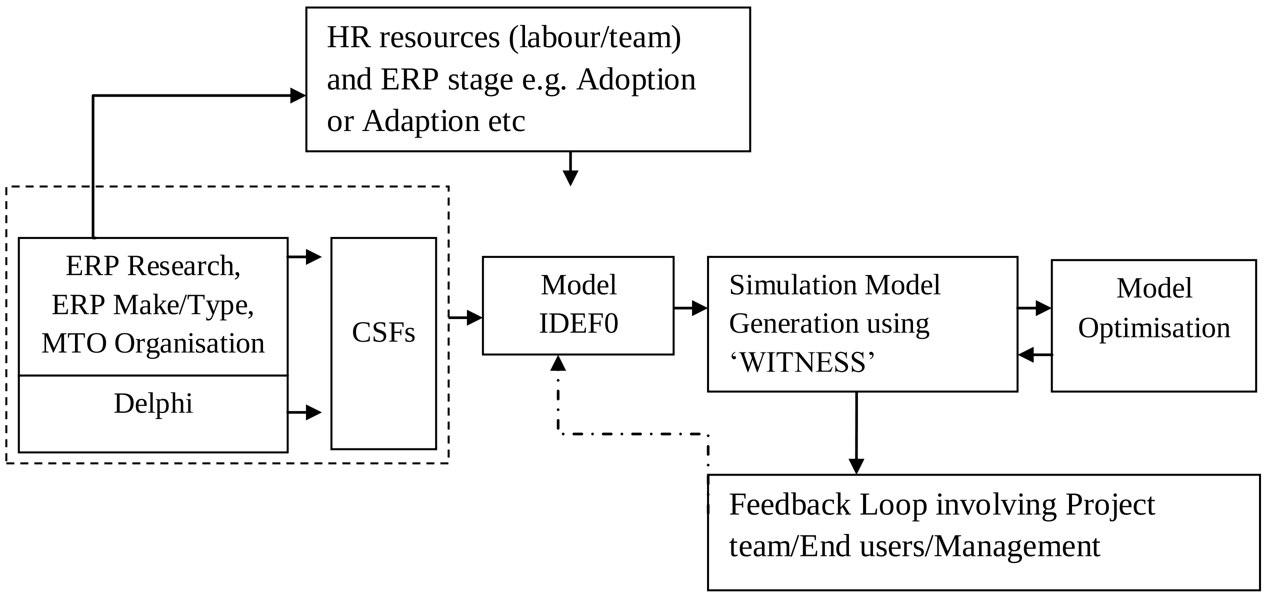


Figure 4-1: DSS- The conceptual model

The DSS system has input stages 1 and 2, process, output, feedback loop and optimisation. These stages are explained below using an example from ERP adaption phase. Company 'A' has an active service operation for its finished goods as these goods generally have a lifespan of ten years. The function that needed to be modelled here was populating the service engineer's field visits entered in the ERP to their smart phones.

4.2.1 Input Stage '1': CSF-ERP Link and Delphi Analysis

CSFs among the different stages of implementation would provide a better approach of identifying Key Performance Indicators (KPI's) for measuring the implementation. The proposed model involves the CSFs and their attributes. It is based on the idea that CSF performance during the implementation process is drawn from a number of key attributes and the level of focus given during implementation. Ability to incorporate real-time CSFs relationships was a key factor. CSFs for an ERP stage are subjective and along with data from ERP research Delphi analysis is proposed to reach a valid estimate of CSFs.

In this study, the sample size is taken as ten participants. Continuous improvement workshops were used to carry out Delphi analysis. The criteria used to invite individuals to participate in a Delphi study their association to the project. Most of the Delphi participants were end-users and Project team members. All participants are related to the ERP system implementation and the target issue of identifying CSFs for a particular stage.

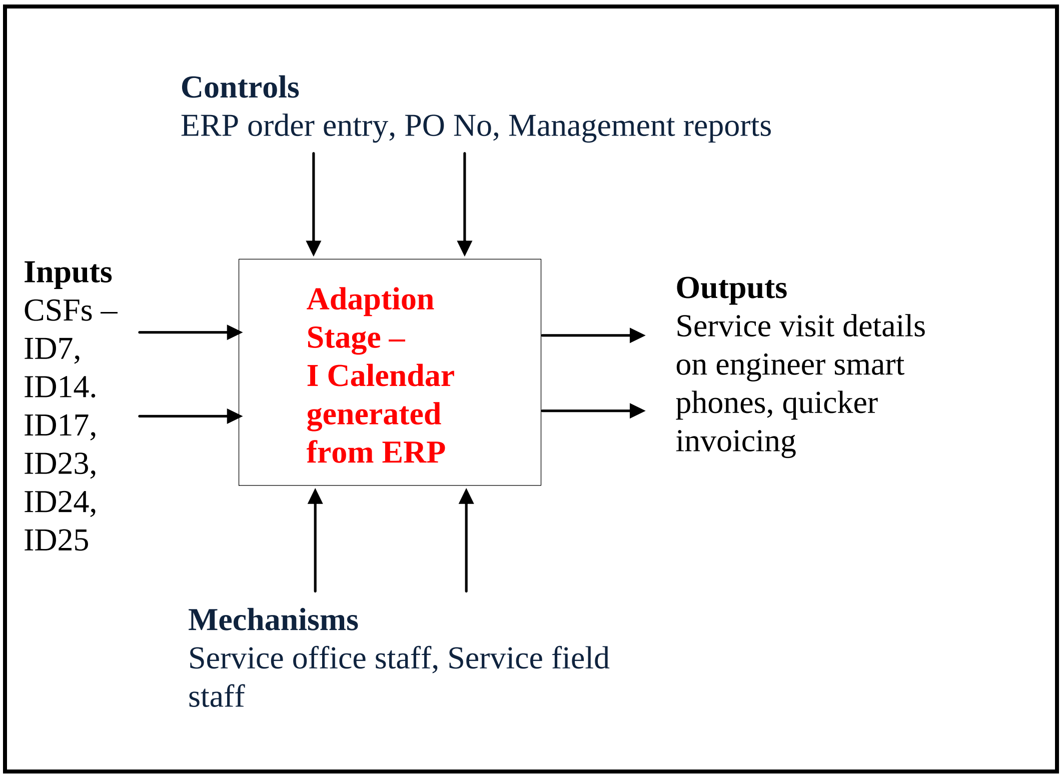
Delphi study can be summarised as follows:

- Three iterations were required to gain a consensus.
- Median was the major statistics used in Delphi studies are the measure of central tendency and level of dispersion.
- In this study out of 15 identified subjects only 10 participated.
- Potential of investigators moulding opinions of the participant was avoided by having Delphi exercises within continuous improvement workshops involving both the end-users and project team members.
- The risk of identifying general statements instead of specific topic related information was overcome by having a work breakdown structure with the lowest level of tasks for a participant and within their domain of operations where the ERP system would be implemented.

4.2.2 Inputs Stage '2': IDEF0 Modelling for Service Visits

As shown in Figure 4-2, the IDEF0 hierarchical modelling approach has four aspects i.e. input, control, mechanisms and outputs:

- Inputs: CSFs required such as system customisation, team skills, budget or end-user co-operation.
- Control: The service order number and the customer purchase order number in ERP system.
- Mechanisms: Agents that facilitate this activity are service office staff and service engineers.
- Outputs: The output of this task is that service visits entered in the ERP are populated automatically on Microsoft Outlook. The service engineer can see the jobs on their smart phones. Thus, service office staff do not have to enter data in the outlook calendar manually.



ID7=Cultural change/political issues, ID14=Interdepartmental cooperation, ID17=Management support and commitment, ID23=Software configuration, ID24=Appropriate technology, ID25=Reduced trouble shooting-project risk

Figure 4-2 : IDEF0 Approach during ERP Adaption Phase

4.2.3 Process and Output Stage: Simulation model

The input stages comprising of the CSF-ERP link, Delphi Analysis, and IDEF0 act as the data depository for the simulation model. The components that form the basis for determining the CSF relationship are the input, discrete event simulation system and feedback loop.

The first step requires feeding the data obtained via the input stages system to the simulation model. An interface to read data from the input stage has been developed using MS Excel spreadsheet and text files called as ‘part’ files that would result in an automated update of the simulation model. The considered data in the simulation model includes resources (labour and team) and parameters (release time of CSF, priority and shift system)

The second step involves the incorporation of further changes based on changes to the work breakdown plan and iterative subjective nature of the CSFs into the simulation model. This is managed by a feedback loop.

4.2.4 Optimisation Stage: Feedback loop

The feedback loop consists of two steps. The initial estimate of “arrival time” and “expected cycle time” of CSFs are used as starting point. This scheduled data is fed into the simulation generator to check the validity for current stage. Ideally, the expected completion time for a stage should be close to initial stage completion estimates. If not then changes are required to the parameter levels. The first step is to increase the cycle time for the stage. The updated lead time is fed into the simulation model and the run time for the stage is adjusted. The second step is to update the parameters to ensure the initially agreed stage completion is met. This may include CSF priority or changing the composition or availability of stage related project team.

Different scenarios can be simulated manually by changing these parameters. A more efficient way is to run the simulation model from Microsoft Excel to automate optimisation process but this is not currently used. The simulation model calls for the updated part files to run and 10 experiments are conducted to account for randomness. At the end, WITNESS writes the output values, which comprises of the cost to a spreadsheet as well as the expected completion time on the WITNESS screen. On the simulation screen, the project team and end-users can visualise how the CSFs arrive based on their priority and arrival time and how a particular stage is completed.

4.3 Model Layout

ERP CSFs analysis was done using DE simulation manufacturing platform from WITNESS. The integration architecture used is a layered type to separate application, service and database. This allows clear separation of responsibilities. The ERP system stores its data in a MS SQL database. The ERP data along with data from the CSF-ERP linkage, Delphi Analysis and IDEF0 processes is maintained in a MS Excel file format. As the quality of data improves in the ERP (depending on the completion of various phases), some of the data in the MS Excel file format can be populated from the MS SQL database using Crystal reports writer and an add-on to schedule the running of these reports periodically. Alternatively, WITNESS can access the data directly from the MS SQL database, but this is not done in this case. On the simulation end WITNESS functions directly read the MS Excel file and load data into the model. The feedback loop depending on the output allows amending the data in the ERP system, CSF-ERP linkage, Delphi

Analysis and IDEF0 processes. This allows optimising a generated model.

4.4 Model Features

Each ERP stage i.e. Initialisation, Adoption, Adaption and Routine is modelled as an assembly machine. The *define element* module is used to create various entities such as CSFs and team members that represent parts flowing through the system. The arrival schedule is controlled in the MS Excel file. User defined CSFs and team configuration arrive in the simulation model using 'part files' as per the sequence defined by the project team. 'Part files' contain default WITNESS attributes such as part type, quantity, arrival time, height, length and weight. Parts i.e. CSFs and team are pulled by the assembly machine as per MATCH rule. On reaching the assembly machine, the parts wait to form a batch. Once the batch is formed, the completion of the stage depends on the CYCLE_TIME assigned to the assembly machine.

4.5 Initialisation: Base Case Example

The concept of studying CSFs and their interrelations is explained with the *Initialisation* stage. During input stages CSFs were marked on a scale of 1 to 5 by 10 Delphi participants. Then the IDEF0 model for the phase was developed. Only CSFs having a median of four and above were selected for simulation modelling. For the *Initialisation* stage, 22 CSFs had a score greater or equal to four. Further, based on the CSF classification by Ahmad *et al.* (2012), 13 CSFs were organisational, eight were operational and one neutral. Also these CSFs have interdependencies which were analysed using Delphi and the Project Management Body of Knowledge (PMBOK) guide. Based on these interdependencies and using Program Evaluation and Review Technique (PERT) estimation the project team estimate the arrival time for each CSF. This is shown in Table 4-1.

	Initialisation Stage			
CSF id	**CSF Description**	**Type**	**Median**	**Dependencies**
ID7	Cultural change/political issues	OR	4	
ID17	Management support and commitment	OR	4.5	
ID9	Experienced project manager-leadership	OR	4	ID17
ID31	Carefully defined information and system requirements	OR	4	ID7,17,ID9
ID33	Clear goals and objectives	OR	5	ID31
ID1	Good project scope management	OP	4	ID31,ID33
ID4	Project management	OR	4.5	ID7, ID17,ID31

	Initialisation Stage			
CSF id	CSF Description	Type	Median	Dependencies
ID5	Steering committee	OP	4	ID1,ID4,ID9,ID12,ID17
ID12	Trust between partners	OP	4	ID7,ID9,ID17,ID31,ID33
ID14	Interdepartmental cooperation	NF	5	ID12
ID13	Interdepartmental communication	OR	5	ID7,ID14,ID17
ID3	Formalised project plan/schedule	OR	5	ID7,ID31,ID33
ID15	Project team composition/team skills	OR	5	ID7,ID17,ID3
ID10	Project champion role	OR	4.5	ID7,ID9,ID15,ID17
ID16	Empowered decision makers	OP	4	ID4,ID7,ID9,ID12,ID17
ID11	Adequate resources	OP	4.5	ID4,ID17,ID31,ID33
ID24	Appropriate technology	OR	4	ID1,ID31,ID33
ID26	Training on software	OR	4	ID11
ID22	Software customisation	OP	4	ID24
ID27	Education on new business processes	OP	4	ID10,ID15,ID26
ID29	Data analysis and conversion	OP	4	ID15,ID24
ID18	Monitoring and evaluation progress	OR	4	ID4,ID31,ID33,ID1

Table 4-1: Possible CSFs Initialisation Stage

Later the *Initialisation* stage implementation team was developed and acquired. This team developed the work breakdown structure for this stage. The priority and arrival time for each CSF was determined by the project team based on the work breakdown structure and activity sequence list. The MS Excel file that stores the data obtained from input stages 1 and 2 is then exported as a text file (called ArrivalCSFs) as per WITNESS part file format. Once the model is initialised, the CSFs and team are sent to the *Initialisation* stage which behaves like an assembly machine using WITNESS features like *push*, *cycle_time*, *if-then-else*, *match*, *tag*, *Excel READ and WRITE array* functions. Below are the codes used in making the model;

- For the *Initialisation* stage one part file for CSFs and staff/team is defined
- Parts are pushed to buffers on arrival using *push or if-then-else* functions. Buffers have a maximum capacity of 50 for CSF arrivals and ten for each stage. For example,

  CSFs for *Initialisation* stage are pushed to BUFFER1.

  Witness command: PUSH to BUFFER1
- Team members are pushed to labour buffers example TEAM1, using WITNESS attribute *height*, *if-then-else* and *push* functions. Five labour buffers are defined

  Witness command:

```
IF HEIGHT = 1
PUSH to TEAM1
ELSE
IF HEIGHT = 2
 PUSH to TEAM2
ELSE
IF HEIGHT = 3
  PUSH to TEAM3
ENDIF
ENDIF
```

- The total number of parts and team members required can vary and this is controlled by the MATCH1(1) and MATCH1(2) variables. Excel READ array function is used to read the MATCH1 variables from the Excel file.

  For *Initialisation* stage

  MATCH1(1) = 22, CSFs and MATCH1(2) = 5, members in the team.

  Witness command:

  XLReadArray("J:\\Witness\\Witness

  Modelling\\CSF.xlsx","Match1","$B$2:$B$3",Match1,1)

- Once the MATCH1(1) and MATCH1(2) have been read, the *Initialisation* stage which is modelled as an assembly machine access this input data using WITNESS

  MATCH command.

  Witness command: Match1 (1) + Match1 (2)

- After the input data is accessed, parts and team members are *pulled* by the assembly machine from part buffers using MATCH rule depending on the MATCH variables.

  Witness command: MATCH/ANY

  BUFFER1 # (Match1 (1)) AND TEAM1 #(Match1 (2)

- The anticipated completion time for each stage is defined as cycle time for the assembly machine, which is a real variable. This is controlled by the CT(1) and CT(2) variables. Excel READ array function is used to read the CT variables from the Excel file. The distribution used is a Truncated Normal (TNORMAL) distribution, which is a real distribution. This distribution was used to capture the estimation of cycle time during input stage 1 and 2 from each participant. TNORMAL distribution is similar to the normal distribution with the difference being minimum (14 weeks) and maximum (16weeks) values for sampling are specified. For the *Initialisation* stage, the model the mean cycle time is 15 weeks. The parameters specified are

- Mean: Real = MNSDev1 (1),
- SD; Standard deviation: Real = MNSDev1 (2),
- Min value: Real = CT (2),
- Max value: Real = CT (1))
- XLReadArray ("J:\\Witness\\Witness Modelling\\CSF.xlsx","CT","$B$1:$B$10",CT,1)
- Cycle Time Input :TNormal (MNSDev1 (1),MNSDev1 (2),CT (2),CT (1))

- An eight hours shift is defined with 60 minutes of rest during shift time and 960 minutes between shifts as shown in Figure 4-3 and Table 4-2.

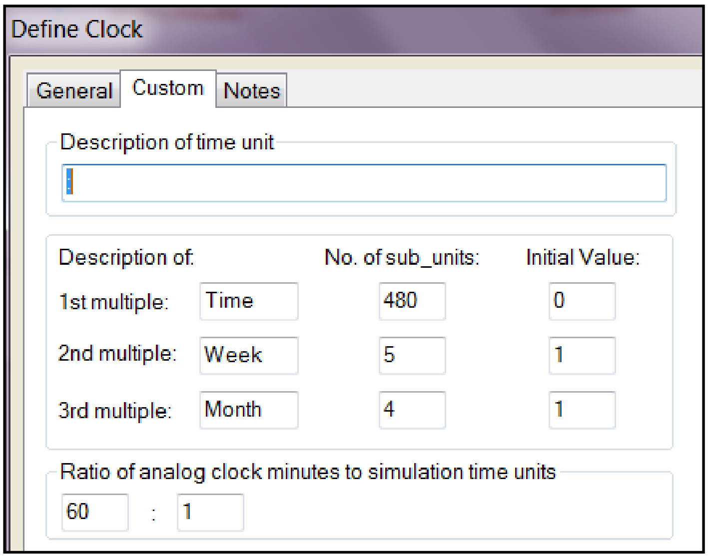


Figure 4-3: Simulation Model Clock Settings

Time	**Work Time (mins.)**	**Break Time (mins.)**	**Over- time (mins.)**	**Total Time (mins.)**
Period 1	150.0	15.0	0.0	165
Period 2	135.0	30.0	0.0	165
Period 3	180.0	15.0	0.0	195
Period 4	15.0	900.0	0.0	915
Summary	480.0	960.0	0.0	1440

Table 4-2: Shift Time

- Cost for each block is defined as a real variable. This is initialised during the start of the model using excel READ array functions in WITNESS. Below is the read array WITNESS function and cost calculation for CSFs related to the *Initialisation* stage of this ERP project.
    - XLReadArray("J:\\Witness\\WitnessModelling\\CSF.xlsx","CSF

Intilaisation","$G$2:$G$33",InitialisationCSFCost,1)

- CostInitialisation = Normal (InitialisationCSFCost (7) *55+…+InitialisationCSFCost (18)*55,0.5)
- ICON = 463

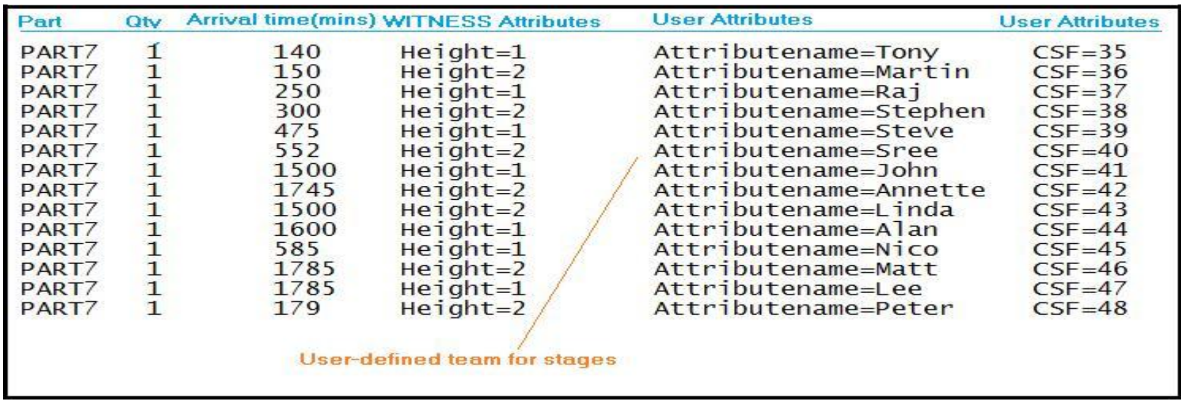
- 'Part' and 'Excel' files allow project team to:
  - Edit sequence of CSFs: As shown in Figure 4-4, the team can change the sequence of the CSFs entering the model based on dependencies of the CSFs during a project stage
  - Edit arrival time in minutes as shown in Figure 4-5 where required: End-user can edit the arrival time based on real time dependencies and estimations.
  - Table 4-1 showed the interdependencies of the various 22 CSFs for the Initialisation stage. After Delphi analysis, PERT was used to estimate the arrival time for each CSF
  - For example, CSF ID17 (i.e. to gain management support and commitment) during the Initialisation stage had the most pessimistic estimate (mpe) of 60 hours, most optimistic estimate (moe) of 30 hours and most likely estimate (mle) of 37.5 hours. Using PERT this gave the arrival time as
    - ➢ PERT = {moe + 4 (mle) + mpe}/ (6)…… (PMBOK guide)
    - ➢ PERT = 40 hours or 2400 minutes

CSF	Qty	Arrival Time	WITNESS Attribute	User Attribute	CSF ID
PART1	1	0	Height=1	Attributename=Intialisation	CSF=7
PART1	1	0	Height=1	Attributename=Intialisation	CSF=17
PART1	1	1	Height=1	Attributename=Intialisation	CSF=9
PART1	1	1	Height=1	Attributename=Intialisation	CSF=31
PART1	1	1	Height=1	Attributename=Intialisation	CSF=33
PART1	1	1	Height=1	Attributename=Intialisation	CSF=1
PART1	1	1	Height=1	Attributename=Intialisation	CSF=4
PART1	1	1	Height=1	Attributename=Intialisation	CSF=5
PART1	1	2	Height=1	Attributename=Intialisation	CSF=12
PART1	1	2	Height=1	Attributename=Intialisation	CSF=14
PART1	1	2	Height=1	Attributename=Intialisation	CSF=13
PART1	1	3	Height=1	Attributename=Intialisation	CSF=3
PART1	1	4	Height=1	Attributename=Intialisation	CSF=15
PART1	1	4	Height=1	Attributename=Intialisation	CSF=10
PART1	1	4	Height=1	Attributename=Intialisation	CSF=16
PART1	1	5	Height=1	Attributename=Intialisation	CSF=11
PART1	1	6	Height=1	Attributename=Intialisation	CSF=24
PART1	1	7	Height=1	Attributename=Intialisation	CSF=26
PART1	1	7	Height=1	Attributename=Intialisation	CSF=22
PART1	1	7	Height=1	Attributename=Intialisation	CSF=27
PART1	1	7	Height=1	Attributename=Intialisation	CSF=29
PART1	1	14	Height=1	Attributename=Intialisation	CSF=18

User defined CSF sequence

Figure 4-4: User-Defined CSFs Sequence

- Edit team sequence: as shown in Figure 4-5, the team can edit the labour quantity, depending upon the availability of staff.



Part	Qty	Arrival time(mins)	WITNESS Attributes	User Attributes	User Attributes
PART7	1	140	Height=1	Attributename=Tony	CSF=35
PART7	1	150	Height=2	Attributename=Martin	CSF=36
PART7	1	250	Height=1	Attributename=Raj	CSF=37
PART7	1	300	Height=2	Attributename=Stephen	CSF=38
PART7	1	475	Height=1	Attributename=Steve	CSF=39
PART7	1	552	Height=2	Attributename=Sree	CSF=40
PART7	1	1500	Height=1	Attributename=John	CSF=41
PART7	1	1745	Height=2	Attributename=Annette	CSF=42
PART7	1	1500	Height=2	Attributename=Linda	CSF=43
PART7	1	1600	Height=1	Attributename=Alan	CSF=44
PART7	1	585	Height=1	Attributename=Nico	CSF=45
PART7	1	1785	Height=2	Attributename=Matt	CSF=46
PART7	1	1785	Height=1	Attributename=Lee	CSF=47
PART7	1	179	Height=2	Attributename=Peter	CSF=48

Figure 4-5: User-Defined Team/Staff Sequence

Feature	Element	Qty	Details
Part 1 to 5	Passive Part	5	Arrival of CSFs is controlled by part files *arrival1,arrival2, arrival3, arrival4 and arrival5.*
Part 7	Passive Part	1	Arrival of project team is arrival7.
Arrivals 1 to 5 & 7	Part File	6	Data from user defined CSFs exported as *text* file using Crystal Reports add-on. This export is automated and happens at regular intervals.
ERP Stages	Machine	5	Five stages as (INTIALISATION, ADAPTION, ADOPTION, ROUTINE, RETIREMENT) made by Company 'A' modelled as machines A,B,C,D & E.
CSF id	String Attribute	1	CSF ids defined as a STRING attribute. TAG feature allows to visually see the movement of CSFs.
Arrival Stage Buffer	Buffer	5	Each stage has its own buffer for CSFs
Arrival Team Buffer	Buffer	5	Each stage has its own buffer for team members
Finished Stage Buffer	Buffer	5	Once a stage of ERP lifecycle is completed, machines A,B,C,D & E send them to finished goods buffers such as InitialisationBuffer, AdoptionBuffer, AdaptionBuffer, RoutineBuffer and RetirementBuffer.
Cycle Time (CT)	Variable Real	10	The model accepts user defined cycle times. This reflects near real-time CT estimates. Example for the initialisation stage CT is given as TNormal(MNSDev1 (1),MNSDev1 (2), CT (2), CT (1)) where CT(2) and CT(1) are the lower and upper limits of cycle time.

Feature	Element	Qty	Details
Cost		165	Each CSF has its own cost for a stage, for example, CSF ID7 (cultural change & political issues) may have a different overhead cost in adoption stage compared to adaption stage.
User Attribute	Name Attribute	1	Attribute name used in part file to identify stages.

Table 4-3: ERP CSFs Model Elements

4.6 Model Results

Based on Delphi and work breakdown analysis the total effort required for the *Initialisation* stage was estimated at 14 weeks. This estimation is the sum of the expected effort in time units to have the 22 CSFs specific to *Initialisation* stage available. For example, the CSF 7 i.e. ‘Identifying cultural change/political issues’ and CSF 17 i.e. ‘Management support and commitment’ first enter in the model with arrival time of one week. CSFs 7 and 17 each have duration of 0.5 weeks. This estimate is based on the effort in time required to accomplish the identified work breakdown elements such as kick off meeting, developing project charter, PESTLE (Political, Economic, Social, Technology, Legal and Environmental) analysis, internal audits and questionnaires, stakeholder mapping, indentifying key individuals etc.

As shown in Table 4-1, CSFs have linked dependencies, which control how they enter the model. CSFs 7 and 17 do not have any dependencies. The arrival sequence for CSFs was 7, 17, 9, 31, 33,1,4,5,12,13,3,15,10,16,11,24,26,22,27,29 and 18. The cost associated with making a CSF available is accounted at Full Overhead Recovery (FOR) rate, which is £55/Hour for Company ‘A’. So for CSFs 7 and 17 this would be £55x20 hours i.e. £1100 each. For the *Initialisation* stage, two runs RUN1 and RUN2 were conducted.

The cycle time variables CT (1) and CT (2) were established as 14 and 16 weeks respectively. In RUN1, it was assumed that all CSFs arrived into the model as per the estimated sequence. The model converts the 22 CSFs and 5 team members into one part and updates the output counter as ‘1’. Depending on the duration for each CSF and the FOR rate, the cost variable ‘CostInitialisation’ is populated for the Initialisation stage. In addition, the end user can visualise how different CSFs link and move in the model while entering, assembling and exiting. To establish confidence in the model a set of 10 experiments were conducted. The steps involved are:

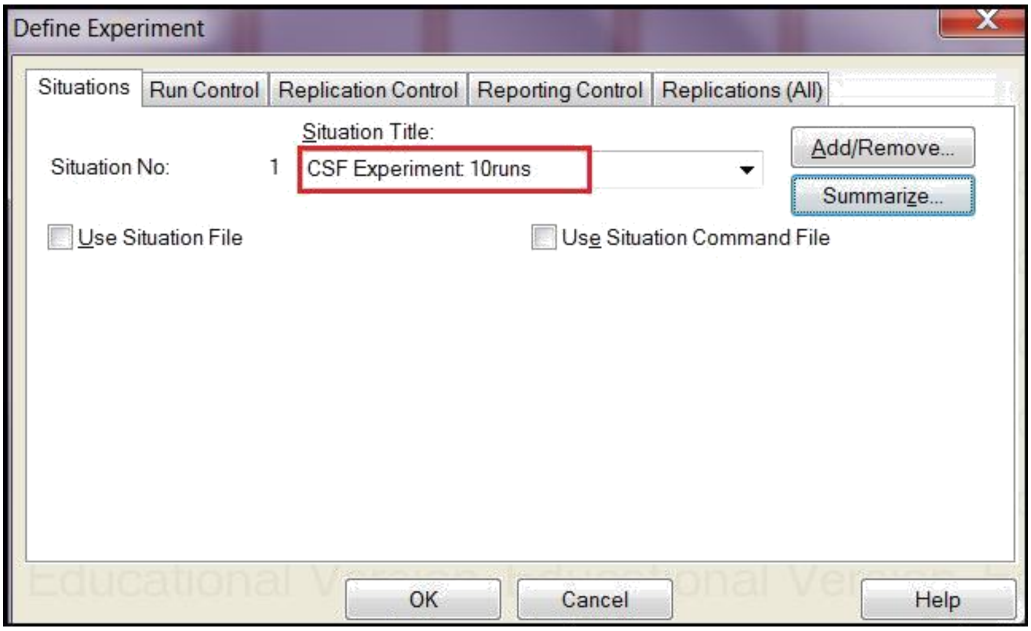


Figure 4-6: Experiment Runs

- Name of the proposed run (Figure 4-6)
- Define suitable warm up period and replication period (Figure 4-7)
- Define start of replication number and control for the random number streams
- Specify output format for the experiment. CSV file is selected here. For each experiment specify random or antithetic number and random number replication control by specifying the skip and stream offset

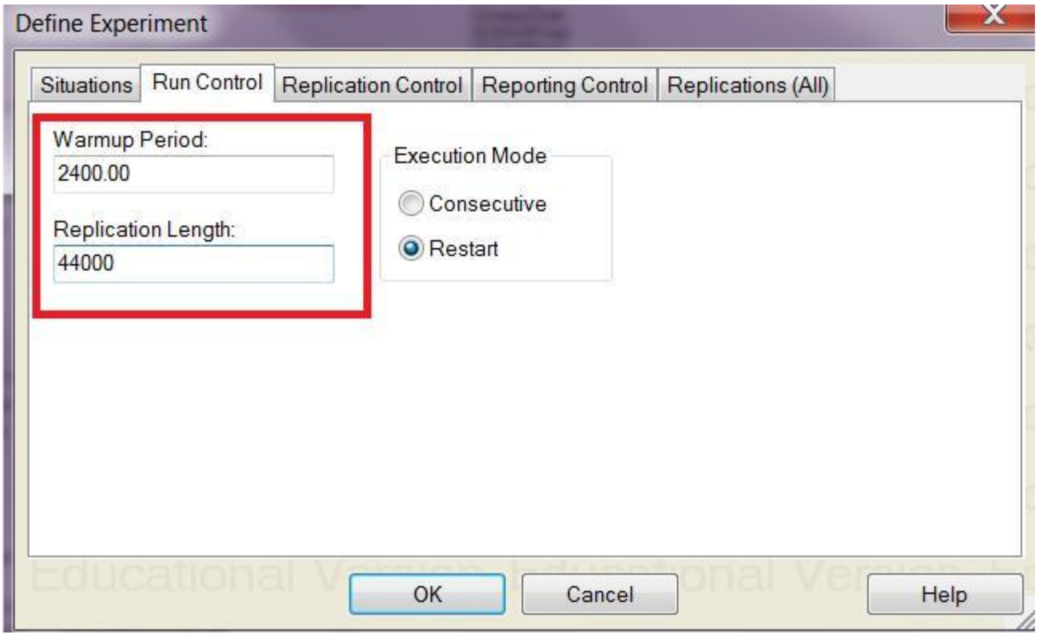


Figure 4-7: Experiment Run Warm-up Period and Replication Length

- Default WITNESS random number seeds were used

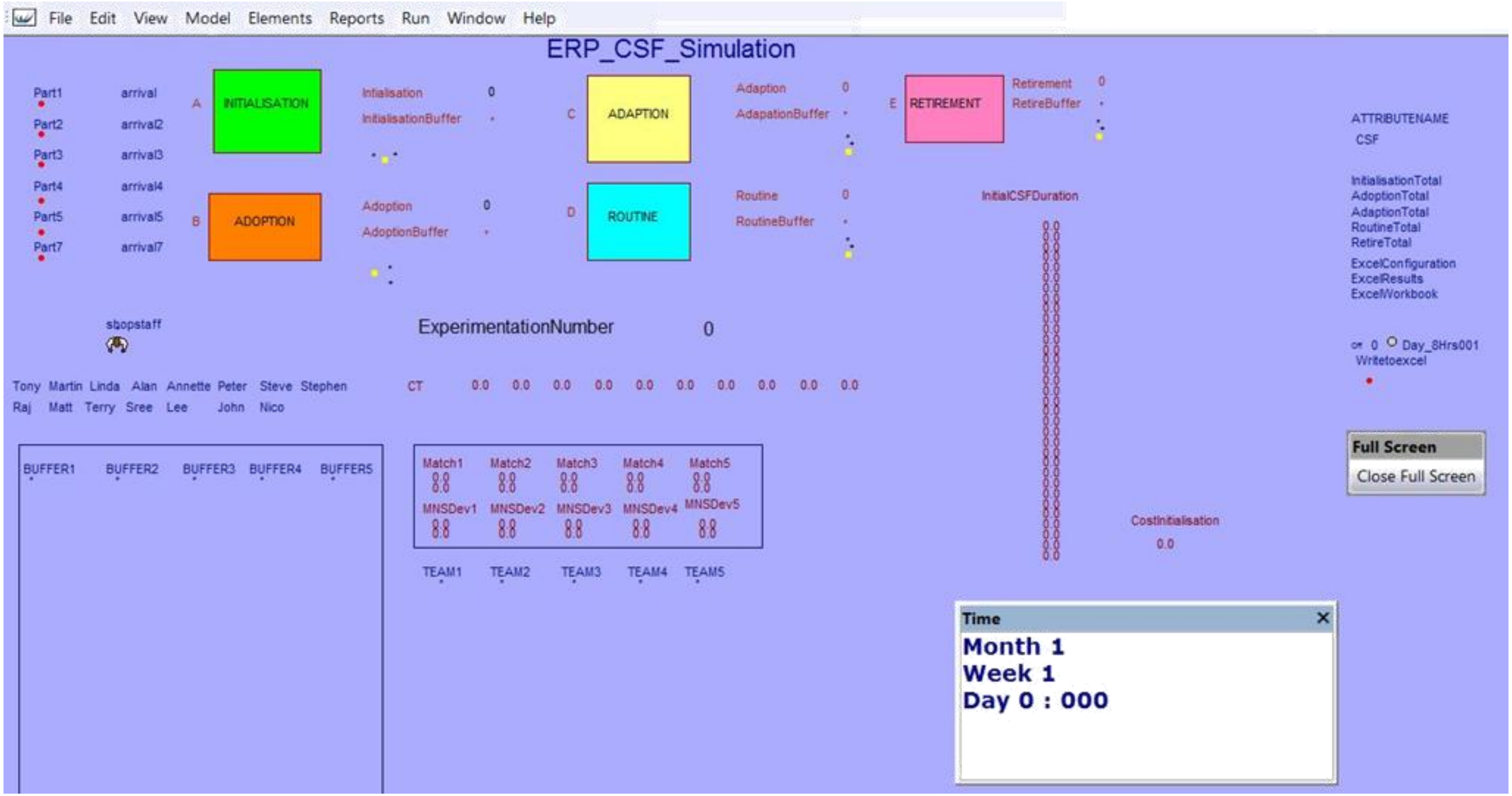


Figure 4-8: ERP Stages & CSFs Simulation Model Layout

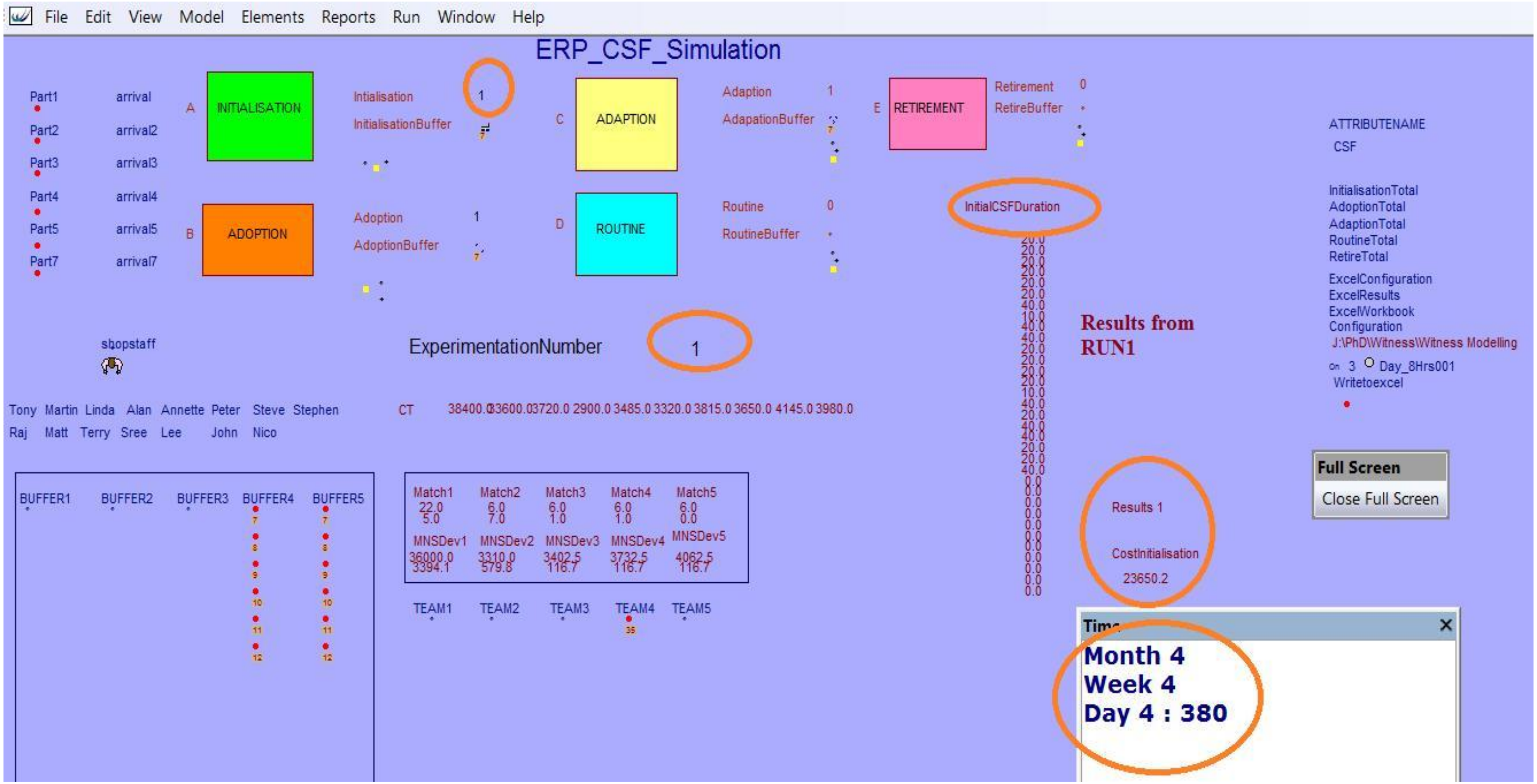


Figure 4-9 : Results from RUN1 for CSFs Simulation Model

- The warm up period was selected as one week i.e. 2400 minutes (40hour week*60 minutes).

The ERP stages and simulation model layout is shown in Figure 4.8 and the results from the first experiment for RUN1 is shown in Figure 4-9. Validity of the model was checked by comparing the costs for RUN1 that was parametrically estimated as 'total time' for making a CSF available multiplied by the 'FOR rate'. This is shown in Figure 4-10. Thus, 560 hours * £55 i.e. £30800 was the total parametric cost for Initialisation stage. This was stored in the MS Excel input sheet. The costs in RUN1 were between 23.22 to 23.21 % less than the values in the MS Excel input sheet. Further, the results were identical for both regular and antithetic random numbers. To establish confidence in a model's results it is important to run it with random activity by using several different sets of random number streams. Otherwise, it is possible that the results obtained are solely the consequence of one set of the random number streams chosen rather than any model changes that have been made. In WITNESS, random numbers are generated by first generating a pseudo-random fraction, i.e. a number between 0.0 and 1.0. Further, using antithetic sampling makes low values high and vice versa. The random number seeds used in RUN1 are shown in Table 4-4.

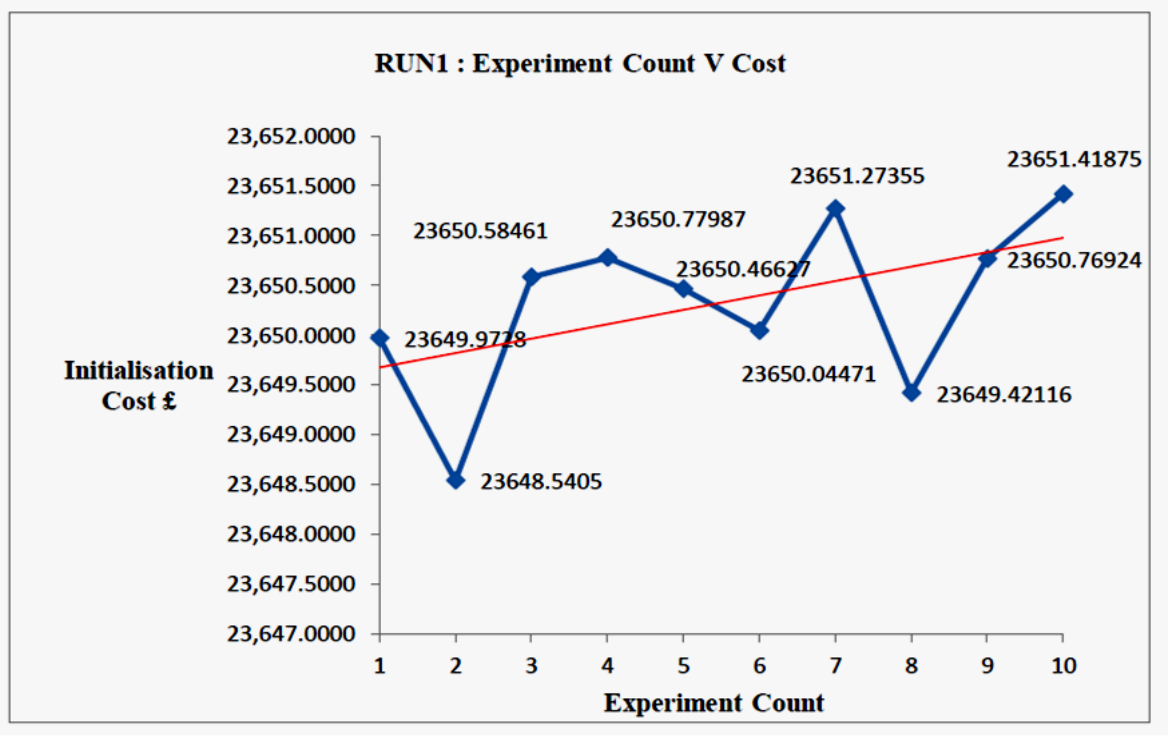


Figure 4-10: The 10 results for RUN1 for costs

ERP implementation requires CSFs and teamwork hence if a particular CSF or team member is not available then completion of the stage is delayed. In RUN2 the scenarios of handling planned and unplanned changes to the availability of CSFs or team members was simulated.

Experiment No	Random No Seed 1	Random No Seed 2	Random No Seed 3	Random No Seed 4	Random No Seed 5	Random No Seed 6
1	12345	12345	12345	12345	12345	12345
2	1	22	12345	77	2	456
3	10	119	777777	13	145	45789
4	100	200	300	400	500	600
5	1	300000	425	7989	47412	99999
6	23	49	425	8423	67892	142969
7	171	641	527	7145	3126	8756
8	236	417	8970	2356	4789	145000
9	5446	7456	3221	2	89	1342
10	7419	6452	312	278	1334	99756

Table 4-4: Random number seeds selected for RUN1 and RUN2

In this example, availability of CSF 24 i.e. 'Appropriate technology' was delayed by 2 weeks. Further, one of the key management staff i.e. CSF 35 was unavailable due to an unexpected quality issue at a customer's site. RUN2 captured these changes and a set of 10 experiments were conducted. The cost results for RUN2 are shown in Figure 4-11. The parametric estimation for the total cost was 640 hours * £55 i.e. £35200 for the Initialisation stage. For the same random number settings used in RUN1, the costs in RUN2 were 20.38 % less than the values in the MS Excel input sheet. The parametric estimation for the total cost was 640 hours * £55 i.e. £35200 for the *Initialisation* stage. For the same random number settings used in RUN1, the costs in RUN2 were 20.38 % less than the values in the MS Excel input sheet.

Moreover, effective experimentation involves using a warm-up period or starting conditions, deciding on a suitable run-length, and running the model with more than one random number stream. It can be concluded the accuracy in RUN2 improved as the reporting period increased for same set of warm-up and random number streams. RUN1 and RUN2 involved running the model for a 14 weeks and 16 weeks of time respectively under same circumstances. The length of the run is determined by a number of factors. As a verification of this conclusion, RUN3 was carried out for 18 weeks and the costs in RUN3 were 17.56 % less than the values in the MS Excel input.

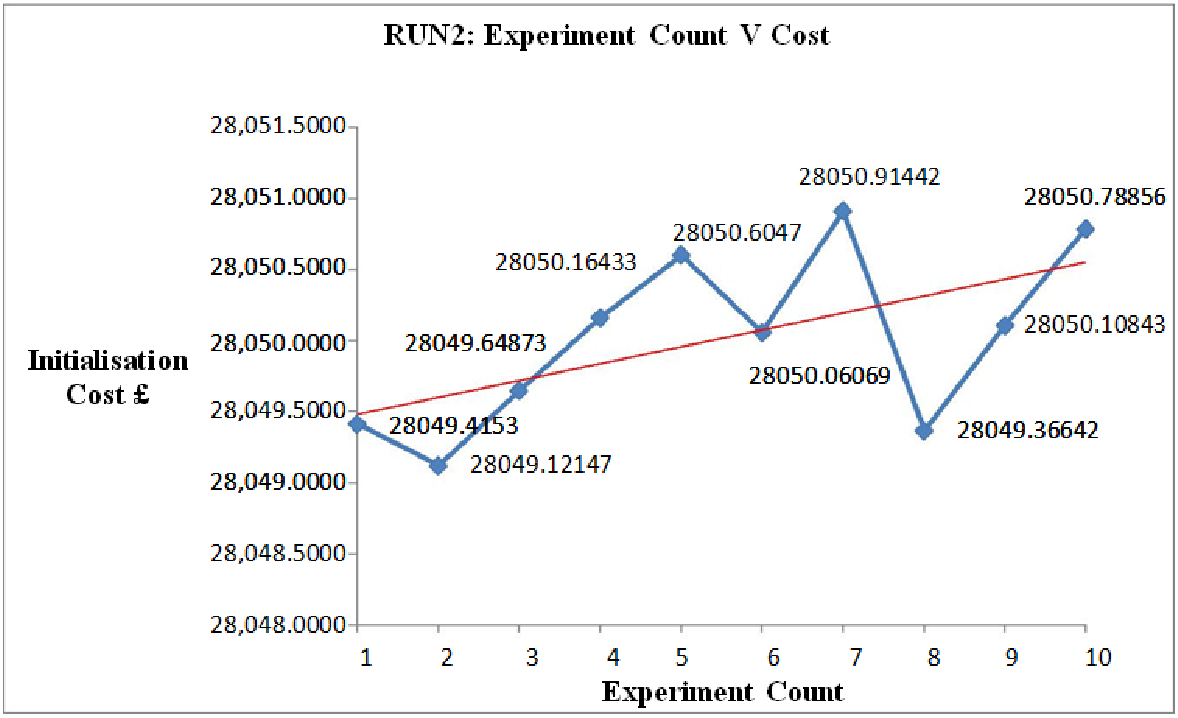


Figure 4-11: RUN2 Experiment Count versus Cost

Further, as the *Initialisation* stages was modelled as an assembly machine WITNESS provides useful statistics such as idle and busy time. This information was used by the project team to carry out resource levelling analysis to reduce the idle time and reduce costs. The resource levelling analysis involved conducting what if scenarios with the existing dependencies of the CSFs and their interrelations and finding out the optimum sequence and arrival time for CSFs. One interesting observation is although CSF 24 was delayed by two weeks in RUN2 but this did not have a negative effect on the stage was idle time. A project team could make significant tradeoffs between the availability of a CSF and the actual implementation of the stage.

RUN No	RUN Duration In Weeks	WITNESS Statistic '% IDLE'	WITNESS Statistic '% Busy'
RUN1	14	6.81	93.19
RUN2	16	3.79	96.23

Table 4-5: RUN1 and RUN2 Idle Time

4.7 Discussion

DE simulation models can be used for planning, design, and day-to-day operational implementation planning of ERP systems in manufacturing facilities. Such models provide project teams and end-users the ability to evaluate the capacity of the system for implementation stages and its sub-stages. Unforeseen events like unavailability of a particular CSF, team composition and resulting changes in operations can be studied. Some simulation models provide schedules that allow implementers and SMEs to visualise project implementation. Further, it can be used to validate plans and confirm schedules. Previous ERP CSFs models are usually based on static resources with false assumption of unlimited capacity and this is a limitation. DE simulation allows forecasting the implementation time for an ERP project phase by being able to visualise potential delays.

Some of the benefits of implementing an operational simulation model is the reduction of effort required to plan day-to-day interactions, synchronisation of flow and 'what-if' scenario analysis. The DE simulation model overcomes the inability to study ERP systems in decision-making based on real time data. 'Delphi Analysis' is helpful to build consensus on CSFs interrelationships and validation of model. The model visualises the dynamics of CSFs based on project and stage specific needs. This enables SMEs to determine time and costs for future events during ERP project stages.

The DSS related to interrelationship of CSFs enables the end-user or ERP project team to visualise the near real time CSF relationships. The interrelationships of over thirty CSFs were modelled. Attributes like sequence, time, cost, and resources such as team are simulated. All these attributes are controlled via excel or text files hence allowing the user to manipulate the DDS from a known platform. Users can determine the attributes of the CSF from real-time data and visualise the inter-relationships of CSFs during phases of the ERP project. Currently four stages of the ERP project i.e. Initialisation, Adoption, Adaption and Routine are modelled. Data on the last stage i.e. Retirement is scarce, as most of the firms have not yet reached this stage of an ERP project. Further, testing of simulation models involves verification and validation. Verification ensures that the content of the model is consistent with your expectations. Validation usually done after verification investigates the accuracy of the model compared with the real world. These processes are usually iterative and involve re-visiting some of the stages of the model. This may require the addition of some processes not yet modelled, thus increasing the model's scope.

4.8 Benefits and Implication of SME's

The developed DSS is a mixture of simulation model, spreadsheets and text files. Within an MTO SME environment, it is possible to bring the knowledge and expertise of all the people involved in an ERP project into a DSS via Delphi analysis. Users can determine the attributes such as availability of CSFs based on real-time scenario and visualise the inter-relationships of CSFs during phases of the ERP project. This will improve the percentages of SMEs realising benefits from ERP systems due to scenario visualisation and necessary preventative or corrective actions.

There could be more simulation-based studies in SMEs if the experimentation and execution of the model were done from spreadsheets rather than from the model itself. This may be due to a general and somewhat valid perception that simulation software is too complex to use, and a preference to interact with a more standard tool like MS Excel spreadsheet. Such an approach will give SMEs a head start to adopt simulation. The author reckons that simulation will follow the same path as ERP and simulation packages for SMEs will be developed.

4.9 Summary

A DSS to analyse CSFs for ERP projects was developed. The model incorporates the four stages of an ERP project i.e. Initialise, Adoption, Adaption and Routine except Retirement. Various CSF attributes such as arrival time, quantity, sequence, team and cost were modelled. Further, the duration of stage can be controlled. Ten experimental runs were conducted with random and antithetic numbers. The model allows the end-user to visualise the relationships of CSFs based on near real time decisions.

Chapter 5: Traditional Technologies and ERP Integration

5.1 Introduction

Chapter 4 focused on a Decision Support System (DSS) developed to study Critical Success Factors (CFSs) during ERP implementation. A direct output of the ERP project, a three stage DSS was developed. In this chapter, the first stage of the DSS i.e. system development of a Prototype Planning and Scheduling System (PPSS) linked to an ERP system for Company ‘A’ is described.

Make to Order (MTO) manufacturer Company ‘A’ Ltd, who manufactures Autoclaves for laboratory use require effective capacity management to efficiently manage accurate due date and lead time settings. Quite often MTO, high-end laboratory equipment SMEs are challenged by the nature of medium/low volume and rich mix due to the complexity involved in the management of various products and an extensive number of production recipes in a mixed production-flow. In addition, facing dynamic demands and the large amount of system connections required to successfully manage the entire process further intensifies the complexity of the high-mix manufacturing industry (Su *et al.*, 2003).

To give customers a quality product and a responsive service, MTO production requires detailed, realistic, and flexible operational plans, along with a control mechanism for easy track of production status of customer orders (Yeh, 2000).

Chapter 2 emphasised the influence of variables related to the product, the demand and the manufacturing process, both current and future (Porter *et al.*, 1999). These variables result in the products being more or less engineered to customer order, small batch sizes often equivalent to customer orders, complex products and bill of materials, long manufacturing throughput times and delivery lead times and the layout of the shop floor being a process oriented one. All these features were evident to be present at Company ‘A’.

A major issue for Company ‘A’ was determining accurate Due Dates (DD) for firm orders. As concluded in Chapter 2, analytical and algorithmic aids have limited benefit compared to appropriate use of computer technology in such an environment. The human scheduler requires a production planning system to manage the situation, wherein the production planning system is a specialised form of DSS. Heuristic scheduling, focusing on simulation-based approaches using dispatching rules cannot adequately handle various attributes and specific requirements of the individual jobs. MRP logic-based production planning systems are the most applicable planning method and functions well in complex customer order type production (Jonsson *et al.*, 2003).

Accurate due date assignment and lead-time management need to be supported by a higher level of planning tools (Özdamar *et al.*, 1999). Capacity load needs to be balanced over a period of time at the higher planning level, for an order release strategy to work. Capacity constraints need to be considered while preparing a production schedule (Özdamar *et al.*, 1999). Hence, a Master Production Schedule (MPS) from a MTO perspective should be capacity feasible.

An integration of MRP and capacity planning is essential to consider actual production capacity and workload implicitly. This is followed by finite capacity scheduling, which simultaneously schedules both materials and capacity (Dumond, 2006). It is a preferred technique for correctly scheduling shop floor activities in a MTO manufacturing environment (Mahoney, 2007). It can determine a realistic delivery date and reduce cumulative lead times, considering the actual capacity and workload. This chapter shall emphasise the system development and its integration.

5.2 Concept - Prototype Planning and Scheduling System

Customer driven manufacturing is the key concept at Company 'A'. In order to remain competitive, it is desirable to quote realistic DD and have shorter lead times. To enable this, a Prototype Planning and Scheduling System (PPSS) using Microsoft Excel linked to ERP system was developed to ensure effective planning and scheduling of MTO production activities at Company 'A'. In particular, capacity management was used to effectively manage a number of future periods with known firm orders.

5.3 Production Planning and Scheduling

Production planning and scheduling activities are complex. However, the relationship between planning and scheduling holds the key to understand what constitutes a good production planning and scheduling system (Kempf *et al.*, 2000). Scheduling can be related to the execution of activities on the shop floor with a typical period of a day or a shift. On the other hand, production planning involves making decisions on how to allocate a firm's productive capacity among its range of products and customers over a longer term. As a result, scheduling decisions are tightly constrained by the planning decisions leading up to them (Kempf *et al.*, 2000).

Several production planning and scheduling approaches exist with different viewpoints on how to analyse them. The three important perspectives are: issue-solving approach, the decision-making perspective and the organisational perspective (Herrmann, 2006). The issue-solving approach considers scheduling at shop floor level as an optimisation issue and encourages formulation of combinatorial optimisation procedures. The decision-making perspective is of the view that schedule is a decision that planners make. The organisational perspective takes a view that planning and scheduling are part of a more complex flow of information and decision-making. Herrmann (2006) further suggested that production planning and scheduling was not an optimisation issue, but a complex system of information flow, decision-making, and issue-solving. This perspective closely links to the relation between planning and scheduling suggested by Kempf *et al.* (2000).

Scheduling within a planning framework and trends in management information decision support systems propagate the view of a human-machine interface, often necessary and desirable for making effective decisions (Gupta,2002). Such an approach enables the use of managerial and technical experience and judgement of the people to evaluate factors which are difficult and sometimes impossible to include in quantitative or optimisation models.

Further, the PPSS needs to be feasible and acceptable. Feasibility implies that the planning and scheduling system should not violate any of the constraints present in the manufacturing system in which it has to be executed. Whereas an acceptable schedule generated by the process plans is the one that cannot be improved by trivial changes. A trivial change is the one that could be made by a knowledgeable person examining the schedule manually. This perspective closely links to the relation between the human scheduler and the planning and scheduling system suggested by Gupta (2002).

5.4 Business Challenges

Company ‘A’ had disjointed legacy systems for sales, service and accounts operations. Based on the present production activities, Company ‘A’ cannot promise a customer if the delivery of an Autoclave will be as per the due date, or not. Presently when Due Dates (DD) are missed then the delay duration cannot be estimated. The firm wanted to avoid such a situation.

Company ‘A’ realised that it needed a structured way to streamline the external and internal supply chains. The company decided to implement an ERP system in 2009 and the project went live in 2010. To manage capacity a Prototype Planning and Scheduling System (PPSS) linked to ERP is proposed. The PPSS linked to the ERP can provide *to make* and *to procure* information. In subsequent chapters, the ‘to make’ data links to a DE simulation model and forms a DSS.

An empirical case study is presented here. Single case studies are useful to represent unique cases when there is a lack of theory. While this may have limited generalisation, it gives direction for future research (Zach *et al.*, 2011). The methodology used is of an exploratory case study with rich data collected for a period of over 30 months. The data was collected as the ERP project was implemented on a daily basis. This involved formal four-monthly review meetings, monthly project meetings, and weekly continuous improvement workshops. As the project was implemented, data was gathered from project team, project manager, office-based end-users, middle and top management, shop floor based users, ERP vendor representatives and caseworkers. Additional data sources were project plan, emails, and support cases with ERP vendor, custom software request and specifications.

5.5 PPSS: Capacity Planning and Spreadsheet

Considering the production status at Company ‘A’, rough cut capacity planning (RCCP) was a realistic and viable approach. RCCP is the basic and fundamental concept on which finite scheduling can later be built on. RCCP involves three aspects - exploding through the routings, work centre data, and schedule calendars (Rice, 2001). It compares the hours required with the hours available for a particular job or order. The scheduling system proposed for Company ‘A’ is based on the concepts of Materials Resource Planning - MRP I and Manufacturing Resource Planning – MRP II. MRP I gives answers to two questions- a) What to make? b) What to procure? The information on what to buy is then analysed with purchase orders. The information on what to make is analysed using capacity planning. It is here where MRP II gives an insight on capacity planning and finite scheduling (Rice, 2001). This is shown in Figure 5-1.

Capacity planning answers capacity problems in an organisation. For example, the punching machine would be loaded up 70% on a particular day in a week. A more enhanced and detailed approach is finite scheduling, which tells the production manager that “X” out of “Y” pressure vessel jobs are going to be delayed by “Z” hours.

“Wherever there is planning and scheduling going on, there are Excel spreadsheets” (Rice, 2008). The management at Company ‘A’ expressed a preference for Excel as a platform. A valid reason for this could be that spreadsheets are so well known and integrated throughout the business world, even first-time users of a spreadsheet have an intuitive understanding of the format and choices available (Walton *et al.*, 2008). The spreadsheet model may be complex, but the basic learning curve on spreadsheet usage has been usually covered by almost every member of the Company ‘A’ management.

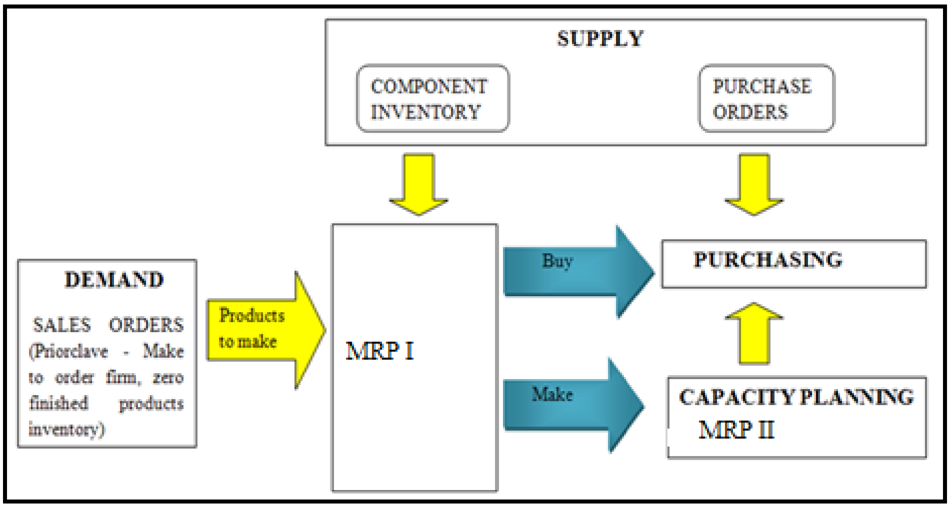


Figure 5-1 Rough Cut Capacity Planning - MRP I & MRP II linkage (Reproduced from Rice, 2001)

A spreadsheet-based solution is of an intangible value, but it creates an important level of confidence in the user. In order to keep the spreadsheet model at a level where the company employees themselves could modify the system, it was important to use only Excel functions without the Excel programming language Visual Basics (VBA). Most businesses have a good depth of spreadsheet literacy which can be a cost effective way to implement a planning and scheduling system and negate the risk of being stranded without technical support for a commercially available scheduling package. However, it must be realised that spreadsheets may be good at manipulating data, but they are not transaction processors and it is a wise idea to interface them with a host ERP system (Rice, 2001).

5.6 Building a Production Planning and Scheduling System

The first step of developing a spreadsheet model involves organising the basic operational data in Excel (Walton *et al.*, 2008). It is important to realise that in real-world applications, there are changing data that must be managed independently and then synchronised. Building a planning and scheduling system involves carrying out numerous sub-tasks, such as collecting, analysing and documenting input system data. Generally such data is imported from a host ERP system and it is preferable to have them saved as text files. This data is further organised into seven tabs that constitute the input system (Rice, 2007). The planning and scheduling system has the following additional features - Master Production Schedule (MPS) provides to 'make data' and respective DD after considering sales orders and finished inventory (if any); MRP 1 with multi level bill of materials; Routings involving multiple work centres; Shift calendar for each work centre and Rough cut capacity planning.

1. Design Principles

The design principles mentioned below have been implemented to follow a structured and systematic approach while using Microsoft Excel as the platform.

- *Packaged versus customised software:* Normally software packages contain many features and parameters so that they can be adapted by many different end-users or companies. As a result, they often end up with numerous features that are not used by the end-user. The prototype planning and scheduling system is developed to suit the requirements of Company 'A'.
- *Data Storage:* Microsoft Excel is a great tool in doing calculations and manipulating data, but it is not good at capturing and storing data (Rice, 2007). Hence, data is stored outside Excel and pulled into the system for calculations and manipulations. Company 'A' has recently purchased an ERP package; thus the prototype system can harness this feature as shown in Figure 5-2.

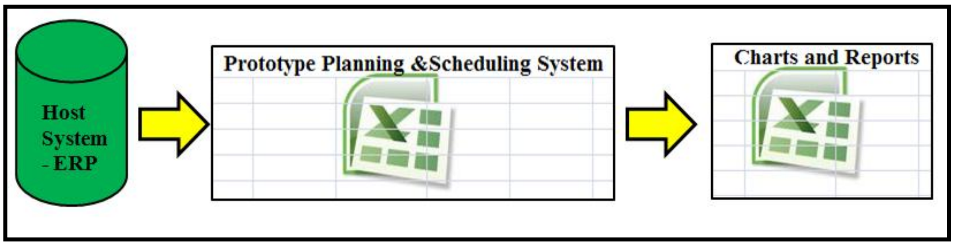
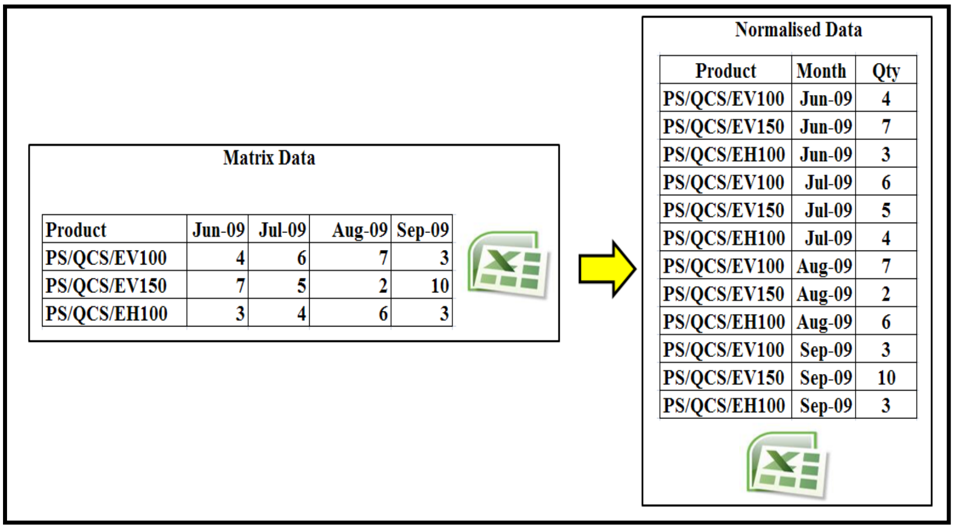


Figure 5-2: Data capture and storage outside Excel (Rice, 2007)

- *Structured and Disciplined Approach:* As with many aspects of technology, a system would only work if a structured and disciplined approach is used. Excel has earned a poor standing among software purists as a result of it being used in an unstructured way. The key to achieving success while using Excel is by following the two simple rules – each type of data on a separate sheet, and data flow from left to right in a sheet (Rice, 2007). As a result, the developed system has data, calculations, and reports on separate sheets.

- **Normalised Data Tables:** It is a widespread practice to present data in matrix form. However, it is important to convert them to normalised tabular form (Rice, 2007). This has been used in the PPSS and shown in Figure 5-3.



Matrix Data

Product	Jun-09	Jul-09	Aug-09	Sep-09
PS/QCS/EV100	4	6	7	3
PS/QCS/EV150	7	5	2	10
PS/QCS/EH100	3	4	6	3

Normalised Data

Product	Month	Qty
PS/QCS/EV100	Jun-09	4
PS/QCS/EV150	Jun-09	7
PS/QCS/EH100	Jun-09	3
PS/QCS/EV100	Jul-09	6
PS/QCS/EV150	Jul-09	5
PS/QCS/EH100	Jul-09	4
PS/QCS/EV100	Aug-09	7
PS/QCS/EV150	Aug-09	2
PS/QCS/EH100	Aug-09	6
PS/QCS/EV100	Sep-09	3
PS/QCS/EV150	Sep-09	10
PS/QCS/EH100	Sep-09	3

Figure 5-3: Separate input, calculations & output sheets (Rice, 2007).

- *Visual Basic for Applications (VBA) Free:* The developed system uses native Excel functionality and is totally VBA free. The system uses native Excel functions like formulas and Pivot Tables. Tools like recording macros for pasting down formulas are used, which are simpler than programming.
- *Prototyping Nature:* The system methodology is designed for prototyping so that it is flexible and adaptable. The approach of working in the direction of data flow was used. Excel is a visual tool and hence one could validate the logic with real data before moving to the next step.
- *Colour and Naming Conventions:* Naming conventions can be considered as an off-cut of the structured approach. The idea is to have uniformity and simplicity in the system.

2. Data Input Approach

Work centre data for three high selling Autoclave models i.e. PS/QCS/EV100, PS/QCS/EV150, and PS/QCS/EH100 was collected and studied. The input system relates to these three models and consists of seven input worksheets and follows colour and naming conventions. They are classified as: Sales_Orders,Finished_Inventory,Item_Master,Bill_of_Material,Material_Inventory,WIP(work-in-progress), Purchase_Orders. The next set of data required was user defined parameter settings. It involved quantitative dynamic data being collected and documented. They too follow the colour and naming conventions. They are classified as: Location, Products, Work Centre, Work_Centre_(1), Holidays, Weeks, Cal_A(Shift Calendar).

3. *Explanation of Tools*

Excel tools that were widely used in building the system are discussed below. This would give a clear view of the techniques used to link the data.

Static and Dynamic Named Range

This is the key for recording 'paste down macros'. Two 'static named ranges' and one 'dynamic named range' are required to record a 'paste down macro'. As a result, when fresh data gets imported the formulas used become dynamic and the worksheet gets updated. It involves extensive use of the Excel functions "=OFFSET" and "=COUNTA".

Importing Data

The prototype system developed is not a standalone system. The data is imported from an ERP system or a 'Sales Order & Inventory' system. The prototype system is designed to be run by a single user, so that the parameters are properly maintained. The data for the prototype systems is imported via text files. Text files just contain characters i.e. numbers and letters, no formatting, no colours or lines (Rice, 2007). They are small, simple, resilient, and can be read by other systems. Also by using text files, the user gets rid of complex file sharing violation issues and they can be read by other systems too. The author would like to use an example to illustrate how text files were used to import data in the proposed PPSS.

Recording Paste Down Macro

A widely used technique in building the prototype system was recording 'paste down macros'. It has two distinct advantages – firstly it is not as difficult as writing a VBA program and secondly it does not slow the workbook. Further leaving live formulas in worksheets slows the calculation drastically.

Excel Functionalities

This section would focus on some of the Excel functions that are used in the prototype system. In the coming chapters, the reader would observe how many of these functions were repeatedly used in the worksheets. It is important to know the role of these functions to understand the reason for their use. A brief description of these Excel functions has been given below.

- "=COUNTA": It counts the number of cells in a range that are not empty
- "=OFFSET ": It returns a reference to a range that is a given number of rows and columns from a given reference.
- "=MATCH": Returns the relative position of an item in an array that matches with a specified value in a specified sequence.
- "=INDEX": It returns the value or reference of a cell at the intersection of a particular row or column, in a given range.
- "=INDIRECT": It returns the reference specified by a text string.

The design principles discussed in this chapter, along with the input data, parameter setting, naming and colour conventions, data flow logic, and Excel tools and functions led to the development of the prototype planning and scheduling system. Also a structured and systematic approach with an iterative mind-set was adopted to achieve this objective.

Worksheets - Name & Description

The proposed planning and scheduling system comprises of 31 worksheets. All the worksheets can be classified into five types of data. The five data types can be identified as – Input, Parameters, Calculations, Control and Reports. Table 5-1 shows the name, type, and description for all worksheets in the proposed planning and scheduling system. They adhere to the colour and naming conventions discussed earlier.

4. Flexibility and Customisation

It was important to make the system flexible and user-friendly. It was one of the objectives of the project. The PPSS has 16 recorded paste-down macros and each is designed to perform a particular task. However, to run them individually would be lengthy and non-efficient process. Hence, the recorded macros were assembled into a single macro to make the system simple to use. The technique used was to arrange the recorded paste down macro as per the data flow sequence. An additional macro was recorded so that after the report was RUN the "Menu" worksheet could get displayed. The "RUN ALL" macro contents have been shown in Figure 5-4. A form control button was assigned to this macro. The user needs to click just one button to run the entire report.

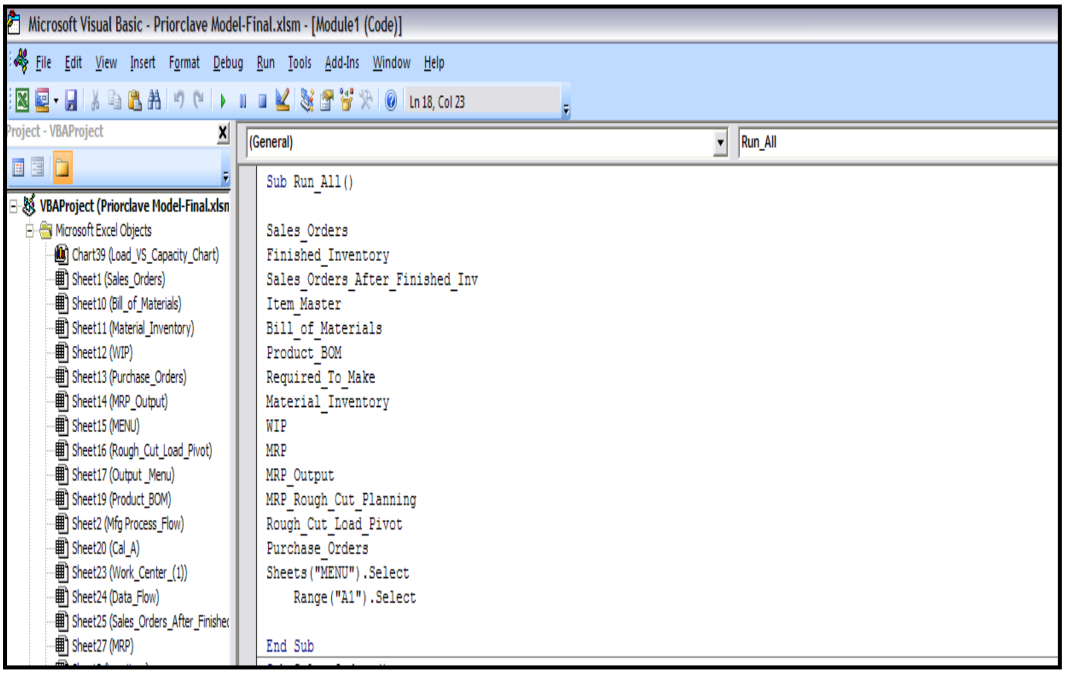


Figure 5-4: Structure of "RUN ALL" macro (Source - The Author)

To further improve user interface, all outputs and reports were hyperlinked, so that the user can navigate directly to a particular report. The hyperlinked reports are provided in the worksheet "Output_Menu". However, Pivot Charts cannot be hyperlinked in Excel and hence, a recorded macro was used. The macro 'form control button' was made invisible and when the user clicks a Pivot Chart name, the macro navigates to the particular Pivot Chart. A screen capture for the "Output_Menu" worksheet has been shown in Figure 5-5. One can also try this feature out by using the software CD-ROM.

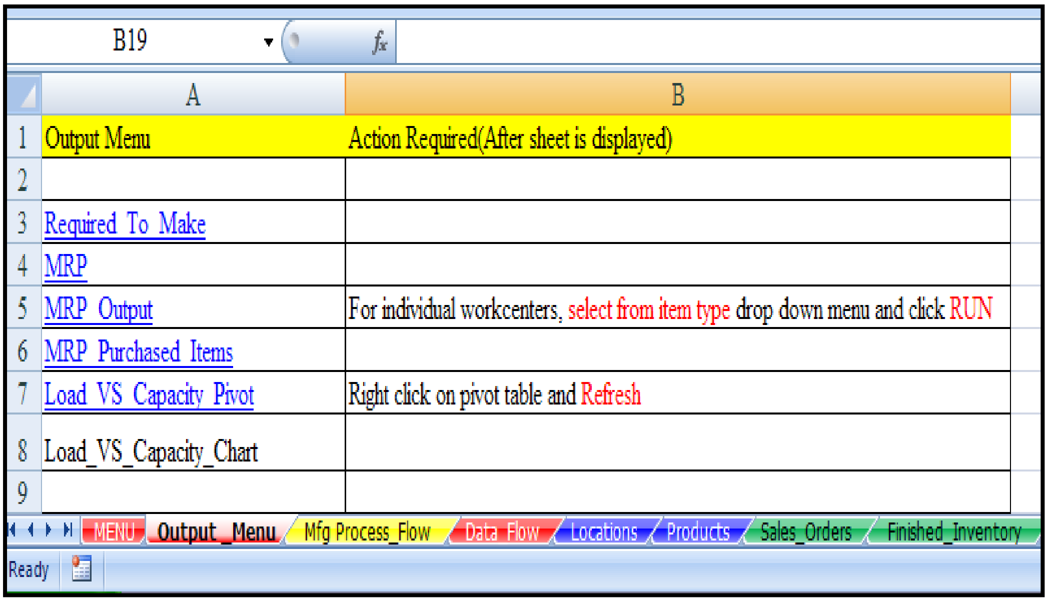


Figure 5-5: Screen capture for Output Menu (Source - The Author).

Sr. No.	Worksheet Name	Data Type	Description
1	MENU	Control	Contains a RUN all button to run the prototype system.
2	Output _Menu	Control	Provides the user with a list of outputs for direct access to a particular report.
3	Data_Flow	Control	Contains the information flow.
4	Mfg. Process_Flow	Control	Contains the manufacturing flow.
5	Sales_Orders	Input	Contains customer orders which are still outstanding.
6	Finished_Inventory	Input	Contains inventory of finished products/models at factory/warehouse.
7	Item_Master	Input	A list for all components, items and finished products.
8	Bill_of_Materials	Input	Lists all/significant parent - component relationship.
9	Material_Inventory	Input	List of inventory for all purchased materials or components and own manufactured components which are available and would be used for production.
10	WIP	Input	Contains the list of components issued to work-in-progress to make a particular parent item and cannot be reassigned to make another parent item.
11	Purchase_Orders	Input	Contain the list of components for which purchase orders are live. It includes components still to be delivered by the supplier.
12	Locations	Parameters	Specifies the location for delivery and despatch.
13	Products	Parameters	Specifies the product type-capacity, loading, and heating system.
14	Work_Center	Parameters	Specifies work centre details for all sequence from purchasing to final assembly.
15	Work_Center_(1)	Parameters	Specifies work centre details for completed QCS model
16	Holidays	Parameters	List of UK holidays between the time periods of 01/05/2012 to 30/04/2013

Table 5-1: List, type, and description of worksheets in proposed planning and scheduling model (Source - The Author). **Contd.**

Sr. No.	Worksheet Name	Data Type	Description
17	Weeks	Parameters	List of weeks starting Monday in the time period of 01/05/2012 to 30/04/2013.
18	Cal_A	Parameters	Shift calendar between 01/05/2012 to 30/04/2013
19	Sales_Orders_After_Finished _Inv	Calculations	Calculates sales orders after finished inventory.
20	Product_BOM	Calculations	Calculates product bill of materials level
21	Required_To_Make	Calculations	Calculates required to make with DD and links to Product _BOM level.
22	MRP	Calculations	Calculates and provides material resource planning explosion.
23	MRP_Rough_Cut_Planning	Calculations	Calculates set up days, run time days and transfer days for "to make" data.
24	Rough_Cut_Load_Pivot	Calculations	Calculates load hours for "to make" data.
25	Rough_Cut_Capacity	Calculations	Calculates capacity hours for planning horizon i.e. DD till which confirmed orders have been received.
26	Capacity_Load	Calculations	Stacks load and capacity hours for integrating with load versus capacity Pivot
27	Finished_Inventory_Pivot	Reports	Pivot table representing finished inventory
28	MRP_Output	Reports	Pivot table representing "to make" data and work centre, sequence and set up details.
29	Load_VS_Capacity_Pivot	Reports	Pivot table representing monthly load and capacity.
30	Load_VS_Capacity_Chart	Reports	Pivot chart for stacking load and capacity
31	MRP_Purchased_Items	Reports	Pivot chart providing list of components to be purchased for each model.

Table 5-2: List, type, and description of worksheets in proposed planning and scheduling model (Source - The Author).

5.7 Pivot Table – Drop down selection features

The prototype scheduling system makes extensive use of Pivot tools like tables and charts. They are linked to a dynamic data range and get updated when the system is run. An important feature of this tool is the drop down menu shown in Figure 5-6, which enables a user to select specific parameters such as work centres, item type, and so on. Questions like – What is the load on cutting pressure vessel shells? What is the set up time involved? What should be the batch size? etc. are addressed within a production planning process taking into account the firm's goals and resources.

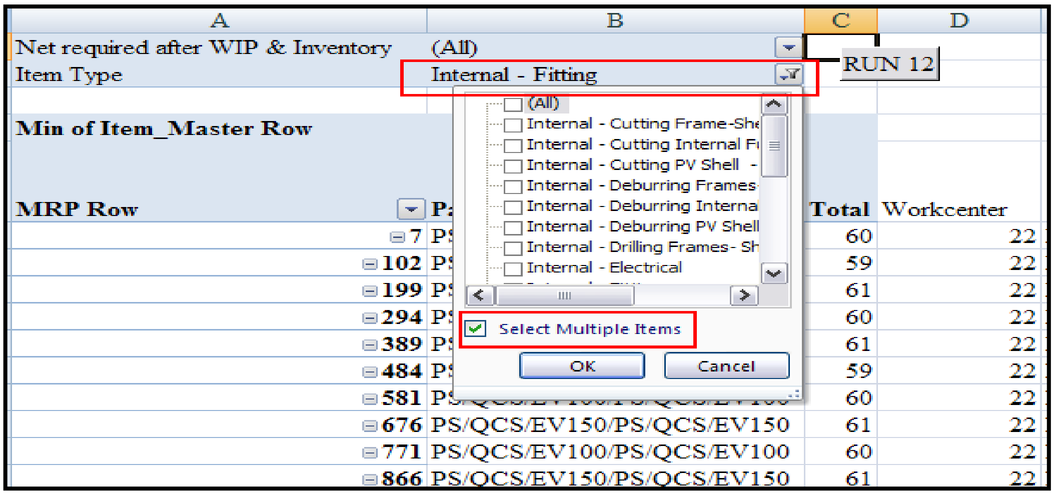


Figure 5-6: Example of drop down selection using Pivot Tables (Source -The Author).

5.8 ERP System at Company 'A'

MTO environment must overcome output diversity with a flexible manufacturing process, thus the need for an ERP type of system that integrates both supply chain management and production scheduling (Raymond *et al.*, 2007). The motivation for SMEs to adopt an ERP system can be many. This was true at Company 'A' too. At Company 'A' these were identified as environmental, organisational and technological factors.

Environmental Factors:

- The need to optimise the supply chain
- Company 'A' operates in a market which is sensitive to price and thereby depends on its Information System (IS) for effective control of its production costs
- Company 'A' operates in a dynamic sector i.e. high technology; hence to react rapidly to any change, a high degree of integration is required.

Organisational Factors:

- Fit between an ERP system and the organization's processes tops the list of criteria in the selection of an ERP system for SMEs. Company 'A' was using various legacy systems to perform, monitor and control daily business operations. This meant that an information vacuum was created with no two systems interacting with each other. An example of this was inaccurate return of investment figures for Service operations.

Technological Factors:

- The expiration of a maintenance contract for an existing "legacy" system can also motivate a business to contemplate on system migration. Company 'A' was using various legacy systems with Microsoft Access 97 being one, lack of support to perform, monitor and control daily business operations also contemplated this move.

Service related issues and the desire to improve due date and lead time performance were adequate reasons for the management to go for an integrated system. The ERP system has dedicated modules for Accounts, Sales, Service, Production, Purchasing and Secondary Processing, CRM. This chapter would cover how PPSS would link with the ERP system.

5.9 PPSS Linkage to ERP

As discussed earlier, the PPSS has its input via text files. The ERP system allows the seven input files to be saved in text format. This is shown in Figure 5-7. All production orders are shown in a portal view and these production assemblies can be saved as text files. This is then imported into the PPSS. Once text files are imported, the system is ready to be run. The planning horizon was selected as March 31, 2013. This meant Company 'A' has confirmed outstanding orders till the date specified by the planning horizon. Also "Today" was taken as June 01, 2012. When sales orders past March 31, 2013 are received, then the end-user has to update the Rough_Cut_Capacity worksheet. It is advisable to have a planning horizon of six months or more. To gauge the system performance and results, trials were carried out. One such trail, RUN1 is discussed. RUN1 assumed that Company 'A' had received

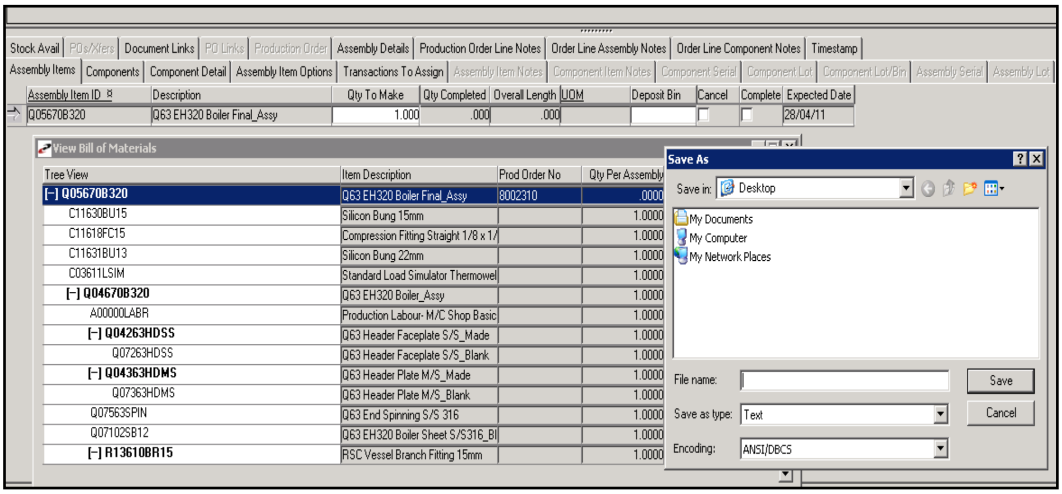


Figure 5-7: Text File from ERP System

confirmed orders till Feb.15, 2013. It constituted of 22 confirmed orders for PS/QCS/EV100, PS/QCS/EV150, and PS/QCS/EH100 models with a total of 126 Autoclaves. The due date started from June 26, 2012 and extended up to Feb.15, 2013.

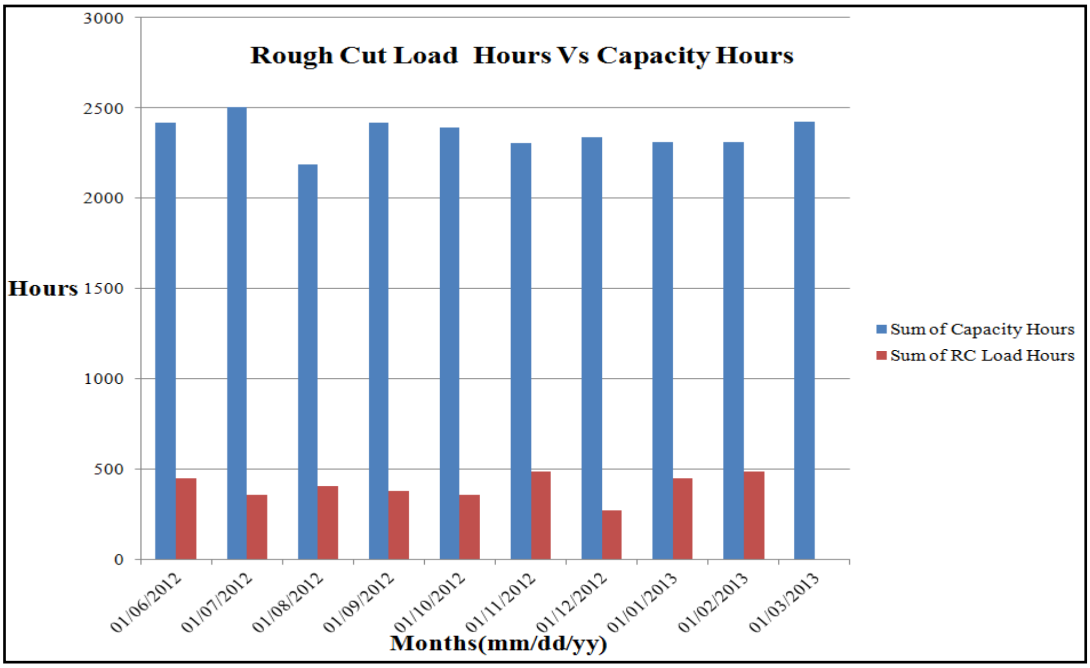


Figure 5-8: Load_VS_Capacity_Chart during RUN1

The system run was executed with these parameters. The number of records in RUN1 MRP explosion was 2100 records. These records constitute the "to make" and "to buy" data. The sum of Rough Cut (RC) load for Feb.2012 was determined as 486.745 hours during RUN1. This involves the "to make" data and this is where "MRP II" plays its role. The system calculated these values based on order quantities for a particular month. The execution time for RUN1 was less than forty seconds. The data reflected that Company

‘A’ had sufficient capacity to meet the customer requirements for the QCS Autoclaves and also the DD. The visual features of the system are shown in Figure 5-8, which stacks load versus capacity data for RUN1. This helps a user to graphically analyse the results and to co-ordinate efficient capacity utilisation. It provides answers to questions like - Can production scheduled for Feb. 2013 start in Jan. 2013 itself?

5.10 **Discussion:**

Planning and scheduling systems are complex in nature and to build such a system at Company ‘A’, iterative and co-learning approach was important. Due date determination for firm orders is a difficult task in make-to-order manufacturing environments. This becomes more visible and hard to answer with increasing Workload. Various approaches can be taken to address these issues. However, effective lead time and capacity management can help in addressing these issues. It is in this context that a planning and scheduling system plays a critical role.

The key to the system evolution were the choice of a responsive, iterative and co-learning approach. The learning and development of sound understanding of make-to-order manufacturing environment and suitable software engineering concepts permitted the system to grow without losing its core functionality. Planning and scheduling systems are vital for efficient production management. They must be resilient in nature so that people can actually use them. A system that is not resilient will not be dependable and hence, may not be utilised. The prototype planning and scheduling system for Company ‘A’ was built in a structured and disciplined way. This approach was important to achieve the project objectives when using Microsoft Excel as a platform for the system and to develop a programming-free system.

As the input data is stored outside the system, there is very little which can go wrong. On occurrence of a fault, the original copy of the system comes handy. The system is designed for single user-interface and is run from a single form control button. The results are hyperlinked to an output menu and this prevents any unnecessary navigation to find worksheets. This feature enables a user- friendly interface. The system uses Pivot Charts & Tables to display results and this provides a graphical interface. Further, one can use the drop down menu in Pivot Tables and Charts to access a particular type of information of interest. Data is imported to and exported out of the system using text files which can be read by other systems as well. This helps to avoid complex file sharing restrictions. The ability to build a customised solution can make this prototype system a more appropriate and affordable option for Company ‘A’. It provides a middle ground between excessively restrictive and expensive large-scale commercial applications, and the other extreme of investing in a unique production scheduling solution using programming languages.

The prototype system is generic in nature, as parameter settings are user-defined. However, the prototype system is limited to the QCS family of Autoclaves only. This was due to lack of work centre data at Company ‘A’. Data for Compact and RSC families of Autoclaves have to be collected to enable future implementation. The work centre template developed by the author can be used for this purpose. Once work centre data on the other families are collected and documented, their integration into the prototype system is possible by suitably modifying the user-defined work centre parameters. However, the future implementation of the system could be a time-consuming process. Commitment from the management and co-operation from the entire workforce are crucial for the final success of the system implementation. Also one needs to explore how the system can be made capable for multiple user-interfaces. A possible solution might be to auto-run the system. The system also needs a user-defined planning horizon to be selected. Research to automate this process with the time period for known sales orders should be pursued.

During the demonstration of the system, the management at Company ‘A’ acknowledged the usefulness of the system to manage load and capacity issues. Recommendations were given on the actions to be taken and their priorities, for the future integration work. The feedback received indicates that the management at Company ‘A’ wish to support the development of detailed version of the system.

5.11 Benefits of Prototype Planning and Scheduling System (PPSS):

- Prototype Planning and Scheduling System (PPSS) interfaces to the ERP system and overcomes the inability of the ERP system in helping the human scheduler to make real-time decisions. ERP systems are more suited for transactional processes.
- It provides an insight into capacity planning and it determines the load and capacity parameters.
- The prototype system is not a stand-alone planning and scheduling system, but a dynamic processor. It does not use any programming and input data for the system is stored outside. As fresh external data is pulled from the ERP system, it performs

MRP I and MRP II explosions. The system determines whether ‘to procure’ or ‘to make’ data.

- It determines the work centres involved, sequence, set-up time, transfer batches, and lead offset hours for the ‘to make’ data. The ‘to procure’ data is then compared with purchase orders. It provides an insight into capacity planning and it determines the load and capacity parameters. This demonstrates its usefulness in making informed lead-time and due date related real-time decisions.

5.12 Summary:

A PPSS for a MTO manufacturing environment was developed using Microsoft Excel at Company ‘A’. The new ERP system has a window to communicate with the PPSS. More importantly, the system responds to the basic needs of Company ‘A’, involving accurate due date determination and lead time management by achieving efficient capacity utilisation. The ERP system links service and manufacturing operations and provides effective component stock control and traceability. The system generates feasible production schedules in terms of capacity overloads and maximum allowed lead times of orders. The schedules generated identifies jobs or orders with varying routings, set-up times and material requirements and covers a time period to the extent of known firm orders. The system uses no programming and provides flexibility, user-friendliness, and it suits to the customised production approach of Company ‘A’. There are other benefits of the developed prototype system such as affordability, maintainability, and future expansion capability.

The research has shown how crucial system customisation and staff learning are to successful implementation of customised integrated systems. In terms of operational management it has identified how in SMEs run by a family & staff management, decision-making can be a crucial and time-consuming process. Academia can positively benefit from this case study by reflecting on the management and technical skills needed by students or future system implementers to efficiently manage change in such management style environments.

Chapter Six: Decision Support System for Production Strategy using Computer Simulation

6.1 Introduction

Chapter 5 focused on the details related to the development of a Prototype Planning and Scheduling System (PPSS). This chapter discusses how the PPSS linked to an ERP system can be used to develop a simulation based Decision Support System (DSS). Earlier Chapter 2 concluded that simulation could often capture and describe complex interactions within a manufacturing system where analytical methods fail. Simulation has been recognised as the second most widely used technique in the field of operations management. As mentioned in Chapter 2, of the two hundred and eight one journal papers reviewed by Jahangirian *et al.* (2010) on simulation, Discrete Event (DE) simulation had been used in over 40% of the papers.

The appropriate use of computer technology to address scheduling issues was indentified in Chapter 2. In such an environment, the human scheduler requires a production planning system to manage the situation, wherein the production planning system is a specialised form of DS system. Such a system must be able to provide support through most of the production planning, control stages, and be suitable for the job shop. ERP extensions such as APS can provide such functionality, but they have their own drawbacks. Aslan *et al.* (2011) suggested that Advance Planning and Scheduling (APS) appeared to lack adequate support for due date, price determinations and design and engineering stage. Aslan *et al.* (2011) argued that CRM utilisations in MTO sector needed to be explored further. Extensions of ERP have received only limited attention. MTO specific solutions do not exist in the ERP market. The fit between the needs of a MTO firm and the functionality of ERP and these extensions is limited in some and not clear in others.

Montonen *et al.* (2010) suggested that there were limited examples of the use of simulation tools in the operational planning of manufacturing. They proposed a simulation based DSS to augment the task of planners and schedulers to run production more efficiently. The benefits of implementing an operational simulation scheduling system are less effort required to plan day-to-day scheduling, customer order due date (DD) conformance, synchronisation of flow, minimisation of set-ups/changeovers, and 'what-if' scenario analysis of capacity planning. The main challenges identified were data integration, automated simulation model creation, and visualisation of results for interactive decision-making.

- To design and develop a DSS which derives its data from PPSS and ERP to run production more efficiently and also to support Customer Relationship Management activities (CRM)

6.2 Business Process Modelling

Integrated Definition for Function Modelling (IDEF0) emerges as a powerful tool for modelling the complexities of a MTO environment. IDEF0 is a hierarchical modelling approach allowing the user to understand the sequence of system functions. An activity block is the main unit of IDEF0 and describes the main function of the process. The input, control, output and mechanism are represented by horizontal and vertical lines. Process controls can be company regulations, standards or legislations whereas process mechanisms are usually agents which facilitate the activity. IDEF0 allows the user to comprehensively follow the undertaking production processes. In addition, the routes of the production processes are clearly illustrated, which makes the simulation process easier and effective.

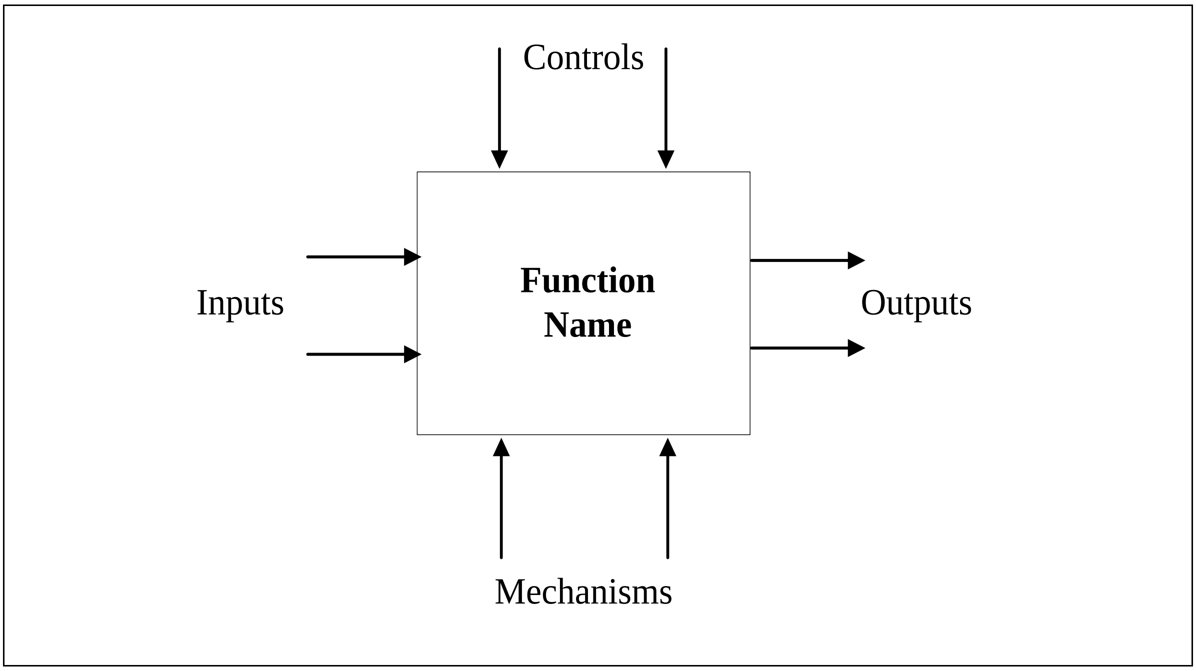


Figure 6-1: IDEF0 Model (Mahfouz et al., 2011)

6.3 Data Latency

Heilala *et al.* 2010 referred data latency as that characteristic of the data which relates to how current the information needs to be. Accordingly, data is classified as:

- Real time data which is current up-to the second
- Near real time data is information that is updated in set intervals rather than instantaneously
- One time data is typically updated once every month or very rarely

Most of the data in the model is near real time and is extracted from the ERP and exported as American Standard Code for Information Interchange (ASCII) or text files using Crystal Reports (CR) add-on. Further, the model tries to use near real-time data for machine utilisation and workflow data management.

6.4 Data Error Analysis

Errors do not carry the usual connotations as a mistake or blunder. Error in a scientific measurement means the inevitable uncertainty that affects all measurements. Unlike mistakes, errors cannot be eliminated by being careful. The best approach is to ensure that the errors are small (as reasonably as possible) and the error estimate is reliable. Not all types of experimental uncertainty can be assessed by statistical analysis. For this reason, uncertainties are classified as random uncertainties that can be analysed statistically and systematic uncertainties that cannot (Taylor, 2004).

The distinction between random and systematic errors is not always clear. An issue, which may cause random errors in one experiment, may produce systematic errors in another.

Systematic errors are usually hard to detect and evaluate. Often this involves anticipating the possible sources of systematic error and all systematic errors are much less than the required precision. Doing so will involve checking meters in a calibration lab against acceptable standards and correcting them or buying better ones. For this research work we consider all sources of systematic error being identified and made smaller than the required precision.

As long as systematic uncertainties are negligible, the uncertainty in a best estimate for a measure ‘x’ is the standard deviation of the mean (SDOM).

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{N}} \qquad \text{Equation 6-1}$$

$\sigma_{\bar{x}}$ = SDOM gives the random component of uncertainty in our best estimate

σ_x = Standard Deviation

N = No of measurements for x

Often, if the systematic errors are acceptable, then δx_{ran} the random component of uncertainty is equal to $\sigma_{\overline{x}}$.

Further, if there is a way to estimate systematic error component δx_{sys} and if δx_{ran} is the random component of uncertainty, then a reasonable expression for the total uncertainty is the quadratic sum of

$$\delta x_{total} = \sqrt{(\delta x_{ran})^2 + (\delta x_{sys})^2} \qquad \text{Equation 6-2}$$

6.5 Modelling and Simulation

Due to the market dynamics of the MTO environments, there is high variability of orders. Lean strategies such as pull system, demand levelling and Kanban can work harmoniously in MTO environment. Company ‘A’’s sales team receives customer orders with several product specifications and quantities in unorganised and random patterns. Usually customer orders are forwarded to the production managers who then chase demand fluctuations by making continuous changes to the resources and material capacities. Often *chasing strategy* can lead to high customer satisfaction, but inconsistent production and capacity plans result in high production costs and sometimes underutilisation of resources and materials. Demand levelling strategy could be an effective lean practice that identifies a constant demand rate to be produced in a specific time. It results in stable resource capacity that leads to proper labour utilisation and cost efficiency.

A probabilistic model is required in order to account for uncertainty in customer demand, product specifications, product cycle time, unpredictable breakdowns of resources. The stochastic technique of DE simulation is selected due to its capability of manipulating the variability and uncertainty of a system’s parameters. Simulation model was developed based on IDEF0 conceptual model. The model describes the product movement through the production line and the resources (e.g. machines, workstations) used to produce them. Resources are characterised by their capacity, cycle time, breakdown schedules, repair time and preventive maintenance scheme; while attributes of the products are arrival time, processing time and product configurations. Logical entities have simulated the decisions for routing, buffering and branching entities. Each product specification has its own statistical arrival distribution and routing.

The ERP database provides the unique product information such as product code, routing, specifications such as litres, frame, pressure vessel etc. The simulation model allows evaluating demand management by changing various parameters i.e. production level and staff capacity. The simulation model's accuracy and efficiency are verified by decomposition method (verifying each block of the IDEF0 model) and using the simulation software debugger, face validation by interviewing production manager and manufacturing teams. Further 'comparison testing' by comparing the model output with the system output under identical conditions can be used.

In a lean environment, priority is given to reduce cycle time and WIP level, which are important elements that contribute to customer satisfaction and reduction of waste. Further, within a MTO SME context, adherence to DD is important. These two environments and their requirements complement each other. Further, as per WLC concept, WIP levels are critical in MTOs and are directly proportional to mean throughput. Reducing the demand rate will result in decreasing the production bottlenecks. However, resource underutilisation and slow production are drawbacks of this strategy. Similarly if the firm's priority is to increase labour utilisation, then increasing demand rate in parallel with reducing labour capacity are the optimal settings.

Demand management was evaluated against response functions – cycle time, WIP, staff utilisation, priority, cost and material availability based on order book. The system was initially modelled using IDEF0 and then DE simulation was used to analyse the selected factors.

DE simulation models can be used for planning and design and day-to-day operational production planning of manufacturing facilities. These as built models allow manufacturers the ability to evaluate the capacity of the system for new orders, unforeseen events such as equipment downtime, effects of missing materials and change in operations. On the DSS model developed experiments are then performed by changing the input parameters to conduct 'what-if' scenarios and predicting the response. Some simulation models provide schedules that manufacturers can use to run facilities. Similarly, it can be used to validate plans and confirm schedules. When taking new orders simulation can show when the order will be completed and how taking the new order will affect other orders in the facility. Simulation models can be used for constraints or unlimited capacity analysis. Capacity constraints could be used to show when the order will be ready and how late it will be identifying the reason for lateness such as shortage of material, overload in resources or absenteeism of staff. Often manually intensive jobs can be analysed with unlimited capacity. The analysis shows the amount of resources needed in order to keep customer promise. Production manager has an option to add additional labour for critical phases. The model's integration with the ERP system also checks the availability of critical materials. *Ideally, it should check the stock values versus ordered components and indicate whether materials may run out at certain time in the future.* Priority control strategies are embedded into the simulation model by changing the DD in the ERP system.

6.6 Model Layout

Analysis of ERP data and simulation based production strategy analysis was done using DE simulation manufacturing platform from WITNESS. The model uses WITNESS features like part file, cycle time, push and match logic, tags, random and antithetic numbers, experimentation, Excel READ and WRITE array functions. Ability to incorporate real-time shop floor status was the key factor and data was collected and analysed for over two years at Company 'A'.

Orders from ERP arrive into PPSS. PPSS gives the 'to make' and 'to buy' date. The 'to make' arrives in simulation model using 'part files'. 'Part files' follow a definite structure as per WITNESS. It contains default WITNNESS attributes part, quantity, arrival time, height ,length and weight. Simultaneously the end-user can specify attributes as shown in Figure 7.9-3, where attributes like sales order number (SalesOrderNo) and assemblies such as QCSHORFrame or COMPACTFrame. Error analysis was done to find random errors in the cycle time and cost data from the ERP system.

6.7 Model Features

- Autoclaves are classified as six product groups
- Each product group was divided into six blocks as shown in Table 6-1
- Hence, for the entire model 36 (six product groups x six blocks) attributes are defined.
- 36 part buffers are defined

Model/Blocks	Frame	Boiler	Pipe	Electrical	Door	Op Test
Compact	✓	✓	✓	✓	✓	✓
QCS Hor	✓	✓	✓	✓	✓	✓
QCS Ver	✓	✓	✓	✓	✓	✓
Q63	✓	✓	✓	✓	✓	✓
RSC Small	✓	✓	✓	✓	✓	✓
RSC Large	✓	✓	✓	✓	✓	✓

Table 6-1: Product Groups and Simulation Blocks

- Parts are pushed to buffers on arrival, using *if-then-else* and *push* logics
- Labour is pushed to labour buffer using *push* logic
- Parts are pulled from buffers using MATCH rule, depending on the job id (in this case the sales order number)
- Labour is pulled from labour buffer using MATCH rule depending on the job id specified by the production manager
- Product families are modelled as ASSEMBLY machines and depending on product family job id blocks and labour are assembled as shown in Figure 6-2
- Six buffers defined for finished goods
- Six integer variables defined to enable counting of the finished items made
- Time setting in month, week and hours & minutes as shown in Figure 6-3
- One shift has 480 minutes with 60 minutes of rest during shift time and 960 minutes between shifts as shown in Table 6-3
- Cost for each block is defined as a real variable. This is initialised during the start of the model using Excel READ array functions in WITNESS. Current model has cost for 12 blocks related to two families COMPACT and QCSHOR
- Cycle time for each product group is defined as a real variable. As with cost, this is initialised during the start of the model using excel READ array functions in WITNESS. Current model has cycle time for two product groups related to two families COMPACT and QCSHOR.

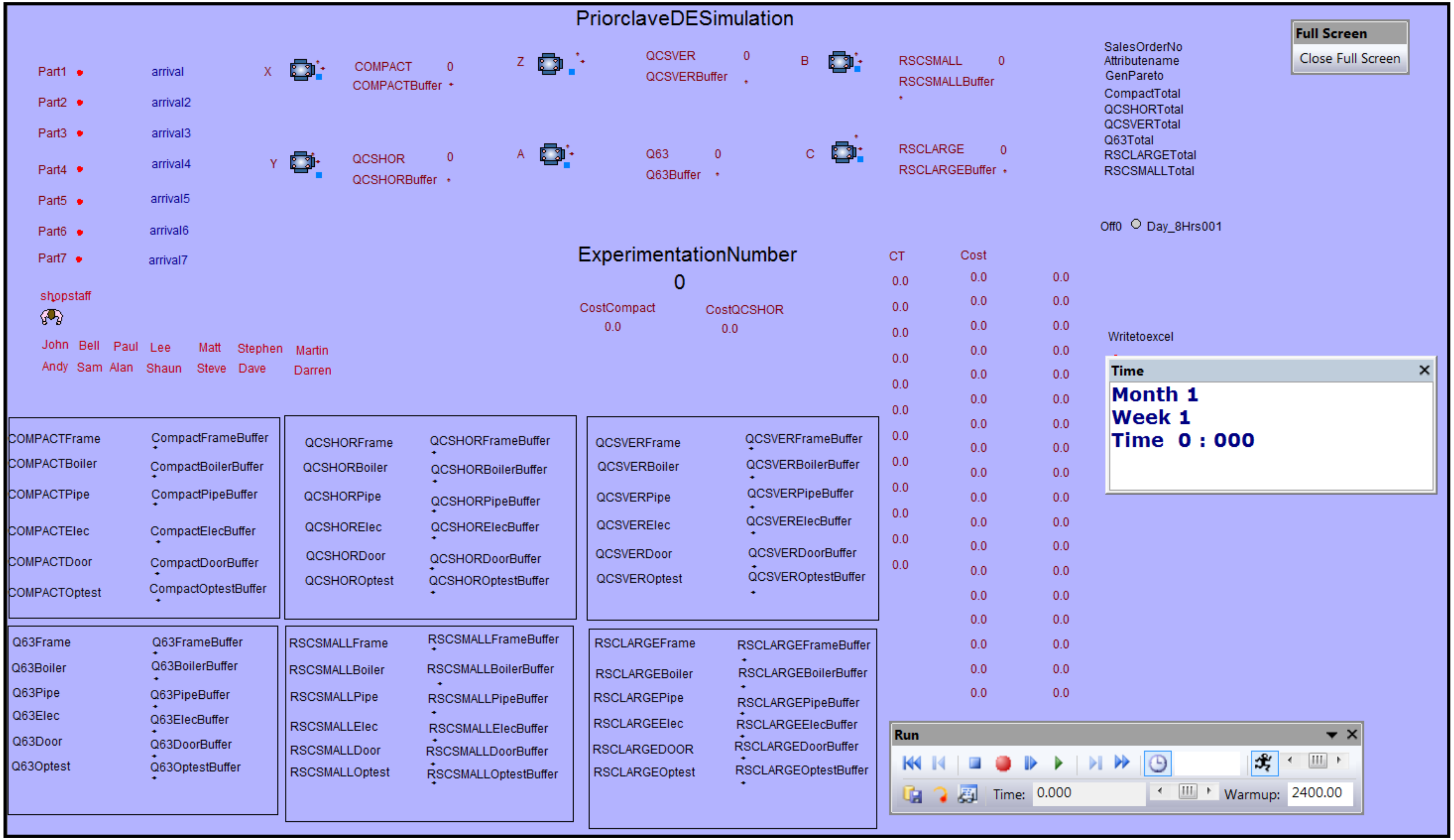


Figure 6-2: Production Strategy Simulation Model Layout Features

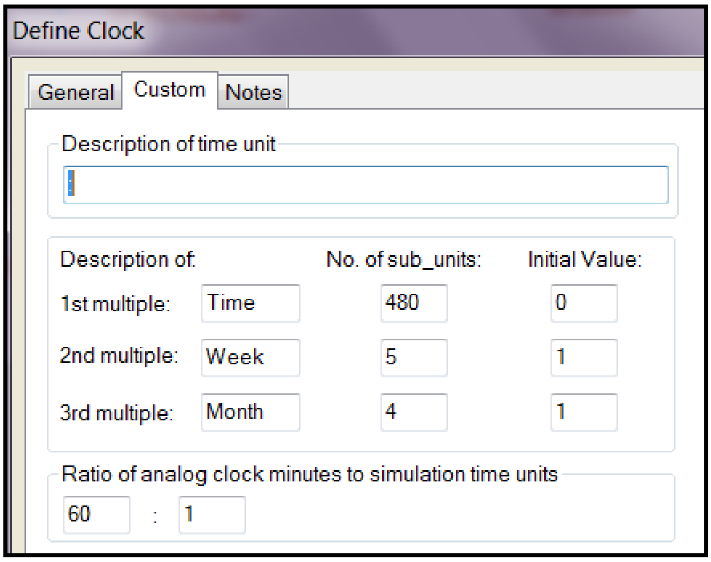


Figure 6-3: Simulation Model Clock Settings

- 8- hour shift defined

Time	Work Time	Break Time	Over- time	Total Time
Period1	150.0	15.0	0.0	165
Period2	135.0	30.0	0.0	165
Period3	180.0	15.0	0.0	195
Period4	15.0	900.0	0.0	915
Summary	480.0	960.0	0.0	1440

Table 6-2: Simulation Model Shift Settings

- Buffers have a maximum capacity of 100 for each block. This is almost 100% more than Company 'A' requirements for a month based on historical data.
- 'Part' and 'Excel' files allow appropriate staff to
  - Edit priority: As shown in Figure 6-4, the production manager can change the priority of the order by changing the required order date in the ERP
  - Edit labour: As shown in Figure 6-5, the production manager can edit the labour quantity depending upon the availability of staff
  - Edit material: Often stock control is an issue in SMEs and ERP stock values do not match shop floor values. The end-user can correct any such instances
  - Edit 'cycle time' where required: End-user can edit the cycle time in the Excel READ array sheet when a particular task is expected to take more time due to material, manpower or breakdown issues.

Part	Qty	Arrival Time	Witness Attribute	User Attribute	User Attribute
PART1	1	1	Height=1	Attributename= COMPACTFrame	SalesOrderNo=1000001
PART1	1	1	Height=1	Attributename= COMPACTFrame	SalesOrderNo=1000002
PART1	1	1	Height=2	Attributename= QCSHORFrame	SalesOrderNo=1000010
PART1	1	1	Height=1	Attributename= COMPACTFrame	SalesOrderNo=1000004
PART1	1	1	Height=2	Attributename= QCSHORFrame	SalesOrderNo=1000005
PART1	1	1	Height=1	Attributename= COMPACTFrame	SalesOrderNo=1000006
PART1	1	1	Height=1	Attributename= COMPACTFrame	SalesOrderNo=1000007
PART1	1	1	Height=1	Attributename= COMPACTFrame	SalesOrderNo=1000008
PART1	1	1	Height=1	Attributename= COMPACTFrame	SalesOrderNo=1000009
PART1	1	1	Height=2	Attributename= QCSHORFrame	SalesOrderNo=1000003
PART1	1	1	Height=1	Attributename= COMPACTFrame	SalesOrderNo=1000011
PART1	1	1	Height=2	Attributename= QCSHORFrame	SalesOrderNo=1000012
PART1	1	1	Height=1	Attributename= COMPACTFrame	SalesOrderNo=1000013
PART1	1	1	Height=1	Attributename= COMPACTFrame	SalesOrderNo=1000014

Priority is user defined

Figure 6-4: Simulation Model User-Defined Order Priority Settings

Part	Q	T	Witness Attr	User Attribute	User Attribute
PART7	1	1	Height=61	Attributename=Matt	SalesOrderNo=1000001
PART7	1	1	Height=61	Attributename=Steve	SalesOrderNo=1000002
PART7	0	1	Height=61	Attributename=Stephen	SalesOrderNo=1000003
PART7	1	1	Height=61	Attributename=Dave	SalesOrderNo=1000004
PART7	1	1	Height=61	Attributename=Martin	SalesOrderNo=1000005
PART7	1	1	Height=61	Attributename=Darren	SalesOrderNo=1000006
PART7	1	1	Height=61	Attributename=John	SalesOrderNo=1000007
PART7	1	1	Height=61	Attributename=Andy	SalesOrderNo=1000008
PART7	1	1	Height=61	Attributename=Bell	SalesOrderNo=1000009
PART7	1	1	Height=61	Attributename=Sam	SalesOrderNo=1000010
PART7	1	1	Height=61	Attributename=Paul	SalesOrderNo=1000011
PART7	1	1	Height=61	Attributename=Alan	SalesOrderNo=1000012
PART7	1	1	Height=61	Attributename=Lee	SalesOrderNo=1000013
PART7	1	1	Height=61	Attributename=Paul	SalesOrderNo=1000014

User can edit the availability of Labour

Figure 6-5: Simulation Model User-Defined Labour Priority Settings

- Crystal Reports (CR) add-on automates creation of WITNESS ‘part files’. Variable data cycle time and cost were analysed using statistical best-fit distribution as shown in Figure 6-6. The goodness of fit analysis was done using Kolmogrov-Smirnov ranking methodology as shown in Figure 6-7.

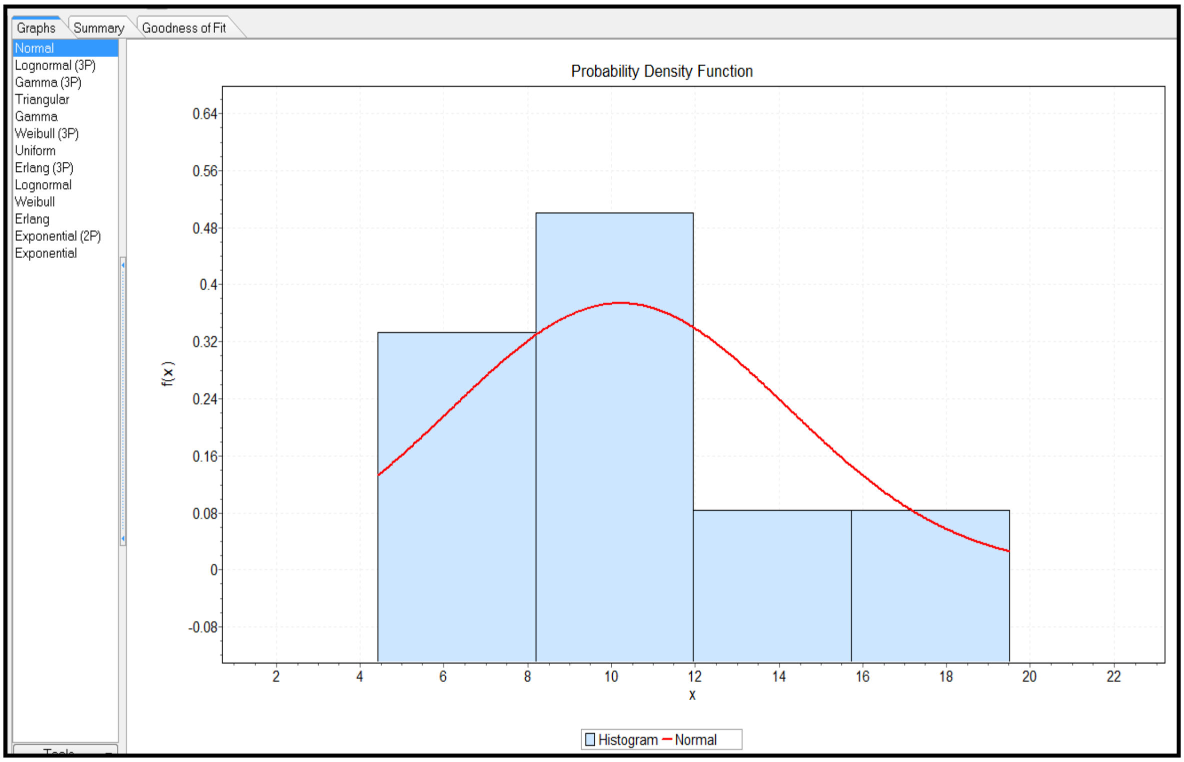


Figure 6-6: Simulation Model Order Arrival Statistical Analysis Output

Graphs | Summary | Goodness of Fit

Goodness of Fit - Summary

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
9	Normal	0.21951	1	0.54386	2	0.05052	1
8	Lognormal (3P)	0.22471	2	0.533	1	N/A	
6	Gamma (3P)	0.22739	3	0.54478	3	N/A	
10	Triangular	0.23491	4	1.8071	10	N/A	
5	Gamma	0.23516	5	0.55731	4	N/A	
13	Weibull (3P)	0.23885	6	0.62523	6	N/A	
11	Uniform	0.24982	7	4.3398	13	N/A	
2	Erlang (3P)	0.25011	8	0.57345	5	N/A	
7	Lognormal	0.2569	9	0.65568	7	N/A	
12	Weibull	0.26481	10	0.68023	8	N/A	
1	Erlang	0.3045	11	0.81112	9	N/A	
4	Exponential (2P)	0.30917	12	3.6383	12	N/A	
3	Exponential	0.35364	13	2.3895	11	N/A	

Figure 6-7: Simulation Model Goodness of Fit Ranking Analysis

Feature	Element	Qty	Details
Part1 to 6	Passive Part	6	Arrival of parts is controlled by part files *arrival1, arrival2, arrival3, arrival4, arrival5, arrival6.*
Part7	Passive Part	1	Arrival of labour is controlled by part files *arrival7.*
Arrivals 1to7	Part File	7	Data from ERP-PPSS linkage exported as *text* file using Crystal Reports add-on. This export is automated and happens at regular intervals.
Autoclave Range	Machine	6	Six product range (COMPACT, QCSHOR, QCSVER, Q63, RSCSMALL, RSCLARGE) made by Company 'A' modelled as machines X,Y,Z,A,B,C.
Autoclave Blocks	Real Attribute	36	Each Autoclave has 6 blocks example for COMPACT we have COMPACTFrame, COMPACTBoiler, COMPACTPipe, COMPACTElec, COMPACTDoor, COMPACTOptest.
Arrival Buffers	Buffer	36	Each block has its own buffer for example COMPACTFrame we have COMPACTFrameBuffer .
Finished Autoclave Buffer	Buffer	6	Six product range assembled by machines X,Y,Z,A,B,C sent to finished goods buffers COMPACTBuffer, QCSHORBuffer, QCSVERBuffer, Q63, RSCSMALLBuffer, RSCLARGEBuffer).
Cycle Time(CT)	Variable Real	12	The cycle time for a range is expressed within the limits of the uncertainty (due to random errors). e.g. the CT for the COMPACT machine is given as TNormal (2840.6,131.01,CT (2),CT (1)) where CT(2) and CT(1) are the lower and upper limits of CT for COMPACT machine.
Cost	Variable Real	36	Each block has its own cost. E.g. COMPACTFrame cost is updated from the ERP via excel READ array function.
Job id	Variable String	1	SalesOrderNo is used to identify each job.
User Attribute	Variable String	1	Attributename used in part file.

Table 6-3: Model Simulation Element Details

6.8 Model Results

ERP and MRP systems are usually based on static resources with unlimited capacity and this is a limitation. At present manufacturing systems cannot be effectively studied with the ERP system. By integrating DE simulation and traditional production planning methods such as PPSS, it is possible to forecast required workloads within given input values. The developed simulation model and graphical user interface make it possible to visualise potential bottlenecks. The load data for simulation indicating the product, its parameters as well as required quantities and delivery dates comes from the ERP.

The benefits of implementing an operational simulation scheduling system are less effort required to plan day-to-day scheduling, customer order due date conformance, synchronisation of flow, minimisation of set-ups/changeovers, and 'what-if' scenario analysis of capacity planning. The DE simulation model overcomes the inability of ERP systems in decision-making based on real-time data support Customer Relationship Management (CRM) activities such as production lead-time. Further, production strategy is an important CSF for MTO SMEs during ERP projects.

When the model is run, initialise actions: check the experiment count, excel READ array inputs cycle time and cost data, part files enter the model. Depending upon the attribute and product group, the blocks are pushed to different buffers. At this stage 'tags' with job id number become visible. Depending upon the job id, the MATCH functions pull relevant blocks including labour assigned. All jobs require labour; hence, if a particular operator is not available then that product is not made.

As a product is assembled, the relevant cycle time is read by the machine. Finally, when the part is assembled, it is pushed to a buffer. This is shown in Figure 6-8. Model validity was checked by staff validation. A real-time shop validation needs to be carried out for cycle time. Currently, the validity of the model was checked with expected completion time and cost of the model in the ERP system. The results came within 2-11% tolerance of ERP data.

6.9 Model Experiments – Reliability and Repeatability

After identifying confidence in the model i.e. the model represents the behaviour of the real-life situation, a number of what-if scenarios can be investigated. The scenarios

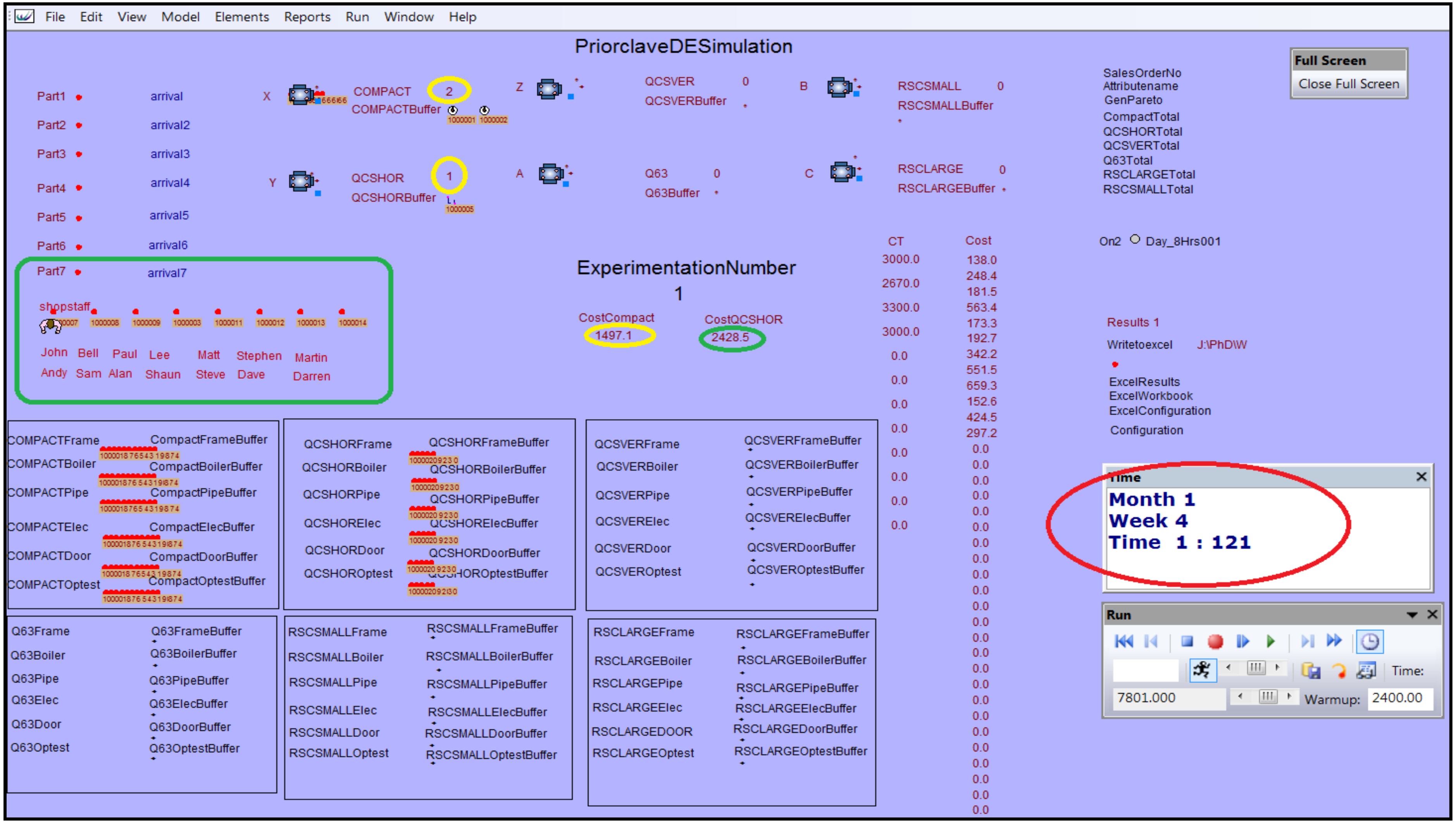


Figure 6-8: Results from Experiment No 1 for Production Strategy

defined within the original objectives of the simulation study such as support CRM activities based on near real time production status. WITNESS allows to define and run an experiment (that is, to run a model under closely controlled conditions with results collected at specified intervals) and record results in an appropriate format. Ten runs for both studies were executed. The steps involved here are:

- Name of the proposed run as shown in Figure 6-9.

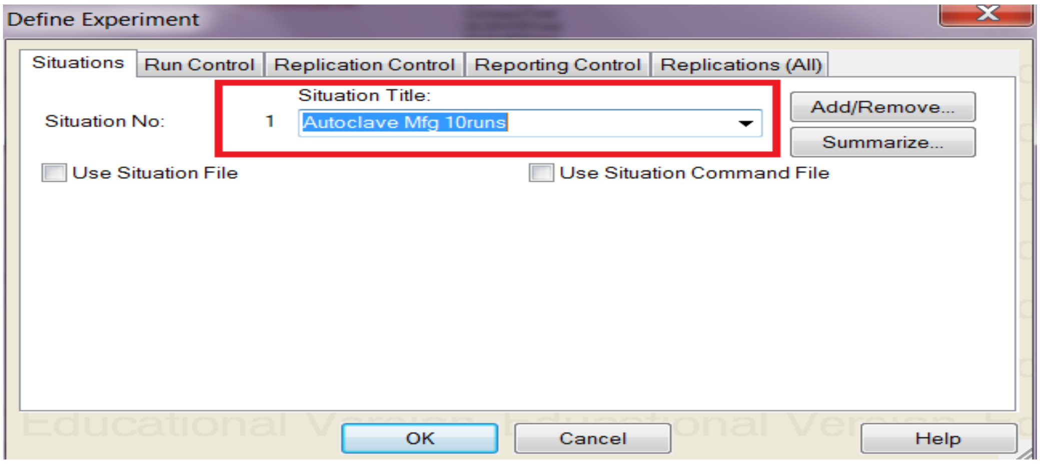


Figure 6-9: Experiment Runs

- Define suitable warm up period and replication period as shown in Figure 6-10.

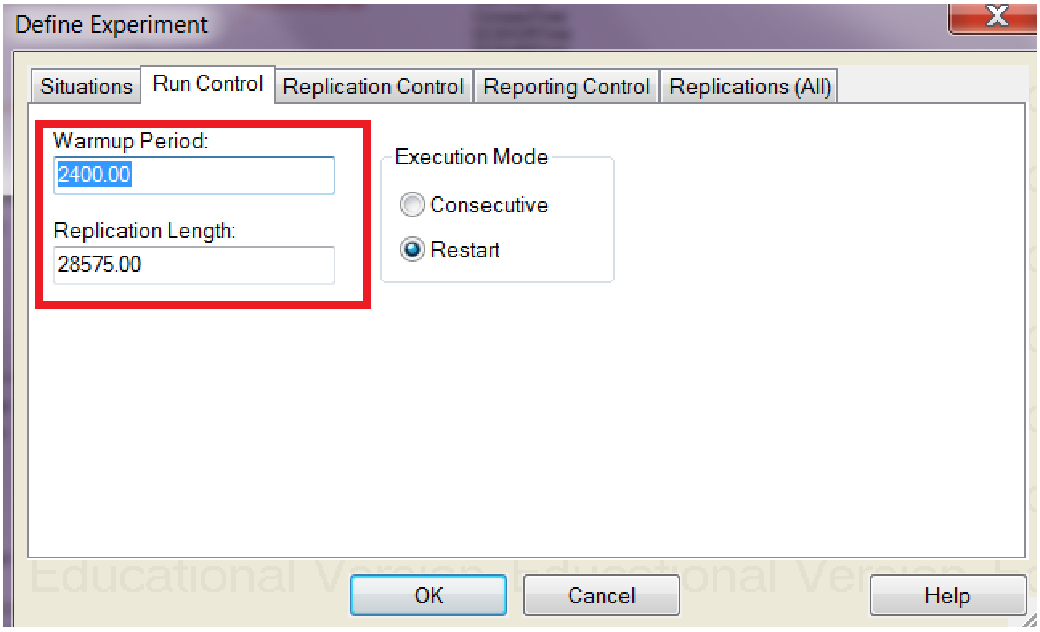
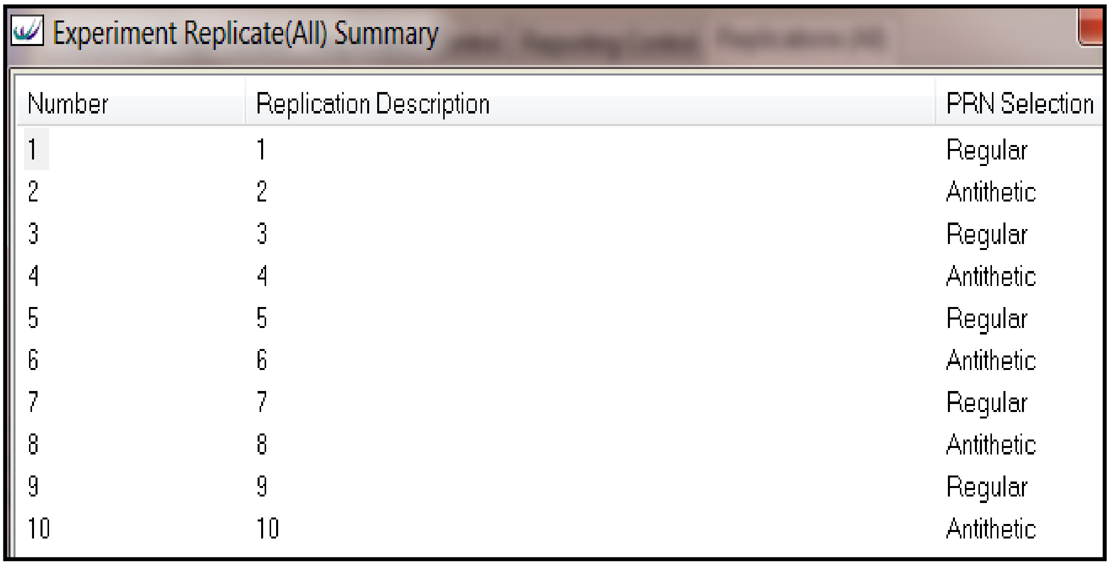


Figure 6-10: Experiment Run Warm-up Period and Replication Length

- Define start of replication number and control for the random number streams.
- Specify output format for the experiment. CSV file is selected here.

- For each experiment, specify random or antithetic number and random number stream control by specifying the skip and stream offset as shown in Figures 6-11 and 6-12.



Number	Replication Description	PRN Selection
1	1	Regular
2	2	Antithetic
3	3	Regular
4	4	Antithetic
5	5	Regular
6	6	Antithetic
7	7	Regular
8	8	Antithetic
9	9	Regular
10	10	Antithetic

Figure 6-11: Experiment Runs - Random and Antithetic Number Settings

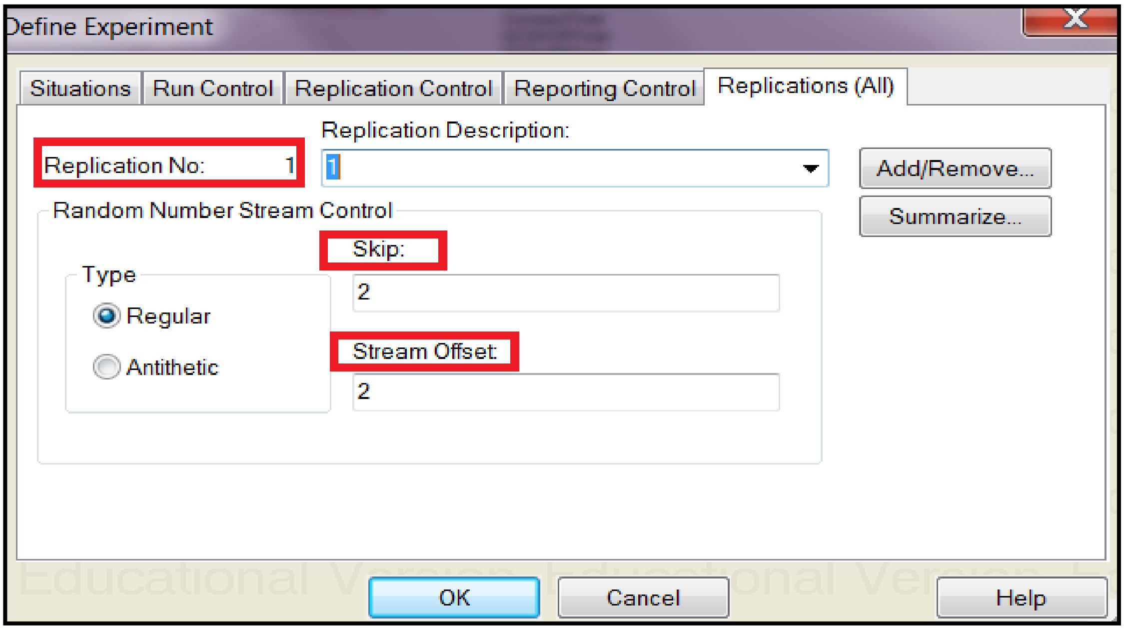


Figure 6-12: Experiment Runs – Random Number Stream Settings

- Specify random number seed control. Default (Seed 1 to 6, settings 12345, Figure 6-13) WITNESS random number seed control settings were used.
- These steps ensured reliability and repeatability. The results of the test are exported using WITNESS WRITE array function.

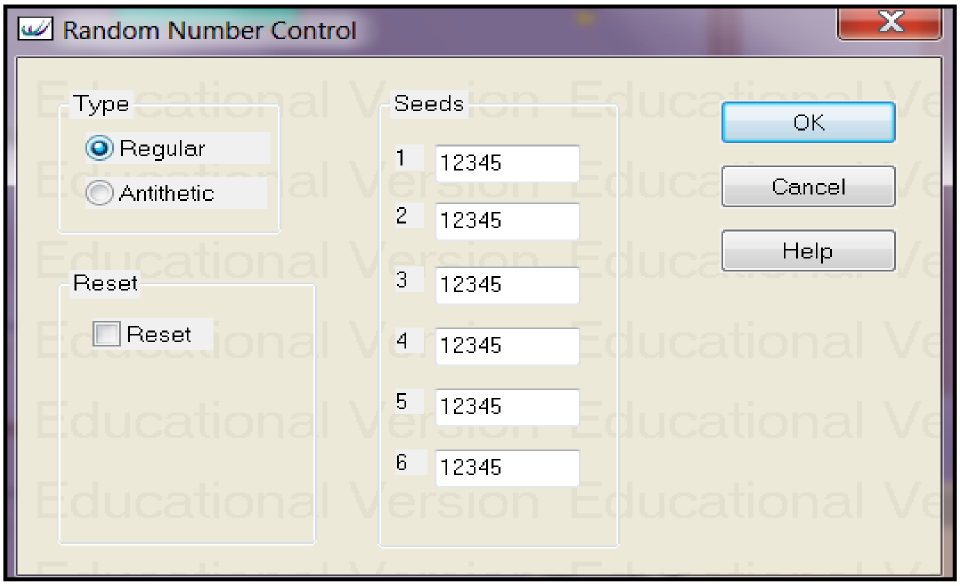


Figure 6-13: Experiment Runs – Random Number Seed Control Settings

6.10 Discussion

The DSS related to the production strategy overcomes some of the inability in traditional production systems such as infinite resources and inability of ERP system to aid in near real time decision-making. Firstly, a PPSS for a MTO manufacturing environment was developed using Microsoft Excel at Company ‘A’. The data for the PPSS comes from the ERP system. The ERP system has a window to communicate with the PPSS. The ERP system links service and manufacturing operations and provides effective component stock control and traceability. The ERP-PPSS linkage generates the ‘to make’ and ‘to procure’ data. The ‘to make’ data then links to a DE simulation model to form a DSS. This provides feasible production schedules in terms of capacity overloads and maximum allowed lead times of orders. The schedules generated identifies jobs or orders with varying routings, set-up times and material, labour requirements and covers a time period to the extent of known firm orders. The DE simulation model supports Customer Relationship Management (CRM) activities such as production lead-time and overcomes the inability of ERP systems in decision-making based on real-time data.

6.11 Benefits

- The system uses no programming and provides flexibility, user-friendliness, and it suits to the customised production approach of Company ‘A’.

- There are other benefits of the developed prototype system such as affordability, maintainability, and future expansion capability.
- The linkage of PPSS, ERP and DE simulation model is generic in nature, as parameter settings are user-defined. The integration of this hybrid model is done via user-friendly platforms such as Microsoft Excel and ASCII text files.
- Provides lead-time input to CRM activities in the ERP system which can be used for the sales quotation process

6.12 Summary

A production strategy based DSS based on DE simulation was developed. The model integrates with the PPSS-ERP model. The orders in 'to make' data enters the DE simulation model. ERP CSF production strategy and MRP tools enabled formulating a DSS for MTO environment. It supports CRM activities and realise the benefit of ERP systems. The end user can edit labour, material, priority, cycle time and cost. Reliability and repeatability of the model was tested with ten runs for both studies. Random and antithetic numbers were used. Face validation was conducted to ensure validity. Further development will require real time validation of orders and exploring the Workload Control (WLC) logic.

Chapter Seven: Decision Support System for Production Strategy and Workload Control

7.1 Introduction

Chapter 6 discussed how DSS using ERP- Prototype Planning and Scheduling System (PPSS) linkage and simulation was developed. Production strategy is an important CSF that would determine how successful ERP projects are in MTO environments. Literature review concluded that Workload Control (WLC) had promise in MTO (Stevenson *et al.*, 2005; Aslan *et al.*, 2011; Hendry *et al.*, 2010). WLC is based on Little's Law – 'Mean throughput time can be reduced by decreasing the mean WIP'. The three stages of WLC are customer enquiry, order release and dispatching. Further, WLC literature has limited mention of pure manual assembly lines which depend on skilled workforce and its availability. Often MTO SMEs do not have automated assembly line and here operator related factors underpin the release decisions. The release of work in an assembly line where tasks are manual and dependent on operator skills and their availability is a crucial decision. This research shows that simulation based DSS can help the end-user to make these decisions. Chapter 7 focuses on the design and development of a DSS to make order release decisions in pure manual assembly lines which depend on skilled workforce and its availability. It also contributes to the conceptual development of WLC.

7.2 The Model-WLC Concept

The successful implementation of Production Planning and Control (PPC) concept is affected by its suitability to a given production environment. Any approach developed needs to be dependent on key company characteristics such as production strategy (Thürer *et al.*, 2011). As a PPC concept, WLC has been primarily developed for high-variety and low-volume products produced on a MTO basis. It has been identified as particularly appropriate for SMEs with limited financial resources (Stevenson *et al.*, 2005; Land & Gaalman, 2009).

WLC can be divided into three tiers i.e. *dispatching*, *order release* and customer *enquiry management*. The most comprehensive WLC approaches incorporate control at the *dispatching*, *order release* and *customer enquiry management* stages to stabilise the level of Work-in-Progress (WIP) and lead times, enabling competitive prices and due dates (DD) to be quoted. The simulation model in Chapter 6 allows supports *customer enquiry management* using demand management evaluation against response functions such as cycle time, WIP, staff utilisation, priority, cost and material availability based on order book.

In this Chapter the release of work in an assembly line where tasks are manual and dependent on operator skills and their availability is considered. A probabilistic model is required in order to account for the various factors related to release decision. The stochastic technique of DE simulation is selected due to its capability of manipulating the variability and uncertainty of these factors. Simulation model was developed based on IDEF0 conceptual model. The model describes the release of orders to skilled operators in an assembly line on a daily basis. Resources i.e. operators are characterised by their availability, skill set, capacity, set-up time for a task; while attributes of the sub-assemblies are arrival time, processing time and product configurations. Logical entities have simulated the decisions for routing, space restrictions, buffering and branching entities. Each sub-assembly can visit any operator depending on their skill set and job availability.

Further, as per WLC concept, WIP levels are critical in MTOs and are directly proportional to mean throughput. Reducing the demand rate will result in decreasing the production bottlenecks. However, resource under-utilisation and slow production are drawbacks of this strategy. Similarly if the firm's priority is to increase labour utilisation, then increasing demand rate in parallel with reducing labour capacity are the optimal settings.

7.3 Aspects of WLC ERP Integration

The ERP system stores information on customer orders. The production orders are created in the ERP system but the ERP is not used for production planning purpose. The ERP/PPSS linkage is used to generate 'to make' and 'to buy' data and control/monitor production.

7.3.1 Manufacturing Environment

Various aspects within the manufacturing environment need to be considered while making the release decision. They have been discussed below:

- **Manual Assembly as Skilled Operator Work Centre**

All job routings during the assembly of the Autoclave are manual. The routing for all jobs is generally the same and a dominant flow exists. The production operations are purely labour intensive and require highly skilled workforce. By definition manual assembly is carried out by workers. This type of manufacturing system is human centred and its performance depends on performance of humans rather than machines. A consideration of human performance often becomes a situation of uncertainty when human workers or operators are involved in production. The production operations are purely labour intensive and require highly skilled workforce. Most of the assembly workforce at Company ‘A’ have been employed for many years and are experts in what they do. Henceforth in this chapter each skilled operator would be considered as a work centre and the terminology *skilled operator work centre* would be used.

Effective usage of labour resources is one of the most critical issues affecting the performance of WLC in such an environment. It is important to focus on a workforce management strategy from one that implements perfect divisions of labour to one that takes advantages of a skill based agile workforce (Wang *et al.*, 2013). Cross-training may be one way of improving flexibility of workers so that they can perform a number of tasks rather than a fixed task. Cross-training have many positive effects such as improvement of communication among workers, increase in job satisfaction, self-motivation and beneficial ergonomics such as less boredom, less repetitive stress and less fatigue. Regardless of these advantages cross training can however be expensive and also depends on individual interest. Further, production losses may occur due to the fact that each worker initially needs more time to reach and stabilise their proficiency levels. Wang *et al*. (2009) demonstrated the use of flexible walking worker in a conventional manual assembly line at Ford Motor Company. In this chapter a methodology to use certain workers referred as ’Key’ workers as flexible walking workers in a manual assembly line is explored. It is suggested that each ‘Key’ worker is cross-trained so that they are capable of individually completing all assembly tasks for an Autoclave by progressively moving along the routing of the job. Further, human factors including cognitive elements such as experience, IQ level or physical elements such as age, gender, and dexterity can affect individual performance of ‘Key’ workers (Wang *et al.*, 2009).

- **Planned Release Date (PRD) and Operation Completion Date (OCD)**

PRD: Sometimes orders in the pool might have a negative PRD (due to the Sales Department agreeing to a DD that did not comply with the DD calculated by the forward scheduling process). Those orders are considered urgent and are the first considered for release.

- **Workload**

The different workloads and major changes made to them compared to original WLC methodology are below:

- **Total Workload (TWL)**

  Potential orders awaiting confirmation were considered only for standard models. The complexity of the machines means the raw materials used are different and hence may not be always available or cannot be interchanged. Only standard Autoclaves without any options are considered as they can be offered to a different customer if the potential order awaiting confirmation did not materialise.

- **Planned Workload (PWL)**

  The workload of a job at a given *skilled operator work centre* is removed from the PWL when the job is effectively concluded and the information is updated in the ERP system by the operator. Lower and upper bounds for planned load limits needs to be set for planned workload control infrastructure as in original WLC methodology. Silva *et al.* (2014) considered only upper bound limits in their study. As per the production manager at Company 'A' the skilled operators get a *job list* for assembly jobs planned for the six weeks horizon. Not knowing what the lower bound limits should be for PWL can induce low workloads in the *job list* and this can cause productivity loss due to behavioural aspects. Some of the reasons observed were the apprehensions of being pulled for other low-skilled jobs such as stock counting, factory cleaning or maintenance. Job security is not usually the immediate fear as the firm keeps their skilled operators when order intake is low because of the cost and time required to train an operator. This case confirms what Silva *et al.* (2014) reported but also provides additional factors especially about highly skilled workforce and lower bound release limits.

- **Release Workload Control (RWL) Infrastructure:**

The release decisions are made on a daily basis as suggested by Silva *et al.* (2014) unlike the original WLC methodology. Greater reduction of WIP levels can be achieved by this design as at a given time only one job is released for a *skilled operator work centre*. Once the job is completed, it moves to the next stage in the job routing and worked on hence fewer traditional buffers are required. Lower and upper bounds were set for release workload control infrastructure. This is to ensure that there is enough loading at a *skilled operator work centre* during the span of the shift or day.

- **Space Restrictions and Buffers**

The company makes large machines and the sub-assemblies are large too. Hence space restrictions can significantly affect the no of subassemblies that can be made. Fewer traditional buffers are recommended. Sub-assemblies once completed are progressively moved to the next *skilled operator work centre* as per the routing where it is queued and prioritised as per the rule defined for that *skilled operator work centre*. Here daily release of work orders and the concept of 'Key' workers can help to reduce the build up of WIP as at a given time.

- **Absenteeism and Capacity**

Adjustability of staffing levels in response to unavailability of a *skilled operator work centre* is an important aspect to consider in such a manufacturing environment. The walking worker strategy also allows the employer to cope with employee absenteeism more effectively.

- **Job Routing - Skill Matrix & Availability**

In such a manufacturing environment the job routings are underpinned by the skills the various operators possess. Hence, the skill matrix needs to be considered while making daily release decisions.

- **Set-up time and Variable Working Speeds**

As the overall manufacturing performance can be significantly affected by the varying performances of the *skilled operator work centres i.e. operators* hence this needs to be considered while making these release decisions. Delphi Analysis was used by to identify set-up and processing time estimates.

- **Fixed and Walking worker: Training and Learning Curve**

As the performance of this type of manufacturing environment is heavily dependent on the skill set of the staff, their availability, working speeds and individual learning abilities so these factors need to be considered while making release decisions. Ideally all workers need to be cross-trained but in reality it can be difficult to train every worker to perform the same work content with equal efficiency. Further, some operators may not be interested to learn a new skill due to reasons such as age or long term benefits for them etc. Also, the financial considerations for the SME i.e. the increase of worker flexibility may incur additional costs that can counteract its benefits. Production losses may occur as each worker needs time to attain and stabilise their proficient levels in operations though learning and forgetting process. Finally flexibility of cross-trained workers plays an important role in making cost-effective decisions while realising jobs.

- **Batching**

Due the manufacturing environment and the diversity of Autoclaves it is often difficult to batch production. However, within machine groups sometimes certain sub-assemblies can be batched. Also, if a customer has ordered a quantity of more than one of the same machine with similar DD settings then the need of batching arises. Batching considerations also needs to be given for production jobs that require the similar tools or same colour in the painting process (Silva et al., 2014). Additional, the *skilled operator work centre* requires jobs to be batched while making the *job list* in the PWL.

- **Materials**

The status of raw material is given by the ERP system. This is considered in the release decisions. This was not considered by Silva *et al.* (2014).

7.3.2 Customer Enquiry Stage

A typical Autoclave consists between 110 to 200 parts. Generally orders arrive as repeat orders from a set of established customers/distributors. The sales department also sends quotations based on sales leads it generates or obtained from other paid sales lead generation services. The negotiation process with the customer is undertaken by the sales department. Here, the ability to quote reliable due date (DD) is paramount. In practice DD can be specified by the manufacturer or by the customer. In this study 75% of DD are specified by the manufacturer and the rest 25% by the customer hence both forward scheduling and backward scheduling are used. If the customer asks for a shorter lead time then usually this is accepted (especially if order intake has been poor) and it will be considered an urgent order. However, all orders are governed by the extent of design input required to make these Autoclaves. Roughly 50% of monthly order intake need design input and is a significant contributor to the overall DD. As controlled order release is used hence a pre-shop pool is used. The DD is defined by the following equation and is defined by the manufacturing department to the sales department.

DD = Design input + Pre-Pool delay + Already released but not started workload + Time required for each operation in the routing…….(Silva et al., 2014).

7.3.3 Order Release:

The current workloads of resources are considered when the release decisions are made. The ERP/PPSS linkage gives information on accepted orders, related production sub-assemblies, material status, production routing, processing times, capacity overloads, maximum allowed lead times for orders and the DD. The planner then decides which sub-assemblies would be made by which *skilled operator work centre*

The Operation Completion Date (OCD) and the Planned Release Date (PRD) are determined used backward scheduling. As in Silva *et al*. (2014), the PRD for each *skilled operator work centre* is determined by linking it with the OCD at the previous *skilled operator work centre* in the routing. This is like a pool with jobs awaiting release for each *skilled operator work centre*. The company accepts as many orders as possible but makes between about 18 to 25 Autoclaves per month and the release decisions are made manually. Each *skilled operator work centre* has an order pool and has a minimum and maximum worked norm.

- Minimum workload: Defined to avoid starvation. This generally matches the available hours a *skilled operator work centre* is available.
- Maximum workload: Defined empirically based on historical data and trial and error procedure. This value used several factors into consideration such as total time a *skilled operator work centre* including overtime is available, buffer capacity and space restrictions.

- **Release Decisions:**

Release decisions are taken on a daily basis based on the PRD and data from ERP/PPSS system. Orders are prioritised in the pool by considering several factors with the main factor being the PRD of the order. Release decisions are made in front of each *skilled operator work centre* using different rules to prioritise the jobs. Orders are released to maintain workloads between the minimum and the maximum limits recommended on each work centre. If necessary, to increase the number of orders that can be released or to expedite urgent orders, short term capacity adjustments are made. This may involve overtime, reallocating operators from an under-loaded to an overloaded work centre, or subcontracting jobs partially or fully.

- **Job Progress:**

For each order released, the released workload is updated. Once a job has been completed at a given *skilled operator work centre* the concerned operator changes the status of the job as closed in the ERP system at computer terminal in respective assembly lines. Once an order has been completed it moves to the next *skilled operator work centre* as per the routing where it is queued and prioritised as per the rule defined for that *skilled operator work centre*.

7.4 Model Layout

Analysis of release decision was done using DE simulation manufacturing platform from WITNESS. The model uses WITNESS features like part file, cycle time, push and match logic, tags, random and antithetic numbers, experimentation, Excel READ and WRITE array functions. Ability to incorporate real-time shop floor status was the key factor and data was collected and analysed for over three years at Company 'A'.

Orders from ERP arrive into Prototype Planning and Scheduling System (PPSS). PPSS gives the 'to make' and 'to buy' date. The 'to make' arrives in simulation model using 'part files'. In WITNESS 'part files' follow a definite structure. It contains default WITNNESS attributes part, quantity, arrival time, height, length and weight. Simultaneously the end-user can specify attributes as shown in Figure 7-2, where attributes like sales order number (SalesOrderNo), routing attribute as NAME, sub-assemblies such as 'CLoomandChassis' or 'CAssembleDoor'. Error analysis was done to find random errors in the cycle time and cost data from the ERP system.

7.5 Model Features

- Autoclaves are classified as three main product groups
- Each product group was divided into 16 sub-assemblies as shown in Table 7-1
- Three skilled cross-trained operators were considered

- Each operator could make any of the sub-assemblies under each product group. These are called as *skilled operator work centre*.
- Therefore

  Total no of *skilled operator work centres are defined as*

  = no of operator * product group * no of sub-assemblies

  = 3*3*16

  = 144 centres
- Also, 144 pre-pool buffers are defined
- One NAME attribute is defined. The values for NAME start at 1 and ends at 144. The NAME attribute controls the routing of the sub-assembly and tell the model which of the 144 work centres would process the job.
- PWL for each *skilled operator work centre* enters the model as parts and held in pre-pool buffers using *if-then-else* and *push* logics
- Parts are pulled from buffers using MATCH rule. The output for the buffer is set as FIRST which means the first part at the front of the buffer is removed

Model/Blocks / **Model/ Sub-Assemblies**	**Frame**	**Boiler**	**Pipe**	**Electrical**	**Door**	**Op Test**
CLoomandChassis				✓		
CPrepVsslPressTest		✓				
CAssembleDoor					✓	
CPressuretestVssl		✓				
CPutPressVsslFrame	✓	✓				
CPipeAutoclave			✓			
CWireAutoclaveFrame				✓		
CWireAutoclaveToRun				✓		
CTestAutoclave						✓
CFirstInspection						✓
CPrepAutoForSecInsp						✓
CSecondInspection						✓
CPrepandWrapAuto						✓
CPackAutoclave						✓
CSpecialLabour						✓
CP21Processing						✓

Table 7-1: Sub-Assemblies for Compact Product Group

- Labour is pulled from labour buffer using MATCH rule. The rule '*Use labour defined by part rule*' is used and as the machine uses a MATCH input rule, and labour is pre-empted from it. User can use this option to specify the machine that will wait until the same labour unit that was pre-empted from it becomes available again.
- The Autoclave is made progressively with each of the 16 sub-assemblies added to it as it gets completed. When all the 16 sub-assemblies for a product group are made it is processed by the respective product family machine. This is product family machine is modelled as ASSEMBLY machine with zero cycle time
- Three buffers are defined for finished goods
- Three integer variables defined to enable counting of the finished items made
- Time setting in month, week and hours & minutes
- One shift has 480 minutes with 60 minutes of rest during shift time and 960 minutes between shifts
- Cycle time for each product group is defined as a real variable. As with cost, this is initialised during the start of the model using excel READ array functions in WITNESS. Current model has cycle time for all three product groups related to three families COMPACT, QCS and RSC
- Cost for each block is defined as a real variable. This is initialised during the start of the model using Excel READ array functions in WITNESS. Current model has costs for all blocks related to COMPACT family.
- Skill matrix for each operator is defined and their variable processing time is estimated using Delphi analysis. These values are defined as a real variable and accounted for each *skilled operator work centre*. It is initialised during the start of the model using excel READ array functions in WITNESS. Current model takes into account the Variable Processing Time (VPT) for all three product groups COMPACT, QCS and RSC. The skills were estimated using Delphi analysis by the assembly workers, assembly supervisor and the production manager. Skills were graded in four categories with scores of 0, 1, 3 and 5, with '0' being the score if the operator cannot work on the job and 5 being the score if the operator is an expert on that job and can train others. The skill scores are given in Table 7-2 for 6 workers for sub-assemblies belonging to the COMPACT product group. The scores can be interpreted as:

- Operator is highly trained and can do job on time & train other so has a skill value of 5
- Operator has a lot of experience but is not as highly trained and so has a skill value of 3
- Operator is an apprentice who has just started and so has a skill value of 1
- Operator cannot do the task or was never trained on the job and has skill value of 0

Operator/ Skill Model/ Sub-Assemblies	MSCOM	MTCOM	DLCOM	DVCOM	STCOM	SCCOM
CLoomandChassis	0	0	5	3	0	0
CPrepVsslPressTest	5	5	0	5	5	1
CAssembleDoor	5	5	0	5	5	1
CPressuretestVssl	5	5	0	5	5	0
CPutPressVsslFrame	5	5	3	5	5	3
CPipeAutoclave	5	3	0	3	3	0
CWireAutoclaveFrame	0	0	5	0	0	5
CWireAutoclaveToRun	0	0	5	3	0	1
CTestAutoclave	5	3	0	3	3	0
CFirstInspection	5	3	0	3	3	1
CPrepAutoForSecInsp	5	5	0	3	3	1
CSecondInspection	5	3	0	3	3	1
CPrepandWrapAuto	5	5	3	5	5	3
CPackAutoclave	5	5	3	5	5	3
CSpecialLabour	5	0	5	3	3	0
CP21Processing	5	0	0	1	1	0

Table 7-2: Skill Matrix Obtained Using Delphi Analysis

Only three of these workers were identified as ‘Key’ Workers i.e. cross-trained. Further, using Delphi analysis an estimate was made into the Additional Processing Time (APT) required for each worker when their skill is not 5 for a given sub-assembly. The APT was estimated by Delphi Analysis as 0.5 * Processing Time (PT) when the skill was 3 and as 2* Processing Time (PT) when the skill was 1. As fresh data starts getting recorded in the ERP these estimates were reviewed periodically. This is shown in Table 7-3

- Buffers have a maximum capacity of 100 for each block. This is almost 100% more than Company 'A' requirements for a month based on historical data.
- 'Part' and 'Excel' files allow appropriate staff to
  - Edit priority: As shown in Figure 7-1 the production manager can change the priority of the order by changing the required order DD in the ERP
  - Edit routing: As shown in Figure 7-2 the production manager can edit the labour quantity depending upon the availability of staff
  - Edit material: Often stock control is an issue in SMEs and ERP stock values do not match shop floor values. The end-user can correct any such instances as shown in Figure 7-3

Operator / Additional Time / **Model / Sub-Assy.**	PT (Mins.)	APT (Mins.) for MSCOM	APT (Mins.) for MTCOM	APT (Mins.) for DVCOM	APT (Mins.) for DLCOM	APT (Mins.) for STCOM	APT (Mins.) for SCCOM
CLoomandChassis	300	0	0	0	150	0	0
CPrepVsslPressTest	90	0	0	0	0	0	180
CAssembleDoor	30	0	0	0	0	0	60
CPressuretestVssl	60	0	0	0	0	0	0
CPutPressVsslFrame	30	0	0	15	0	0	15
CPipeAutoclave	120	0	60	0	60	60	0
CWireAutoclaveFrame	90	0	0	0	0	0	0
CWireAutoclaveToRun	150	0	0	0	75	0	300
CTestAutoclave	180	0	90	0	90	90	0
CFirstInspection	30	0	15	0	15	15	60
CPrepAutoForSecInsp	180	0	0	0	90	90	360
CSecondInspection	30	0	15	0	15	15	60
CPrepandWrapAuto	120	0	0	60	0	0	60
CPackAutoclave	60	0	0	30	0	0	30
CSpecialLabour	0	0	0	0	0	0	0
CP21Processing	60	0	0	0	120	120	0

Table 7-3: Additional Processing Time Using Delphi Analysis

Part	Qty	Arrival Time	WITNESS Attribute	User Attribute	User Attribute	Routing Attribute
PART1	0	1	height=6	Attributename=CPipeAutoclave	SalesOrderNo=1000001	NAME=6
PART1	1	1	height=9	Attributename=CTestAutoclave	SalesOrderNo=1000007	NAME=9
PART1	1	1	height=9	Attributename=CTestAutoclave	SalesOrderNo=1000001	NAME=9
PART1	1	1	height=9	Attributename=CTestAutoclave	SalesOrderNo=1000017	NAME=9
PART1	1	1	height=10	Attributename=CFirstInspection	SalesOrderNo=1000001	NAME=10
PART1	1	1	height=10	Attributename=CFirstInspection	SalesOrderNo=1000007	NAME=10
PART1	1	1	height=10	Attributename=CFirstInspection	SalesOrderNo=1000017	NAME=10
PART1	1	1	height=12	Attributename=CSecondInspection	SalesOrderNo=1000001	NAME=12
PART1	1	1	height=15	Attributename=CSpecialLabour	SalesOrderNo=1000001	NAME=15
PART1	1	1	height=16	Attributename=CP21Processing	SalesOrderNo=1000001	NAME=16
PART1	1	1	height=12	Attributename=CSecondInspection	SalesOrderNo=1000007	NAME=12
PART1	1	1	height=15	Attributename=CSpecialLabour	SalesOrderNo=1000007	NAME=15
PART1	1	1	height=16	Attributename=CP21Processing	SalesOrderNo=1000007	NAME=16
PART1	1	1	height=12	Attributename=CSecondInspection	SalesOrderNo=1000017	NAME=12
PART1	1	1	height=15	Attributename=CSpecialLabour	SalesOrderNo=1000017	NAME=15
PART1	1	1	height=16	Attributename=CP21Processing	SalesOrderNo=1000017	NAME=16
PART1	1	1	height=2	Attributename=CPrepVsslPressTest	SalesOrderNo=1000001	NAME=18
PART1	1	1	height=2	Attributename=CPrepVsslPressTest	SalesOrderNo=1000007	NAME=18
PART1	1	1	height=2	Attributename=CPrepVsslPressTest	SalesOrderNo=1000017	NAME=18

Priority and Routing/Skilled operator work centre are user defined

Figure 7-1: Simulation Model User-Defined Order and Work Centre Priority Settings

- Edit routing: As shown in Figure 7-3, the production manager can edit the labour quantity depending upon the availability of staff
- Edit 'cycle time' where required: End-user can edit the cycle time in the Excel READ array sheet when a particular task is expected to take more time due to material, manpower or breakdown issues.

User can edit material availability

Part	Qty	Arrival Time	WITNESS Attribute	User Attribute
PART1	0	1	height=6	Attributename=CPipeAutoclave
PART1	1	1	height=9	Attributename=CTestAutoclave
PART1	1	1	height=9	Attributename=CTestAutoclave
PART1	1	1	height=9	Attributename=CTestAutoclave
PART1	1	1	height=10	Attributename=CFirstInspection
PART1	1	1	height=10	Attributename=CFirstInspection
PART1	1	1	height=10	Attributename=CFirstInspection
PART1	1	1	height=12	Attributename=CSecondInspectio
PART1	1	1	height=15	Attributename=CSpecialLabour

Figure 7-2: Simulation Model User-Defined Material Settings

Operator	Qty	
		Where,
MSCOM	1	1 = Available
MTCOM	0	0 = Not Available
DLCOM	1	
DVCOM	1	
STCOM	1	
SCCOM	1	

mscomskill	mtcomskill	dlcomskill	Orders	LabourQty
0.0	0.0	0.0	1000001	1
0.0	0.0	0.0	1000007	0
0.0	0.0	0.0	1000017	1
0.0	0.0	0.0	1000004	1
0.0	0.0	0.0	1000005	1
0.0	30.0	30.0	1000006	1
0.0	0.0	0.0	1000007	
0.0	0.0	0.0	1000008	

Figure 7-3: Labour Availability and Control

- Crystal Reports (CR) add-on automates creation of WITNESS 'part files'.

Feature	Element	Qty	Details
Part1	Passive Part	1	Arrival of parts is controlled by part files *arrival1, arrival2, arrival3, arrival4, arrival5 & arrival6.*
MAS, MT and DL	Labour	1	Labour availability is read from Excel file. This allows the user to control routing and handle demand variations and absenteeism.
Arrivals 1 to 6	Part File	6	Data from ERP and ERP-PPSS linkage is exported as *text* file using Crystal Reports add-on. This export is automated and happens at regular intervals.
Arrival Buffers	Buffer	48	Each sub-assembly has its own buffer for example ms1 or mt7 or dl4.
Autoclave Sub-Assemblies	Machine	48	Each product range has 16 sub-assemblies for example in COMPACT range there is CLoomandChassis or CAssembleDoor. They are shown as single machines which pull the part from the Arrival Buffers and once processed pushes it to the Finished Sub-Assembly Buffers
Finished Sub-Assembly Buffers	Buffer	3	Sixteen sub-assemblies made by different *skilled work centre* are sent to relevant product group buffers such as COMPACTBuffer, QCSBuffer or RSCBuffer.
Autoclave Assembly	Machine	3	Three product range (COMPACT, QCS and RSC) made by Company ‘A’ are modelled as machines CAASY, QASSY and RASSY with ‘zero’ cycle time
Cycle Time(CT)	Variable Real	48	The expected cycle time for each sub-assembly done by an operator with skill 5 for a sub-assembly is accessed into the model via excel READ array function.
Cost	Variable Real	48	Each sub-assembly has its own cost. E.g. CLoomandChassis cost is updated from the ERP via excel READ array function.
Labour Quantity	Variable Real	3	The availability of each skilled operator can be controlled in the model. It is accessed into the model via excel READ array function.
Additional Processing time	Variable Real	48	The additional cycle time for each sub-assembly processed by an operator with skill less than 5 for a sub-assembly is accessed into the model via excel READ array function. E.g. *mscomskill* or *mtcomskill*
Job id	Variable String	1	*SalesOrderNo* is used to identify each job
User Attribute	Variable String	1	*Attributename* used in part file to define the names of all the 16 sub-assemblies in the model
User	Variable	1	*Name* used in part file

Feature	Element	Qty	Details
Attribute			
Shipped Quantity Counter	Variable	3	The no of items shipped in a month is counted for each product group

Table 7-4: Model Simulation Element Details

All these features and the model layout are shown in Figure 7-4.

7.6 Model Experiments and Results

WLC has two stages, customer enquiry stage and order release (order release and dispatching) stage. Previous chapter showed how by integrating DE simulation and traditional production planning methods such as PPSS, it is possible to forecast required workloads within given input values. The DE simulation model overcomes the inability of ERP systems in decision-making based on real-time data to support Customer Relationship Management (CRM) activities such as setting Due Dates (DD).

As production strategy is an important CSF for MTO SMEs during ERP projects, the release of production jobs is a crucial decision in manual and operator skilled based MTO environments. The simulation model with its graphical user interface makes it possible to visualise potential bottlenecks during the routing of a job. It enables to minimise WIP as each operator is working at one job at time.

When the model is run, initialise actions: check the experiment count, excel READ array inputs cycle time and cost data, part files enter the model. The sequence of jobs in the part files is controlled by production manager. This is primarily controlled by PRD, OCD, operator availability, operator skills, batching needs and space requirements. Within the part file the 'NAME' attribute specifies which '*skilled operator work centre'* will process the sub-assembly. Accordingly the subassemblies are pushed to different 'Arrival Buffers'. At this stage 'tags' with job id i.e. 'SalesOrderNo' attribute become visible. As the *'skilled operator work centre'* is set up as a machine it looks for released jobs in its dedicated 'Arrival Buffers'. The 'Arrival Buffers' have their dispatching rule set to First In First Out (FIFO). The MATCH function pulls relevant sub-assembly for processing based on the cycle time. The sub-assemblies for an Autoclave are processed by different *skilled operator work centres.* This release decision is made by the production manager based on

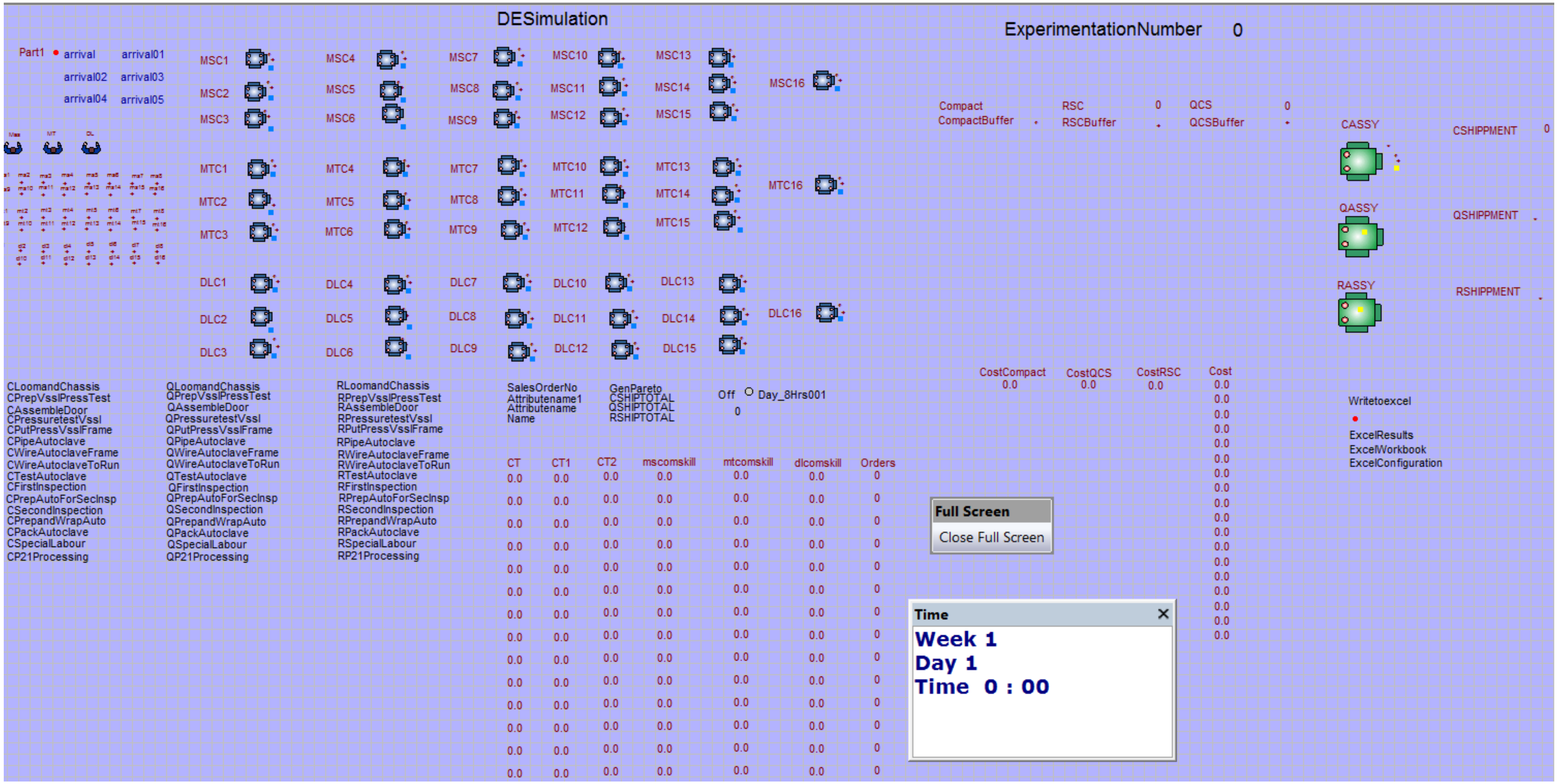


Figure 7-4: Production Strategy Simulation Model Layout Features

factors such as availability and skill set of the operator, space restrictions and batching needs.

As the sub-assemblies are made they are pushed to the relevant product buffer 'Finished Sub-Assembly Buffers'. The assembly of Autoclave is modelled by using an Assembly machine with zero cycle time and MATCH function. The MATCH function pulls the relevant unique 16 sub-assemblies from the 'Finished Sub-Assembly Buffers' and with the job id i.e. 'SalesOrderNo' attribute. Model validity was checked by staff validation. A real-time shop validation needs to be carried out for cycle time. Currently, the validity of the model was checked with expected completion time. The results came within 2-11% tolerance of ERP data.

After identifying confidence in the model i.e. the model represents the behaviour of the real-life situation, a number of what-if scenarios can be investigated. The scenarios defined within the original objectives of the simulation study such as support release of production jobs based on near real time production status.

7.6.1 Scenario 1

Operators are not cross-trained and move along the routing to make a sub-assembly of the Autoclave.

The following parameters were selected for the test.

1. Three operators were selected from a pool of six operators. Using first letters from their full names they are identified as MAS, MT and DL
2. They original cycle time (mean time) to complete a COMPACT product group assembly was identified as 25 hours. This was based on the mean cycle time operator MAS with skill score 5 had demonstrated.
3. The work content across each of the 16 work centres was the same.
4. The jobs were sent to the order release pool based on Planned Release Date (PRD), Operational Completion Date (OCD), availability and skill of operators.
5. Three jobs consisting 1000001, 1000007 and 1000017 consisting of 16 sub-assemblies from the COMPACT range were released into the 'Arrival buffer'.
6. Based on present skill set and availability of operators the jobs were routed to respective *skilled operator work centres*
7. The cycle time, skill based Additional Processing Time (APT), labour availability and material availability information were accessed when the model was initialised. The

three jobs were completed in 5085.01 minutes i.e. 84.75 hours. In an ideal scenario this should have been 75 hours if we look at the mean time to complete the assembly.

8. An important factor is the utilisation of each worker. The utilisation of each worker is the percentage of the time the worker has been used for the planned production shift. The utilisation for the three skilled operators was recorded as below. These results were obtained based on a five working day per week with a single shift and with the same number of workers.

Name	% Busy	% Idle	No. Of Jobs Started	No. Of Jobs Ended
MT	100	0	13	13
MAS	43.77	56.23	14	14
DL	88.68	11.32	13	13

MT= Operator 1, MAS = Operator 2, DL= Operator 3

Table 7-5: Operator Utilisation Values

7.6.2 Scenario 2

All Key workers are cross-trained and move along to make the entire Autoclave

All the parameters in 7.6.2 were kept except:

1. Three operators MAS, MT and DL were selected as ‘Key' operators from a pool of six operators
2. The cycle time, skill based APT, labour availability and material availability information were accessed by during model initialisation. The three jobs were completed in 4891.01 minutes i.e. 81.51 hours. This is 3.2 hours less than the mean time to complete the assembly when Key workers were not considered.
3. The utilisation for the three Key operators was recorded in Table 7-6.

Name	% Busy	% Idle	No. Of Jobs Started	No. Of Jobs Ended
MT	100	0	14	14
MAS	75.65	24.35	11	11
DL	100	0	14	14

MT= Operator 1, MAS = Operator 2, DL= Operator 3

Table 7-6: Operator Utilisation Values

4. The utilisation for operators MAS and DL improved by 31.33% and 11.68% respectively.

7.7 Discussion

On the DSS models developed in chapter 6 and 7, experiments were performed. This is done by changing the input parameters to conduct 'what-if' scenarios as shown in section 7.6.1 and 7.6.2 and predicting the response. This enables to address the first part of WLC i.e. order enquiry. The DSS supports order enquiry analysis by showing when the order will be completed and what effects the new order will have on the system. Simulation models can be used for constraints or unlimited capacity analysis. Capacity constraints could be used to show when the order will be ready and how late it will be identifying the reason for lateness such as shortage of material, overload in resources or absenteeism of staff.

MTO SMEs can have manually intensive assembly lines. Under these circumstances the individual operator's availability and skills are two crucial factors. Jobs can be analysed with unlimited capacity with the analysis showing the amount of resources needed in order to keep customer promise. Production manager has an option to add additional labour for critical phases. The model's integration with the ERP system also checks the availability of critical materials. *Ideally, it should check the stock values versus ordered components and indicate whether materials may run out at certain time in the future.* The DD in the ERP system are managed to change the PRD.

The simulation model's accuracy and efficiency are verified by decomposition method and using the simulation software debugger, face validation by interviewing production manager and manufacturing teams. Further 'comparison testing' by comparing the model output with the system output under identical conditions can be used.

7.8 Benefits

The DSS related to the production strategy overcomes some of the inability in traditional production systems such as infinite resources and inability of ERP system to aid in near real time decision-making. Firstly, a PPSS for a MTO manufacturing environment was developed using Microsoft Excel at Company 'A'. The data for the PPSS comes from the ERP system. The ERP system has a window to communicate with the PPSS. The ERP system links service and manufacturing operations and provides effective component stock control and traceability. The ERP-PPSS linkage generates the 'to make' and 'to buy' data. The 'to make' data then links to a DE simulation model to form a DSS. This provides feasible production schedules in terms of capacity overloads and maximum allowed lead times of orders. The models developed in Chapters 6 and 7 enable to implement the customer enquiry and order release tiers of WLC control. The models developed in Chapters 5, 6 and 7 enable the formation of a DSS to manage CSFs such as production strategy and CRM activities in an SME MTO environment.

7.9 Summary

A WLC order release DSS based on DE simulation considering operator availability and skills along with PRD, OCD, space limitations was developed. The model overcomes the limitations of other WLC empirical studies where capacity was considered a constant and the material management was not considered. The capacity could be changed because of the manual assembly nature of the MTO SME. The model integrates with the PPSS-ERP model developed in the previous chapter which handles the customer enquiry stage of the WLC. The orders are sequenced by the production manager to different *skilled operator work centres* based on their availability and skills. The end user can edit the release decision to counter any unplanned event such as absenteeism. Face validation was conducted to ensure validity. Further development should study explore case studies on OEM MTO's where assembly lines are purely manual and skill based.

Chapter Eight: Discussion and Conclusion

8.1 Research Discussion

The section will discuss the literature review, research methodology and the results from the study.

8.2 Literature Review

Chapter 2 reviewed concepts related to Make-to-Order (MTO) manufacturing, Enterprise Resource Planning (ERP) systems and Decision Support System (DSS). Some of the important points are summarised as follows:

- ERP system projects are not just IT projects but are continuous projects. These systems are made from traditional MRP systems. ERP markets in Large Enterprises (LEs) have saturated and ERP vendors since mid 2000's have modified their products to suit SMEs. Often these packages are similar to the ones used in LEs but SMEs are different from LEs. There is a generalisation issue in ERP packages made for SMEs. Hence, it is not surprising that almost 40 to 57% of ERP projects fail to realise any benefit or run over budget or overtime (Zach *et al.*, 2011).
- Critical Success Factors (CSFs) are not well defined in ERP projects in SMEs. (Ahmad & Cuenca, 2013; Leyh, 2012; Zach & Olsen, 2011). Interrelations between CSFs and ERP project phases are not clear in published literature. MTO SMEs have different requirements from ERP projects than Make-to-Stock (MTS) SMEs. Production strategy is an important CSF in MTO environment.
- ERP project system evaluation and achievement is complex and needs further research.
- DE simulation is not a panacea for all issues, nor is it only to aid decision-making. DE simulation and traditional technologies such as MRP can aid the human scheduler. However, use of DE simulation usage in SMEs is limited with some case studies related to ERP project achievement evaluations and lean strategies. Data integration with ERP or manufacturing system is vital for DE simulation to be effective.
- Work Load Control (WLC) has potential in MTO SME environment. Customer enquiry and order release via pre-shop pools are important aspects of WLC. However, use of WLC in manual assembly lines dependent on operator skills in SME MTO environment is not documented.

8.3 Research Methodology

For this research the interpretive paradigm was chosen which lead to the selection of an appropriate research method. As part of a KTP project the research was exploring answers to ERP implementation, impact of Critical Success Factors (CSFs), utilisation of ERP, benefits and challenges of ERP systems in Make-to-order (MTO) SME context, thus it is interpretive in nature (Myers, 1997). The positivist paradigm was not chosen due to its restrictions when dealing with people and capturing their social beliefs i.e. subjectivity. As far as the research approach goes a mixed approach involving both qualitative methods in a descriptive manner and as well as quantitative research methodology was used.

Considering the research objectives and the characteristics of the challenges facing the Company ‘A’ action research were assessed to be the most appropriate research strategy. Action research is a widely used strategy for Information Science (IS). The ERP system at Company ‘A’ was implemented with high involvement from both researchers and company. The ERP project was driven by the company’s agenda and company representatives collaborated fully with the researcher in all phases of the project. In terms of the research objectives this resulted in deeper and more valid data than data gathered in researcher-initiated projects (Schein, 2006). This increased the practicality and workability of the implemented solutions, and ultimately the quality of the final methodology. Some experts hold the view that action research is unique because it is context-bound and involves action which is designed to change local situations. The researcher is involved in the research process which underpins practice and knowledge is generated from practice. Co-learning was an important aspect of this research. The KTP collaboration enabled to understand the organisation, its requirements and to work concurrently with the members of the organisation in changing it to what was jointly regarded as a sought-after direction. This research strategy enabled a holistic and issue-solving approach, rather than a single method of collection and analysis of data.

The framework of the research methodology was supported by literature review, the KTP project, various tools such as; Delphi analysis, observation and open ended interviews, Integrated Definition for Function Modelling (IDEF0), Discrete Event simulation using WITNESS software, Microsoft Excel, Crystal Reports, Project Management Tools. The led to identifying two areas of study. The first was to study CSFs and ERP systems in

MTO organizations. The second study was to manage production strategy using a three tier Decision Support System (DSS).

8.4 Research Results

Chapters 4-7 demonstrated the development of a two DSS models in a MTO SME manufacturer Company 'A' to address some of the above questions. Company 'A' is implemented an ERP system via a 30-month Knowledge Transfer Partnership (KTP) project. ERP systems projects have CSFs. Production strategy and linked to it Customer Relationship Management (CRM) activities in MTO environment are important CSFs, apart from other management, people, or system related CSFs. The DSS developed in chapter 4 studies the interrelationship of CSFs which supports successful implementation of an ERP system. A three stage DSS model was developed in Chapters 5-7 to study production strategy and CRM activities as CSFs.

The DSS related to the production strategy overcomes some of the inability in traditional production systems such as infinite resources and inability of ERP system to aid in near real time decision-making. Firstly, in Chapter 4 a DSS related to interrelationship of CSFs enables the end-user or ERP project team to visualise the near real time CSF relationships. Using DE simulation it is possible to forecast required CSFs within given input values. The simulation model and the developed graphic user interface make it possible to visualise potential delays during an ERP project stage. The interrelationships of over thirty CSFs were modelled. Attributes like sequence, time, cost, and resources such as team are simulated. All these attributes are controlled via excel or text files; hence it is possible for the user to manipulate the DDS from a known platform. Users can determine the attributes of the CSF from real-time data and visualise the inter-relationships of CSFs during phases of the ERP project. Currently four stages of the ERP project i.e. Initialisation, Adoption, Adaption and Routine are modelled. Data on the last stage i.e. Retirement is scare, as most of the firms have not yet reached this stage of an ERP project

In Chapter 5, a PPSS for a MTO manufacturing environment was developed using Microsoft Excel at Company 'A'. The data for the PPSS comes from the ERP system. The ERP system has a window to communicate with the PPSS. The ERP system links service and manufacturing operations and provides effective component stock control and traceability. The ERP-PPSS linkage generates the 'to make' and 'to procure' data. The 'to make' data then links to a DE simulation model to form a DSS as shown in Chapter 6.

Feasible production schedules, in terms of capacity overloads and maximum allowed lead times of orders are generated. The schedules generated identify jobs or orders with varying routings, set-up times, materials, and labour requirements. They also cover a time period to the extent of known firm orders. This information supports the first tier of Workload Control (WLC).

Later in Chapter 7, the second tier of WLC i.e. release aspect of WLC logic in pure manual assembly lines is covered. The system uses no programming and provides flexibility, user-friendliness, and it suits to the customised production approach of Company ‘A’. There are other benefits of the developed system such as affordability, maintainability and future expansion capability. The linkage of PPSS, ERP, WLC and DE simulation model is generic in nature, as parameter settings are user-defined. The integration of this DE simulation based DSS is done via user-friendly platforms such as Microsoft Excel and ASCII text files.

The DSS models have been developed and tested in an SME MTO environment. Future improvement to this research should cover automatic creation of the DE simulation based DSS models using Microsoft Excel. Further, *retirement* stage in an ERP life cycle should be incorporated in the DSS using data from firms who have migrated to a different ERP system or ERP vendor. Also, the validity of the DSS should be tested with data from another MTO SME for the Initialisation, Adoption, Adaption and Routine stages.

A successful ERP project implementation was carried out at Company 'A' by managing ERP related CSFs and their interrelationships in a continuous manner both during and after the ERP project. Key CSFs related to the MTO SME such as production strategy and CRM activities were continuously managed. The feedback and results obtained have been encouraging. It is hence strongly emphasised that such an approach of continuous management of CSFs during and after ERP implementation will help more firms to realise benefits from an ERP project.

8.5 Main Contribution to Knowledge

The research work has made a number of contributions to knowledge. The originality of the research contributions can be categorised into 4 main themes; the research findings in terms of data and results, research method pursued, knowledge transferability and the developed DSS’s capability.

Contribution to knowledge in terms of data and result

In terms of data and results, the research has provided an understanding of how to generate data relevant to CSFs in managing ERP projects within SMEs. This is important as the obtained data provided the research with a unique opportunity for understanding and managing CSFs for ERP project within MTO SMEs. By managing CSFs, it is possible to realise ERP benefits. In turn, this allows one to analyse the impact of ERP project within SMEs. The use of simulation to study CSFs and inter-relationships during ERP projects in SMEs discussed in Chapter 4 enabled the end-user or ERP project team to visualise the near real time CSF relationships. The simulation model overcomes the inability of ERP systems in decision-making based on real time data. A further contribution to knowledge in terms of research findings is the concept of key worker in assembly lines within MTO manufacturing SMEs and the use of simulation to make release decisions. These findings have been published in peer reviewed journal and internationally recognised conference proceedings.

Contribution to knowledge in terms of research method pursued

The second research contribution comes from the selected research method adopted while developing the Decision Support System (DSS) framework. Real-world engineering problems are complex both in the identification and problem definition. The KTP program allowed the use of a hybrid research method in developing the DSS framework for ERP project within SMEs. This approach allowed the researcher the opportunity to work both within the academic and industrial contexts. The systematic research method pursued enabled the research investigation to achieve targeted goals. It was possible for analytical assessments to be made as to whether the course of action was appropriate for a particular problem. For example, the KTP allowed the research to be undertaken within an academic setting while the specific real-world research problem was being defined. It was accomplished through literature review. Thus, findings from the literature review provided research gaps that underpinned the course of this research work.

Contribution to knowledge in terms of knowledge transfer

The developed DSS for ERP implementation within SMEs provides practitioners with an efficient tool for aiding decision-making process. Hence, it may be fair to assert that the tool may also facilitate other MTO SMEs to solve problems within their manufacturing environments. This inference may be derived from the developed DSS's capability in managing different CSFs to realise ERP benefits. However, to achieve this objective, it should be realised that CSFs within the DSS need to be readjusted in order to accommodate individual SME needs. An example would be in the context of the DSS ability to assess CSFs impact within a particular SME. Here, the original design considered the implementation of ERP within MTO SMEs considering production strategy and the concept of key workers. Thus, for the developed DSS to achieve the objective of conducting similar tasks within another organisation, it would require a calibration of the key worker assessment features to consider company specific needs.

Contribution to knowledge in terms of the developed DSS's capability

The research study has provided an original DSS for managing ERP projects and realising the impact of ERP systems in MTO manufacturing SMEs. The DSS is intended to aid practitioners for ERP implementation in SMEs. The CSFs analysis allows the project team to visualise the interrelationships of CSFs during an ERP project. The contribution will therefore be beneficial to MTO SMEs in several ways. In the author's opinion, no significant literature demonstrates similar work elsewhere. This assertion can be deduced because of the developed system's capability to perform the following;

The literature review identified that research on ERP implementation technique within SMEs is still limited (Ahmad & Cuenca, 2012; Ali et al., 2012; Aslan et al., 2012; Sun et al., 2005; Zach & Olsen, 2011). It concluded that there exists a research gap from an SME perspective (Ahmad & Cuenca, 2012; Leyh, 2012; Zach & Olsen, 2011). This research addresses this gap by setting the results from a UK based SME within a MTO sector.

The literature review recognised that CSF interrelationships are not well covered and only a few studies provide ERP CSF definition (Nazemi et al, 2011). There exists a need to think ERP implementation as a dynamic and continuous process aligning management technique and as an organisational culture. The research addresses this gap by developing a methodology where CSFs and interrelationships are managed in a continuous manner.

The literature review suggested the need to focus on specific organisational issues based on size and type, especially manufacturing strategy. It concluded with a need to consider production strategy as CSF Zach & Olsen (2011). This research addresses this gap by considering production strategy as a CSF within an MTO manufacturing sector during and after ERP implementation. Workload Control (WLC) based release decisions in pure manual assembly lines from SME perspective was considered.

The literature review identified those CRM utilisations in MTO sector needs to be explored further. Like production strategy, CRM is an important CSF for a firm's successful ERP implementation. WLC embedded in ERP can improve the functionality of the ERP system. This work addresses this gap by considering lead time based CRM activities as a CSF within an MTO manufacturing sector during and after ERP implementation.

The DSS allows MTO SMEs to manage ERP projects during various project phases and realise benefits of an ERP system post implementation.

8.6 Research Limitation

One of the limitation of this study is that it was conducted at only one firm i.e. Company 'A' a UK based SME manufacturer. The proposed design methodology should be applied to other manufacturing environments and industries. This can validate the robustness of CSF model with data from another MTO manufacturer implemented. Another limitation is that the 'Retirement' phase of an ERP system could not be verified as Company 'A' is yet to reach that stage. Ideally, this methodology should be tested in a SME firm which is migrating from one ERP system to another.

8.7 Conclusion

The Knowledge Transfer Partnership (KTP) initiated this research. The research investigated Critical Success Factors (CSFs) in ERP implementation in Make-to-Order (MTO) SMEs. This involved investigating various environments in which ERP systems are implemented. The inter-relationships of CSFs and how they could be managed during and after an ERP implementation assisted in the creation of the proposed design methodology. The methodology supported various facets of the CSFs involved as per ERP implementation stage, environment, management and technical issues.

The research objectives have been satisfied by testing the methodology to the diverse requiring case study in an MTO SME manufacturing environment thus demonstrating the design methodology flexibility.

As part of this research various objectives were set. These objectives were achieved in Chapters 4, 5, 6 and 7. Critical Success Factors (CSFs) underpin ERP projects. There exist many CSFs related to people, management, system and software. Critical Success Factors (CSFs) underpin ERP projects. There exist many CSFs related to people, management, system and software. Production strategy is an important CSF in MTO SMEs. CSFs are subjective and their interrelations are not always clear. The proposed design methodology created from this research developed two hybrid Decision Support Systems (DSS) incorporating DE simulation.

The first DSS developed is used to study the different inter-relationships between CSFs during ERP implementation. The success of the design methodology to manage the various CSFs and inter-relationships is measured against the completion of the ERP stage or process within an ERP implementation project. The DSS related to study of CSFs aids to understand and visualise the interrelationships of over thirty CSFs. Users can determine the attributes of the CSF from real-time data and visualise the inter-relationships of CSFs during phases of the ERP project.

- For example at Company 'A' Service Order processing is fully integrated with Service Engineer Outlook diaries linked to the system. For this process the various CSFs and CSFs and inter-relationships were managed using the concept explained in Chapter 4. Invoicing times down from 6-8 weeks to 1 week, improving cash flow. Previously up to £30,000 of work was un-invoiced with £800 per month spent on staff overtime to catch up.

The second DSS is related to managing production strategy as a CSF in ERP projects. This model incorporates with traditional technologies such as MRP I, MRP II along with Workload Control (WLC) within the MTO context. As a tangible benefit of the ERP system, a three stage Decision Support System (DSS) was developed. A prototype production planning and scheduling system (PPSS) using Microsoft Excel formed the first stage. This gave the 'to make' data. The second stage involved using DE simulation model to form a PPSS-ERP linkage for manufacturing lead-time analysis in MTO environment for Customer Relationship Management (CRM) activities and planning. The model allows the user to determine and edit priority, material, routing, labour and cycle time for customer orders. Using random and antithetic random numbers experiments runs were made to prove the repeatability and reliability of the models. The final stage involved managing the job release decisions in purely manual assembly lines requiring high skill level. Work Load Control (WLC) logic was incorporated to the DSS considering dynamic parameters such as key workers as a work centres and unbalanced distributions skill and set-up characteristics. This can augment the task of planners and schedulers to run production more efficiently in MTO SME environment and improve the percentages of firms who realise the benefits of ERP implementations.

Few of the benefits due to managing production strategy as a CSF can be summarised as

- Sales quotation process integrated with the DSS. The second DSS is used to confirm expected lead time based on current load in the shop and resource availability.
- Managing production strategy as a CSF. At Company 'A', all manufacturing is now fully integrated into the ERP. Production orders are generated on the system. Stock is booked "live" on the factory floor. Stock levels are now measured not estimated. Prior to this research the variance between counted and estimated stock values after annual stock-take could be up to £40,000. Post ERP this is £5,000 and continuing to improve. Commencement of continuous inventory checking to, in future, eliminate 2 day (£ 3,000 in labour costs alone) annual stock-take.

These two DSS have demonstrated the versatility and flexibility of the proposed methodology. This study will help industry to understand how important it is to identify CSFs in ERP implementation and to manage ERP interfaces with planning and scheduling entities. This work has enabled the researcher to acquire skills and knowledge, which are essential to implement ERP projects and develop credible simulation models for effective use of ERP data in making real time decisions.

8.8 Future Work

This section discusses and highlights future work that is either a direct result of the design methodology used or from the literature review. The areas of research that could be investigated in the future are summarised here.

- **Case Study Application:**
  - Immediate future work would be to apply the proposed design methodology to other manufacturing environments and industries. The robustness of CSF model will be tested with data from another MTO manufacturer. 'Delphi' analysis, a

Project Management Institute (PMI) methodology, should be used to build consensus on CSFs inter-relationships. This should be enforced with statistical best-fit distribution analysis and goodness of fit analysis for these distributions using Kolmogrov-Smirnov ranking methodology of variable data such as CSF arrival time and cost at another MTO firm.

- **Team composition and skills within ERP CSFs DSS**
    - Additional attributes such as implementation team composition and skills should be modelled. Especially, skills related to change management and user acceptance modelling. Often in SMEs, there are employees who have been working since the start of the firm and are not so keen on change. They may not fully co-operate and this needs an exceptionally high level of change management skills. Future work should involve extending the function of the model to include attributes like goal achievement.
- **Developing Areas within Workload Control**
    - Research shows that Workload Control (WLC) has potential use in Make-to-Order (MTO) environment. Within WLC the release of work is a crucial decision. This Decision Support System (DSS) developed can support this release decision. However, in this research batch processing of jobs was not taken into consideration while making the release decision. The future research should incorporate Workload Control (WLC) with batch processing in a manual assembly type MTO SME environment.
- **Topics to Develop within DE Simulation**
    - Further, other challenges identified such as automated simulation model creation and visualisation of results for interactive decision-making should be explored. Automatic creations of models from Microsoft Excel files should be explored. This has a lot of potential as the end-user will have to just change parameters in the Excel files that are a familiar platform for end-users who do not have simulation skills. This will enable non-simulation users to use the system and SMEs can access simulation as a Software As Service (SAS). A main hurdle to this would be data integration.
    - Further work needs to improve the process of obtaining and storing of text files related to the bill of materials for products and work-in-progress. In this research this process required manual intervention. On a daily basis this could be time

consuming and this process should be automated probably by connecting to the ERP database itself. These integration enhancements and its implementation are further research goals.

REFERENCES

Ahmad, M.M. and Cuenca, R.P. (2013), "Critical success factors for ERP implementation in SMEs", *Robotics and Computer-Integrated Manufacturing*, Vol.29, Issue 3, pp.104-111.

Ahmed, M.E. and Latif, M. (2010), "*Exploiting Simulation for Product Returns in SMEs*", Proceedings of World Congress on Engineering, London, Vol. III, pp. 1-6.

Arokiam, C.A. (2006), "Computer Simulation of Atomic-Scale Processes in Fe-Cu Alloys", *Unpublished* PhD thesis, University of Liverpool.

Aslan, B., Stevenson, M. and Hendry, L.C. (2012), "Enterprise Resource Planning systems: An assessment of applicability to Make-To-Order companies", *Computers in Industry*, Elsevier B.V., Vol. 63 No. 7, pp. 692-705.

Ali, M. and Cullinane, J. (2014), "A Study to Evaluate the Effectiveness of Simulation based Decision Support System in ERP Implementation in SMEs," *Procedia Technology*, Elsevier B.V., Vol. 16, pp.542–552.

Ali, M. and Xie, Y.(2011), "A Simulation Model for Decision Support in Small Medium Enterprises (SMEs) for ERP Systems Implementation", *Communications in Computer and Information Science,* Vol. 219, pp.310-321.

Al-Mashari, M. (2003), "Enterprise resource planning (ERP) systems: a research agenda", *Industrial Management & Data Systems*, Vol. 103 No. 1, pp. 22-27.

Ball, P.D. and Bititci, U.S. (2000), "Implementing ERP Systems - Organisational Implications", *Control*, Vol. 26, pp. 17-23.

Bergmann, S. and Strassburger, S.(2010), "Challenges for the Automatic Generation of Simulation Models for Production Systems", Proceedings of the 2010 Summer Computer Simulation Conference, San Diego, CA, USA, pp. 545–549.

Bertrand,W.J. and Fransoo,C.J (2002) "Operations management research methodologies using quantitative modeling", *International Journal of Operations & Production Management*, Vol. 22 No.2, pp.241 – 264

Bertrand, J.W.M. and Van Ooijen, H.P.G. (2002), "Workload based order release and productivity: A missing link", *Production Planning and Control*, Vol.13, Iss.7, pp.665 – 678

BIS Department for Business Innovation & Skills. (2011), "*Business population estimates for the UK and regions 2011"*. Available at: http://www.bis.gov.uk/analysis/statistics/business-population-estimates (Accessed: 14th June 2012).

Jacobs,F.R.and Bendoly, E. (2003),"A New Perspective on the Dynamics of Information Technology-Enabled Strategic change", *European Journal of Operational Research*, Vol.146, pp.233-240

Daneva, M. (2010), "Balancing uncertainty of context in ERP project estimation : an approach and a case study", *Journal of Software Maintenance and Evolution: Research and Practice*, Vol.22 No.5 May, pp. 329-357.

Daneva. M. and Wieringa. R. (2008),"Cost estimation for cross-organizational ERP projects: Research perspectives", *Software Quality Journal*, Vol. 16 No. 3, pp.459-481.

Davis, P.J., Eisenhardt, M.K. and Bingham. B.C. (2007),"Developing theory through simulation methods ", *Academy of Management Review*, Vol. 32 No. 2, pp. 480 – 499

Deep, A., Guttridge, P., Dani, S. and Burns, N. (2008), "Investigating factors affecting ERP selection in made-to-order SME sector", *Journal of Manufacturing Technology Management*, Vol. 19 No. 4, pp. 430-446.

Defee, J, M. (2011), "*Business Performance Modelling for ERP Projects*" , BP Trends, *CACI*, pp. 1-5.

Deif, A. (2010), "*Computer simulation to manage lean manufacturing systems*", 2010 2nd International Conference on Computer Engineering and Technology, IEEE, Vol. 6, pp. 677-681

Detty, R.B. and Yingling, J. (2000), "Quantifying benefits of conversion to lean manufacturing with discrete event simulation: a case study*", International Journal of Production Research*, Vol. 38 No. 2, pp. 429-445.

Doom, C., Milis, K., Poelmans, S. and Bloemen, E. (2010), "Critical success factors for ERP implementations in Belgian SMEs", *Journal of Enterprise Information Management*, Vol. 23 No. 3, pp. 378-406.

Dumond, E.J. (2006), "Understanding and using the capabilities of finite scheduling", *Industrial Management and Data Systems*, Vol.106 No.4, pp. 506-26.

Finlay, P. N. (1994), "Introducing decision support systems", 2nd *Edition*, ISBN 9781855543140, NCC Blackwell Publishing Group.

Grabski, S.V., Leech, S. A. and Schmidt, P.J. (2011), "A Review of ERP Research: A Future Agenda for Accounting Information Systems" *Journal of Information Systems*, Vol. 25 No. 1, pp. 37-78.

Gupta, J.N.D. (2002), "An excursion in scheduling theory: an overview of scheduling research in the twentieth century", *Production Planning and Control*, Vol.13 No.5, pp. 105-16.

Hendry, L., Huang, Y. and Stevenson, M. (2013) "Workload control: Successful implementation taking a contingency-based view of production planning and control", *International Journal of Operations & Production Management*, Vol. 33 Iss:1, pp.69 -103

Herrmann, J.W. (2006), "Improving Production Scheduling: Integrating Organizational, Decision-Making, and Problem-Solving Perspectives", Department of Mechanical Engineering and Institute for System Research, University of Maryland, IIE Annual Conference and Exposition, Orlando , 20th-24th May, 2006.

Hustad, E. and Olsen, D. H. (2011), "Exploring the ERP pre-implementation process in a small-and-medium-sized enterprise exploring the ERP pre-implementation process in Proceedings of ECIS, No.8, pp. 1-11.

Iversen, H.J., Mathiassen, L. and Nielsen, A.P. (2004), “Managing Risk in Software Process Improvement: An Action Research Approach”, MIS Quarterly, Vol.28 No.3,pp. 395-433.

Jahangirian, M., Eldabi, T., Naseer, A., Stergioulas, L.K. and Young, T. (2010), “Simulation in manufacturing and business: A review”, *European Journal of Operational Research*, Elsevier B.V., Vol. 203 No. 1, pp. 1-13.

Jonsson, P. and Mattsson, SA.(2003), “ The implication of fit between planning environments and manufacturing planning and control methods*”, International Journal of Operations &Production Management*,Vol.23 No.8, pp. 872-900

Heilala, J., Montonen, J., Järvinen, P. and Kivikunnas, S. (2010), “Decision Support Using Simulation for Customer-Driven Manufacturing System Design and Operations Planning,” *IEE, VTT Technical Research Centre of Finland*, pp. 342 -53

Heilala, J., Montonen, J., Järvinen, P. and Kivikunnas, S. (2010), “ *Decision Support Using Simulation for Customer-Driven Manufacturing System Design and Operations Planning*”, Decision Support Systems Advances in, Ger Devlin (Ed.), ISBN: 978-953-307-069-8, InTech, Available from: http://www.intechopen.com/books/decision-support-systems-advances-in/decision-support-using-simulationfor-customer-driven-manufacturing-system-design-and-operations-pla (Accessed: 22nd July 2011).

Hevner. R.A., Salvatore, T.M. and Park, J.(2004),"Design Science in IS Research", *MIS Quarterly*, Vol. 28 No. 1, pp. 75-105

Hirschheim, R. (1992), “*Information Systems Epistemology: An Historical Perspective, In R.Galliers(Ed.),* Information Systems Research: Issues, Methods and Practical Guidelines, 1st *Edition*, ISBN 9780761966326, Sage Publications

Hsu, C-C. and Sandford, B.A. (2007), “The Delphi Technique: Making Sense of Consensus”, *Practical Assessment, Research and Evaluation*, Vol. 12 No. 10, pp. 1-8. Available at: http://pareonline.net/pdf/v12n10.pdf. (Accessed: 28th September 2013).

Hussey, J. and Hussey, R. (1997), “Business research: a practical guide for undergraduate and postgraduate students”, 1st Edition , Macmillan Press LTD, Basingstoke, Hampshire.

Kempf, K., Uzsoy, R., Smith, S. and Gary, K. (2000), "Evaluation and comparison of production schedules", *Computers in Industry*, Vol.42 No.2, pp. 203-20.

Kirchhof, P., Meseth, N. and Witte, T. (2008), "*Simulation based evaluation of the workload control concept for a company of the automobile industry*", Proceedings of the 2008 Winter Simulation Conference (WSC), pp. 1856-1862.

Koo, P.H., Moodie, C.L. and Talavage, J.J.(1994), " Performance evaluation of manufacturing systems: A spreadsheet model", *Computers Industry Engineering*, Vol.26 No.4, pp. 673-88.

Kulonda, D.J. and Arif, M.(2009) "Small enterprise systems based on document methodology", *Nonlinear Analysis: Theory, Methods & Applications*, Volume 71, Issue 12,Pages e651-e656.

Land, M.J. and Gaalman, G.J.C. (2009), "Production planning and control in SMEs: Time for change", *Production Planning and Control*, Vol.20, Iss.7, pp.548 - 558.

Lee, H.Y. and Choi, B.K. (2011), "Using workflow for reconfigurable simulation-based planning and scheduling system", *International Journal of Computer Integrated Manufacturing*, Vol. 24 No. 2, pp. 171-87.

Levy, M., Powell, P. and Yetton, P. (2001), "SMEs: aligning IS and the strategic context", *Journal of Information Technology,* Vol. 16, pp. 133-44.

Leyh, C. (2012), "Critical Success Factors for ERP System Implementation Projects : A Literature Review", Advances in Enterprise Information Systems II: Proceedings of the Fifth International Conference on Research and Practical Issues of Enterprise Information Systems (Confenis 2011), Aalborg, Denmark

Lin, H.W., Nagalingam, S.V., Kuik, S.S. and Murata, T. (2012), "Design of a Global Decision Support System for a manufacturing SME: Towards participating in Collaborative Manufacturing," *International Journal of Production Economics*, Elsevier, Vol. 136 No. 1, pp. 1–12

Mahfouz, A., Shea, J. and Arisha, A. (2011), “Simulation based optimisation model for the lean assessment in SME: A case study”, *Proceedings of the 2011 Winter Simulation Conference (WSC)*, IEEE, pp. 2403-2413.

Mahoney, R.M. (2007), “High-Mix, Low-Volume Manufacturing Paradigms”. Available at: *http://holonyx.com/operations/holonics-3.pdf*. (Accessed: 10th June 2009).

Marakas, G. M. (1999),” Decision support systems in the twenty-first century”, 1st *Edition*, ISBN 9780137441860, Prentice-Hall Publishing Group.

Markus, M.L., Axline, S., Petrie, D. and Tanis, C. (2000), “Learning from adopters’ experiences with ERP: problems encountered and success achieved,” *Journal of Information Technology*, Vol. 15 No. 4, pp. 245-65.

Mason, S.J., Hill, R.R., Mönch, L., Rose, O., Jefferson, T., Fowler, J.W. and Kirchhof, P. (2008), “*Simulation based evaluation of the workload control concept for a company of the automobile industry*”, Proceedings of the 2008 Winter Simulation Conference, pp. 1856-1862.

McKay, K.N. and Gary, W.B. (2007), “The evolution of a production planning system : A 10 year case study”, *Computers in Industry*, Vol.58 No.4, pp. 756-71.

McKay, K.N. and Wiers, V.C.S. (1999), “Unifying the Theory and Practice of Production Scheduling”, *Journal of Manufacturing Systems*, Vol. 18 No.4, pp. 241-54.

Middel, R., Coghlan, D., Coughlan, P., Brennan, L., & McNichols, T. (2006), "Action research in collaborative improvement", *International Journal of Technology Management*, Vol. 33 No. 1, pp. 67-91.

Moon, Y.B. and Phatak, D. (2005), “Enhancing ERP system’s functionality with discrete event simulation”, *Industrial Management & Data Systems*, Vol. 105 No. 9, pp. 1206-1224.

Myers, M. (2010), “Qualitative Research in Information Systems”, Association for Information Systems. Available at: http://www.qual.auckland.ac.nz/ . (Accessed 24th, Nov 2014).

Myers, M. (2009), "Qualitative *Research in Business and Managemen*t", 1st *Edition*, ISBN 978-1412921664, Sage Publications

Myers, M. (1997), "*Interpretive Research Methods in Information Systems",* Information Systems: An Emerging Discipline, 1st *Edition*, ISBN 0077092953, McGraw Hill Publication

Myers, M. and Avison, D. (2002), "*Qualitative research in information systems: a Reader*", 1st *Edition,* ISBN 9780761966326, Sage Publications.

Myers, M.D. and Newman, M. (2007), "The qualitative interview in IS research: Examining the craft", *Information and Organization,* Vol. 17 No. 1, pp. 2-26.

Nazemi, E., Tarokh, M.J. and Djavanshir, G.R. (2012), "ERP: a literature survey", *The International Journal of Advanced Manufacturing Technology,* Vol. 61 No. 9–12, pp. 999-1018.

Nisula, K. and Pekkola, S. (2012), "ERP-based simulation as a learning environment for SME business", *The International Journal of Management Education*, Elsevier Ltd, Vol. 10 No. 1, pp. 39-49.

Oates, B. J. (2006), "*Researching information systems and computing",* 1st *Edition*, ISBN 9781412902243, Sage Publications

O'Kane, J. (2004), "Simulating production performance: cross case analysis and policy implications", *Industrial Management & Data Systems*, Vol. 104 No. 4, pp. 309-21.

O'Kane, J., Papadoukakis, A. and Hunter, D.(2007), "Simulation usage in SMEs". *Journal of Small Business and Enterprise Development,*Vol.14 No.3, pp. 514-527.

Olsen, A.K. and Saetre, P. (2007), "ERP for SMEs – is proprietary software an alternative?", *Business Process Management Journal*, Vol. 13 No. 3, pp. 379-89.

Olsen, A.K. and Saetre, P. (2007), "IT for niche companies: is an ERP system the solution?" , *Information Systems Journal,* Vol. 17 No. 1, pp. 37-58.

Özdamar, L. and Yazgac, T. (1997), “Capacity driven due date settings in make-to-order production systems”, *International Journal of Production Economics,* Vol.49, pp. 29-44.

Park, C., Song, J., Kim, J. and Kim, I. (1999), “Delivery date decision support system for the large scale make to order manufacturing companies: A Korean electric motor company case”, *Production Planning and Control*, Vol.10, Iss: 6,pp. 585-597.

Pegden, D.,Shannon, R.E. and Sadowski, R.P.(1995), "Introduction to Simulation Using SIMAN/C, 2nd *Edition,* ISBN 0-0070493-20-0, Mc Graw-Hill, New York.

Pillai, S., Arokiam, A., Bhatti, R. and Collins, A. (2011), “Make to Order Manufacturing and Operational Management Strategies – A Case Study at Company ‘A’ ”, *Proceeding of the 18th International Annual EurOMA Conference, June 3-6, University of Cambridge, UK*

Pillai, S., Arokiam, A. and Bhatti, R. (2013), “Linking simulation, critical success factors and enterprise resource planning in small and medium size enterprises”, *International Journal of Information Systems and Change Management*, Vol.6 No.3, pp. 266-290.

Porter, K., Little, D., Peck, M. and Rollins, R. (1999), “Manufacturing classifications: relationships with production control systems”, *Integrated Manufacturing Systems,* Vol.10 No4, pp. 189-98.

Power, D.J. (2002), “Decision Support Systems: Concepts and Resources for Managers”, 1st *Edition,* ISBN 9781567204971, Greenwood Publishing Group.

Power, D.J. (1997), “What Is DSS?” The Online Executive Journal for Data-Intensive Decision Support, Vol.2, pp.15-20.

PROJECT MANAGEMENT INSTITUTE. (2004), “A guide to the project management body of knowledge (PMBOK guide)”, Newtown Square, Pa, Project Management Institute

Ram, J. and Corkindale, D. (2014),"How “critical” are the critical success factors (CSFs)?", Business Process Management Journal, Vol. 20 No. 1, pp. 151 – 174

Rapoport, R. N. (1970), "Three Dilemmas in Action Research: With Special Reference to the Tavistock Experience", Human Relations, Vol. 23 No. 6, pp. 499-513.

Raymond, L. and Uwizeyemungu, S. (2007), “A profile of ERP adoption in manufacturing SMEs” , *Journal of Enterprise Information Management*, Vol. 20 No. 4, pp. 487-502.

Rice, T. (2001), “Production scheduling with a spreadsheet”, Paper Presented at 23rd International Supply Chain Management Conference, Durban, South Africa, 18th -20th June 2001.

Rice, T. (2003), “Buffers, Buckets, East, West and Excel”, Paper Presented at 25th SAPICS Annual conference and Exhibition, Sun City, South Africa, 2nd – 4th June 2003.

Rice, T. (2007), “P-S Cycles Flash Presentation”. Available at: *http://www.production-scheduling.com/downloads.asp*. (Accessed: 02nd June 2009).

Rice, T. (2008), “Planning – How Far Can You Go With Excel”, Paper Presented at 30th International Supply Chain Management Conference, Sun City, South Africa, 29th June - 02nd June 2008.

Riezebos, J., Korte, G.J.and Land, M.J.(2003), “ Improving a practical DBR buffering approach using workload control”, *International Journal of Production Research*, Vol.41 No.4, pp. 699-712

Rockhart, J.F(1979),"Critical Success Factors", *Harvard Business Review*, March-April, pp.81-91

Rory, O-B. (1998), “An overview of the Methodological Approach of Action Research”, Faculty of Information Studies, University of Toronto.

Rubin, H.J. and Rubin, I.S. (2005). “*Qualitative Interviewing: The Art of Hearing Data*”, 2nd Edition, ISBN 9780761920755, Sage Publications.

Rubin, H.J. and Rubin, I.S. (1995). “*Qualitative Interviewing: The Art of Hearing Data*”. 1st *Edition*, ISBN 9780803950962, Sage Publications.

Saad, M.S., Pickett, N. and Kittiaram, K.(2004), “An integrated model for order release and due date demand management”, *Journal of Manufacturing Technology Management*, Computers in Industry, Vol.15 No.1, pp.76-89.

Sharma, A., Yadava, G.S.S. and Deshmukh, S.G.G. (2011), “A literature review and future perspectives on maintenance optimization”, *Journal of Quality in Maintenance Engineering*, Vol. 17 No. 1, pp. 5-25.

Silva, C, Stevenson, M and Thurer, M.(2014), "A case study of the successful implementation of workload control: a practitioner-led approach", *Journal of Manufacturing Technology Management*. ISSN 1741-038X (In Press)

Silverman, D. (2006), “*Interpreting qualitative data: methods for analysing talk, text, and interaction”*, 3rd Edition, ISBN 978-1412922456, Sage Publications.

Snider, B., Silveira, G.J.C.D. and Balakrishnan, J. (2009), “ERP implementation at SMEs: analysis of five Canadian cases,” *International Journal of Operations & Production Management*, Vol. 29 No. 1, pp. 4-29.

Sprague, R. H. and Carlson, E. D.(1982), “Building effective decision support systems” 1st *Edition*, ISBN 9780130862150, Prentice-Hall Publishing Group.

Stevenson, M., Hendry, L.C., and Kingsman, B.G.(2005), "A review of production planning and control: The applicability of key concepts to the make to order industry", *International Journal of Production Research*, Vol.43, No.5,pp.869-898.

Stevenson, M., and Silva, C. (2008), “Theoretical development of a workload control methodology: Evidence from two case studies”, *International Journal of Production Research*, Vol.46, Iss:11, pp.3107-3131.

Stevenson, M., Huang, Y., Hendry, L. and Soepenberg, E. (2010), “Working Paper :The Theory & Practice of Workload Control : A Research Agenda & Implementation Strategy The Theory & Practice of Workload Control : A Research Agenda & Implementation Strategy”, *Lancaster University Management School*,Vol 43, pp.1-43.

Stone, K.B. (2012), “*Four decades of lean: a systematic literature review*”, International Journal of Lean Six Sigma, Vol. 3 No. 2, pp. 112-132.

Straub,D.W., Gefen,D. and Boudreau, M., (2005), “The IS World Quantitative, Positivist Research Methods” . Available at:

https://www.blackwellpublishing.com/content/BPL_Images/Content_store/Sample_chapter/9780632052844/001-025%5B1%5D.pdf. (Accessed 24th, Nov 2014).

Stump, B. and Badurdeen, F. (2009), "Integrating lean and other strategies for mass customization manufacturing: a case study" , *Journal of Intelligent Manufacturing*, Vol. 23 No. 1, pp. 109-124.

Sun, Y.T.A., Yazdani, A. and Overend, D.J. (2005), "Achievement assessment for enterprise resource planning (ERP) system implementations based on critical success factors (CSFs)", *International Journal of Production Economics*, Vol. 98 No. 2, pp. 189-203.

Su, J.C., Marrey, S., Damania, J. and Shaw, K.(2003), "Manufacturing information management and integrated capacity planning in a high mix electronics manufacturing environment", Proceedings of the ASME Design Engineering Technical Conference, Vol.1 B, pp. 669-77.

Taylor, J.R. (2004), "Error Analysis", 2nd *Edition,* ISBN 0-935702-42-3, University Science Books Publication.

Teittinen, H., Pellinen, J.and Järvenpää, M.(2012), "ERP in action - Challenges and benefits for management control in SME context", *International Journal of Accounting Information Systems,*Vol.14 No.4, pp. 278-296.

Thürer,M., Stevenson,M. and Silva,C. (2012), "Three Decades of Workload Control Research: A Systematic Review of the Literature", *International Journal of Production Research*, Vol.49 Iss:23, pp 6905-6935.

Thürer,M., Silva,C., Stevenson,M. and Land, M.(2012), "Improving the applicability of workload control (WLC): the influence of sequence-dependent set-up times on workload controlled job shops", *International Journal of Production Research*, Vol.50 Iss:22, pp 6419-6430.

Turban, E. (1995), "Decision support and expert systems : management support systems", 4th *Edition*, ISBN 9780133203837, Prentice-Hall Publishing Group.

Verville, J., Bernadas, C. and Halingten, A. (2005), "So you're thinking of buying an ERP? Ten critical factors for successful acquisitions", *Journal of Enterprise Information Management*, Vol. 18 No. 6, pp. 665-77.

Waller, A.P. and Ladbrook, J.(2002), "*Experiencing virtual factories of the future*", Proceedings of the Winter Simulation Conference, IEEE, Vol. 1, pp. 513-517.

Wadley, D. and Smith, P. (1998), "If planning is about anything, what is it about?", *International Journal of Social Economics*, Vol.87 No.6/7/8, pp.1005-29.

Walton, S. and Metter, R. (2008), "Production planning by spreadsheets for a start up firm", *Production Planning and Control*, Vol.19 No.6, pp.556-566.

Wang, Q., Lassalle, S., Mileham, A.R. and Owen, G.W. (2009), "*Analysis of a linear walking worker line using a combination of computer simulation and mathematical modeling approaches*," Journal of Manufacturing Systems, Elsevier Ltd, Vol. 28 No. 2-3, pp. 64–70.

Wang, Q., Sowden, M. and Mileham, A.R. (2013), "Modelling human performance within an automotive engine assembly line", *International Journal of Advanced Manufacturing*, Technology Vol.68 No 1-4, pp.141-148.

Wiendahl, H.P., Gläÿner, J., and Petermann, D.(1992), " Application of load-oriented manufacturing control in industry", *Production Planning and Control*, Vol.3, Iss.2, pp.118 - 129.

Yeh, C-H. (2000), "A customer-focused planning approach to make-to-order production", *Industrial Management and Data Systems*, Vol.100 No.4, pp.180-87.

Yang, S.M., Ahn, B. and Seo, K.K. (2006), "ERP - Development of a virtual factory system-2006", *International journal of advance mfg technology*, Vol. 28, pp. 1031-1037.

Zach, O. and Bjorn, M. (2011), "Exploring ERP system outcomes in SMEs : A Czech multiple case study," *Journal of Enterprise Information Management*, Vol. 25 No. 5, pp. 462-78.

Zach, O. and Olsen, D. (2011), "ERP System Implementation in Make-to-Order SMEs : An Exploratory Case Study", *System Sciences (HICSS), 2011 44th Hawaii International Conference on Communication, Networking & Broadcasting; Computing and Processing*, Kauai, HI, pp. 1-10.

APPENDIX A

A] Sample of order arrival from ERP

2010				**2011**				**2012**		
Range	**Qty**	**Percentage**		**Range**	**Qty**	**Percentage**		**Range**	**Qty**	**Percentage**
Compact	53	37.06		Compact	61	27.11		Compact	46	41.82
Horz	37	25.87		Horz	25	11.11		Horz	26	23.64
Vert	28	19.58		Vert	108	48.00		Vert	15	13.64
Q63	3	2.10		Q63	8	3.56		Q63	11	10.00
RSC Small	4	2.80		RSC Small	12	5.33		RSC Small	4	3.64
RSC Large	18	12.59		RSC Large	11	4.89		RSC Large	8	7.27
	143				225				110	
82 % Compact, QCS				86 %Compact, QCS						79 % Compact, QCS

B] Sample of data analysis to compute distribution type

	Compact		Horz		Vert		Q63		RSC Small		RSC Large
2006	39		35		25		1		13		9
2007	40		30		46		3		15		7
2008	46		38		44		12		8		15
2010	53		37		28		3		4		18
2011	61		25		108		8		12		11
2012(july)	46		26		15		11		4		8
ALL	**Gamma**	**ALL**	**Weibull 3P**	**ALL**	**Lognorml 3P**	**ALL**	**Uniform**	**ALL**	**Uniform**	**ALL**	**Lognorml 3P**
Mean	47.801	Mean	-0.2827	Mean	46.382	Mean	6.332	Mean	9.3331	Mean	12.008
Std Dev	9.2575	Std Dev	3.3416	Std Dev	45.77	Std Dev	4.6331	Std Dev	4.7186	Std Dev	9.002
α	26.661	α	1.228	A	0.99541	a	-1.6916	a	1.1602	α	1.1448
β	1.7929	β	4.365	M	3.0648	b	14.358	b	17.506	μ	1.044
γ	0	γ	-4.365	Γ	11.211					γ	6.6182
Excl 2012	**Erlang**	**Excl 2012**	**Uniform**	**Excl eagle,2012**	**Uniform**	**Excl 2012**	**Lognorml 2P**	**Excl 2012**	**Weibull 3P**	**Excl 2012**	**Gamma**
Mean	46.55	Mean	31.833	Mean	36	Mean	4.4817	Mean	-0.41914	Mean	12.002
Std Dev	8.229	Std Dev	5.6364	Std Dev	9.3542	Std Dev	5.8747	Std Dev	2.7864	Std Dev	4.473
m	32	a	22.071	A	19.798	α	0.86821	α	1.4648	α	7.2
β	1.4547	b	41.596	B	52.202	μ	1.3523	β	4.434	β	1.667
γ	0					γ	0	γ	-4.434	γ	0

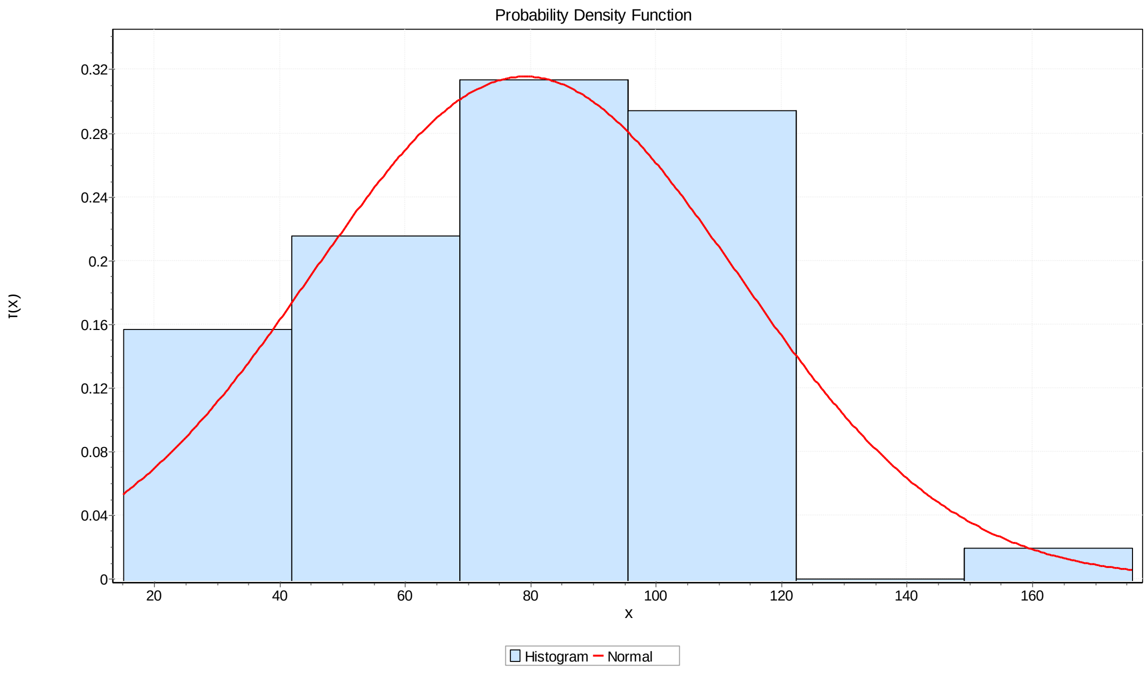
C] Sample of data analysis to compute distribution type.

.Compact Avg for 5 yrs	32.2341362				
Horz Avg for 5 yrs	22.1082621				
Vert Avg for 5 yrs	26.9393939				
Q63 Avg for 5 yrs	4.47371147				
RSCSmall Avg for 5 yrs	6.15695416				
RSCLarge Avg for 5 yrs	7.73789174				
Average Monthly : 20					
Distribution		Monthly %	Avg	Month Avg	Round
Compact Avg for 5 yrs	7	0.2	32.234136	6.446827	7
Horz Avg for 5 yrs	4	0.2	22.108262	4.421652	4
Vert Avg for 5 yrs	5	0.2	26.939394	5.387879	5
Q63 Avg for 5 yrs	1	0.2	4.4737115	0.894742	1
RSCSmall Avg for 5 yrs	1	0.2	6.1569542	1.231391	1
RSCLarge Avg for 5 yrs	2	0.2	7.7378917	1.547578	2

D] Goodness of Fit –summary for compact product range order entry

Goodness of Fit - Summary							
#	Distribution	Kolmogorov		Anderson		Chi-Squared	
		Smirnov		Darling			
		Statistic	Rank	Statistic	Rank	Statistic	Rank
9	Normal	0.08374	1	0.43416	1	1.1499	1
13	Weibull (3P)	0.08952	2	0.45582	2	2.1794	5
8	Lognormal (3P)	0.09004	3	0.47905	3	1.4566	2
6	Gamma (3P)	0.0903	4	0.48364	4	1.4735	3
2	Erlang (3P)	0.09293	5	0.49505	5	2.2987	6
12	Weibull	0.10334	6	0.52673	6	1.572	4
5	Gamma	0.11408	7	0.92614	7	4.6977	9
11	Uniform	0.11588	8	7.9008	13	N/A	
10	Triangular	0.11852	9	1.3195	9	3.0147	7
7	Lognormal	0.14171	10	1.2088	8	4.0224	8
1	Erlang	0.17836	11	2.1718	10	8.3509	10
4	Exponential (2P)	0.22031	12	5.2004	11	16.334	11
3	Exponential	0.27899	13	7.3625	12	26.417	12

E] Distribution Sample of template developed for work centre data collection.



F] Sample of simulation excel read array functions in simulation model

```
CompactTotal = 0
QCSHORTotal = 0
QCSVERTotal = 0
Q63Total = 0
RSCSMALLTotal = 0
RSCLARGETotal = 0
!
ExcelWorkbook = " J:\\PhD\\Witness\\Witness Modelling\\Oct2012\\AutoclaveMfg\\cost.xlsx"
ExcelConfiguration = "Configuration"
XLReadArray (ExcelWorkbook,ExcelConfiguration,"read_experiment_number",ExperimentationNumber)
ExcelResults = EvalStr ("Results " + ExperimentationNumber)
XLReadArray ("J:\\PhD\\Witness\\Witness Modelling\\Oct 2012\\orders.xlsx","CT","$B$1:$B$12",CT,1)
```

G] Sample of simulation excel write array functions in simulation model

```
XLWriteArray (ExcelWorkbook,ExcelResults,"Cost1",CostCompact,1)
XLWriteArray (ExcelWorkbook,ExcelResults,"Cost2",CostQCSHOR,1)
XLWriteArray (ExcelWorkbook,ExcelResults,"write_experiment_number",ExperimentationNumber,1)
ExperimentationNumber = ExperimentationNumber + 1
XLWriteArray (ExcelWorkbook,ExcelConfiguration,"read_experiment_number",ExperimentationNumber,1)
```

H] Sample of simulation match functions in simulation model

```
MATCH/ATTRIBUTE SalesOrderNo

QCSHORFrameBuffer#(1)QCSHORBoilerBuffer#(1)QCSHORPipeBuffer #(1)

QCSHORElecBuffer #(1)QCSHORDoorBuffer #(1)shopstaff #(1) AND

QCSHOROptestBuffer #(1)
```

I] Sample of labour task allocation and availability for production strategy model.

PART7	1	1	Height=61	Attributename=Matt	SalesOrderNo=1000001
PART7	1	1	Height=61	Attributename=Steve	SalesOrderNo=1000002
PART7	0	1	Height=61	Attributename=Stephen	SalesOrderNo=1000003
PART7	1	1	Height=61	Attributename=Dave	SalesOrderNo=1000004
PART7	1	1	Height=61	Attributename=Martin	SalesOrderNo=1000005
PART7	1	1	Height=61	Attributename=Darren	SalesOrderNo=1000006
PART7	1	1	Height=61	Attributename=John	SalesOrderNo=1000007
PART7	1	1	Height=61	Attributename=Andy	SalesOrderNo=1000008
PART7	1	1	Height=61	Attributename=Bell	SalesOrderNo=1000009
PART7	1	1	Height=61	Attributename=Sam	SalesOrderNo=1000010
PART7	1	1	Height=61	Attributename=Paul	SalesOrderNo=1000011
PART7	1	1	Height=61	Attributename=Alan	SalesOrderNo=1000012
PART7	1	1	Height=61	Attributename=Lee	SalesOrderNo=1000013
PART7	1	1	Height=61	Attributename=Paul	SalesOrderNo=1000014

APPENDIX B

A] CSF Analysis via Delphi

ID	CSF	Occurrence	
ID1	Good project scope management	26.32	
ID2	Management expectations	21.05	
ID3	Formalised project plan/schedule	63.16	
ID4	Project management	68.42	
ID5	Steering committee	26.32	
ID6	Legacy systems	36.84	
ID7	Cultural change/political issues	57.89	Critical
ID8	Business process reengineering (BPR)	78.95	
ID9	Experienced project manager-leadership	63.16	Basic
ID10	Project champion role	47.37	
ID11	Adequate resources	42.11	Basic
ID12	Trust between partners	15.79	
ID13	Interdepartmental communication	84.21	Dependent
ID14	Interdepartmental cooperation	73.68	Dependent
ID15	Project team composition/team skills	78.95	Basic
ID16	Empowered decision makers	15.79	
ID17	Management support and commitment	100	Critical
ID18	Monitoring and evaluation progress	68.42	Dependent
ID19	Appropriate use of consultants	57.89	Critical
ID20	Vendor's tool	21.05	
ID21	Managing consultants	21.05	
ID22	Software customisation	36.84	
ID23	Software configuration	31.58	
ID24	Appropriate technology	26.32	
ID25	Reduced trouble shooting-project risk	42.11	
ID26	Training on software	52.63	
ID27	Education on new business processes	42.11	
ID28	Vendor support	26.32	
ID29	Data analysis and conversion	15.79	Basic
ID30	Formal methodology-ERP implementation strategy	63.16	
ID31	Carefully defined information and system requiremen	52.63	
ID32	Adequate ERP software selection	52.63	
ID33	Clear goals and objectives	68.42	

B] CSF cost analysis

			Basic				Critical			Dependent			
Company	**Criteria**		**ID9**	**ID11**	**ID15**	**ID29**	**ID7**	**ID17**	**ID19**	**ID13**	**ID14**	**ID18**	**Total**
	Time	Weeks	2	2	4	6	3	1	2	1	2	4	26
		Days	10	10	20	30	15	5	2	5	10	20	122
		Percent of Total	8.20	8.20	16.39	24.59	12.30	4.10	1.64	4.10	8.20	16.39	104.10
	Cost	GBP Overall	5000	5000	20000	45000	11250	1250	1000	1250	5000	20000	114750
		GBP per week	2500	2500	5000	7500	3750	1250	500	1250	2500	5000	31750
		GBP per day	500	500	1000	1500	750	250	100	250	500	1000	6350
	Achievement = Utilisation of ERP%+functionality of ERP% / 2	Percent	3.75	2.25	11.25	2.25	15	15	1.5	11.25	11.25	1.5	75
		Percent per day	0.375	0.225	0.5625	0.075	1	3	0.75	2.25	1.125	0.075	9.4375