Manufacturing Execution Systems

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Presented in partial fulfilment of the requirements for the degree

Master of Engineering

IN THE FACULTY OF ENGINEERING

DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

UNIVERSITY OF PRETORIA

SEPTEMBER 1999

ABSTRACT

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Degree: **Master of Engineering**

The term Manufacturing Execution Systems (MES) was created in 1990 by Advanced Manufacturing Research (AMR) to describe the suite of software products which enables the execution of manufacturing through the integration of planning and control systems.

The purpose of this dissertation is to determine the current status of MES and to investigate the possible role of the Industrial Engineer in the development, implementation and use of MES. To achieve this objective, the most commonly accepted, recent and relevant definitions, business models, functions and developments of MES are investigated. Based on these, a new MES Function Matrix is developed and validated by a case study. Finally, Industrial Engineering is related to MES and the role of the Industrial Engineer promoted.

The emergence of MES is a result of the evolution of three interrelated elements, namely manufacturing strategies, manufacturing planning and control systems and information technology. The development of global markets and the requirement for agile manufacturing led to the need for MES.

The evolution of various aspects of Enterprise Resource Planning (ERP), and more specifically Manufacturing Planning and Control (MPC) systems, is discussed as part of the investigation of the development of MES. The Three-Layer-model and REPAC-model by AMR Research, as well as variations of these models compiled by MESA ("International MES Association"), are investigated. Manufacturing execution is absent in traditional MPC models. Modern models, such as the Three-Layer-model, suggest an execution layer to be inserted between the planning and control layers.

The investigation of the function models of McClellan and MESA International indicates that discrepancies exist between these models with regard to the functions of MES. A new MES Function Matrix is developed to address such shortcomings and is applied to a case study of DIAMES, a software product used by Aberdare Cables and promoted as an MES product.

As an MES developer, the Industrial Engineer can act as designer, planner and innovator. The greatest value can, however, be added by the Industrial Engineer as integrator to ensure that horizontal plant-wide execution takes place, and not only vertical "islands of automation" integrated with planning systems. In order to accomplish this, the Industrial Engineer needs to fulfill the roles of boundary-spanner, facilitator, coordinator, analyst, chairperson, decision-maker, as well as trainer or educator. MES can also be used by the Industrial Engineer as a tool, for example as part of a program of continuous improvement.

The identification of the relationship between the expertise of the Industrial Engineer and the roles to be played within the MES arena gave birth to the establishment of an MES research initiative at the Department of Industrial and Systems Engineering of the University of Pretoria.

Key Words:

- Manufacturing Execution Systems (MES)
- Industrial Engineering (IE)
- Enterprise Resource Planning (ERP)
- Control Systems
- Manufacturing Planning and Control Systems (MPC)
- Information Technology (IT)
- Manufacturing Systems
- Supply Chain Management (SCM)
- Business System Integration
- Agile Manufacturing

OPSOMMING

Titel:	**Vervaardigingsuitvoeringstelsels**
Outeur:	**Liezl van Dyk**
Leier:	**C de W van Schoor**
Departement:	**Bedryfs- en Sisteemingenieurswese**
Graad:	**Magister Ingenieurswese**

Die term Vervaardigingsuitvoeringstelsels ("Manufacturing Execution Systems" – MES) is in 1990 deur Advanced Manufacturing Systems (AMR) geskep om die sagtewareprodukte te beskryf wat die uitvoering van vervaardigingsplanne, deur die integrasie van beplanning- en beheerstelsels, moontlik maak.

Die doel van hierdie verhandeling is om die huidige status van MES te bepaal en die moontlike rol van die Bedryfsingenieur in die ontwikkeling, implementering en gebruik van MES te ondersoek. Om hierdie doel te bereik word die algemeen aanvaarde, resente en relevante definisies, besigheidsmodelle, funksies en ontwikkelings van MES ondersoek. Gebaseer hierop is 'n nuwe MES Funksionele Matriks ontwikkeling en getoets met 'n gevallestudie. Laastens word die verhouding tussen MES en Bedryfsingenieurswese bepaal en die rol van die Bedryfsingenieur uitgebou.

MES is 'n resultaat van die evolusie van drie verwante aspekte, naamlik vervaardigingstrategieë, vervaardigingsbeplanning en -beheerstelsels en inligtingstegnologie. Die opkoms van globale markte en die vereiste vir buigbare, ratse vervaardiging ("agile manufacturing") het aanleiding gegee tot die behoefte vir MES.

Die evolusie van verskeie aspekte van besigheidshulpbronbeplanning (ERP), en meer spesifiek vervaardigingsbeplanning- en beheerstelsels (MPC), word bespreek as deel van die ondersoek na die ontwikkeling van MES. Die Drie-Vlak-model en die REPAC-modelle van AMR Research, asook variasies daarvan soos opgestel deur MESA ("International MES Association"), is ondersoek. Vervaardigingsuitvoering is afwesig in die tradisionele modelle van vervaardigingsbeplanning en -beheer. Moderne modelle,

soos die Drie-Vlak-model, stel voor dat 'n uitvoeringsvlak tussen die beplanning- en beheervlakke ingevoeg word.

Die ondersoek van die funksionele modelle van McClellan en MESA dui aan dat verskille bestaan ten opsigte van die funksies van MES. 'n Nuwe MES Funksionele Matriks is ontwikkel om hierdie tekortkominge aan te spreek en word getoets in 'n gevallestudie van DIAMES, 'n sagteware-produk wat by Aberdare Cables gebruik en as 'n vervaardigingsuitvoeringstelsel (MES) bemark word.

As 'n MES-ontwikkelaar kan die Bedryfsingenieur optree as 'n ontwerper, beplanner en innoveerder. Die grootste waarde kan egter deur die Bedryfsingenieur bygevoeg as integreerder, deur te verseker dat horisontale, aanlegwye uitvoering plaasvind en nie alleen vertikale "eilande van outomatisering" nie. Om dit te bereik, moet die Bedryfsingenieur die rolle vervul van brugbouer, fasiliteerder, koördineerder, analis, voorsitter, besluitnemer en opleier. MES kan ook deur die Bedryfsingenieur gebruik word as gereedskapstuk, byvoorbeeld as deel van 'n program vir kontinue verbetering. Die identifisering van die verwantskap tussen die kennisvelde van die Bedryfsingenieur en die rolle in die MES-arena het aanleiding gegee tot die vestiging van 'n MES-navorsingsinisiatief by die Departement van Bedryfs- en Sisteemingenieurswese van die Universiteit van Pretoria.

Sleutelwoorde:

- Vervaardigingsuitvoeringstelsels
- Bedryfsingenieurswese
- Besigheidshulpbronbeplanning
- Beheerstelsels
- Vervaardigingsbestuurstelsels
- Informasietegnologie
- Vervaardigingstelsels
- Voorsieningskanaalbestuur
- Besigheidstelselintegrasie
- Aanpasbare vervaardiging

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1. INTRODUCTION

The term Manufacturing Execution Systems (MES) was created by Advanced Manufacturing Research (AMR)[1] in 1990. This term describes systems that enable the execution of manufacturing, through the integration of the planning and control systems of an enterprise:

"Middle-level information systems, known as Manufacturing Execution Systems (MES), bridge the critical information gap between upstream, transaction-oriented, planning activities and downstream, event-oriented execution activities."
(Digital Basestar, 1998:www.asia-pacific.digital.com/info/manufacturing/integr.htm)

According to MacDonald (1998:*www.consilium.com/Publications/roi.htm*) the evolution of MES started long before the term was coined in 1990, and it is still evolving:
"An MES is not something new or something only large, complex manufacturers need. If you have a manufacturing plant, you already have an MES"

CONTENTS OF THIS CHAPTER

1
AMR Research is an industry and market analysis firm specializing in enterprise applications and related trends and technologies. Tracking more than 400 leading software and service providers, AMR Research helps Global 1000 companies evaluate, select, and manage new systems for every part of the enterprise, including logistics and supply-chain management, Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES), and electronic/Internet commerce. (www.amrresearch.com)

1. 1. PROBLEM STATEMENT

A project was launched at the beginning of 1998 as a joint effort between CSM Systems and the Departments of Industrial and Systems Engineering and Computer Science (University of Pretoria). The purpose of this project was to develop an interface between a specific Enterprise Resource Planning (ERP) system (SAP) and a shop floor control system (DIAMES). Through this project the project members discovered the existence of the term MES. Further research brought forward the following categories of issues:

1. MES definitions and business models.
2. MES and the Industrial Engineer.
3. The need for MES awareness and education in South Africa.
4. Developments concerning the original project.

1. 1.1. MES DEFINITIONS AND BUSINESS MODELS

Numerous definitions for MES exist. However, MES definitions, concepts and models still evolve. In October 1998 AMR Research published a completely new model - the REPAC model - to replace the original MES model developed by them less than a decade before. This rapid evolution is to a great extent the result of the evolution of related manufacturing strategy and information technology. The consequences of these rapid changes are the following:

- MES theories and models are changing faster than the rate by which users and potential users are educated.
- Software developers and integrators often abuse the term MES for marketing purposes. Products are often promoted as total MES solutions, while the product only provides partial integration.
- Although underlying technology, strategy and theory are ever changing, the concept of a system that enables the execution of manufacturing, is becoming more and more accepted, throughout manufacturing industries.

1. 1.2. MES AND THE INDUSTRIAL ENGINEER

The concepts associated with the definition of MES (MRP, MRPII, systems integration, shop floor control etc) are associated with (amongst others) Industrial Engineering. During the past four years a total of five articles appeared in the International Industrial Engineering journal, (IIE Solutions), with titles containing the term MES. Approximately ten more articles, which refer to MES in some way or another, appeared in this journal. The assumption is made from this that the Industrial Engineer is concerned with the use/ development/ integration of MES to some extent.

1. 1.3. THE NEED FOR MES AWARENESS AND EDUCATION IN SOUTH AFRICA

As part of a resent survey by South African Instrumentation and Control (1999:8-12), thirty software integrating companies in South Africa were given the choice of highlighting (using five terms) their integration expertise. Nine of these thirty companies choose MES as one of these five terms. Representatives from all of these companies were asked via e-mail to comment on MES in South Africa. From the response the conclusion was made the opinions on the nature, scope and applications of MES varies.

The need to educate South African Industries with regard to MES is identified from interviews with two of the leading MES integrators in South Africa.

1. 1.4. DEVELOPMENTS CONCERNING THE ORIGINAL PROJECT

Since the original project was launched the scope and direction were changed due to several developments:

- The development of a unique interface between the specific shop floor control system and ERP system mentioned earlier proved to be infeasible.
- The need was identified to determine the position of DIAMES in the industry market and to consider the feasibility of developing it into a comprehensive MES product. This need is currently attended to through a separate project.

The term MES is well accepted by South African manufacturing industries. Together with underlying technologies and manufacturing strategies, these systems are evolving at a rapid rate. The Industrial Engineer has a role to play regarding the coordination of this evolution.

1. 2. RESEARCH PURPOSE AND LIMITATIONS

The purpose of this dissertation is to determine and establish the role of Industrial Engineering in the development, implementation and use of MES.

1. 2.1. LIMITATIONS

The following boundaries are drawn for purposes of this dissertation:

- The term *Manufacturing Execution Systems*, implies that it is a concept focussed on the manufacturing industry. MES principles and products can, presumably be applied equally to the service industry. For purposes of this dissertation only the manufacturing industry is considered.
- Although trends regarding information technology are investigated, a detail study of underlying information technology, related to MES, does not fall within the scope of this dissertation. This study is conducted from the viewpoint of the Industrial Engineer. Although the role of the IT analyst in the development op MES is acknowledged, it fell outside the scope of this dissertation.
- All interviews are conducted with *South African* Industrialists. Whilst international literature is used to seed the study, the conclusions and recommendations are limited to the South African manufacturing environment.

1. 3. RESEARCH STRATEGY, STRUCTURE AND CONTRIBUTION

To meet the purpose of this dissertation, the following research question and related key questions have to be answered:

Why should the Industrial Engineer be concerned with MES?
• What are MES? • What is an Industrial Engineer? • How does Industrial Engineering relate to MES?

Within the boundaries (as set in the previous section), two propositions are made. Several objectives are defined to support these propositions. Questions that have to be answered to meet the objectives are compiled accordingly.

PROPOSITION 1: The concept of MES is valid. (It is used by and useful to manufacturing industry.)	
Objectives	**Questions**
Integrate literature regarding MES business models and applications.	• What are Manufacturing Execution Systems? • Where does the concept of MES originate from and in which direction is it evolving? • In which industry sectors (and to which extent and with how much success) are MES implemented?
Integrate opinions of South African role players throughout the literature study	• To which extent is the concept of MES accepted by South African manufacturing industry? • What are the view of South African developers, integrators and users?
Develop a new or combined model – if current models prove to be insufficient.	• Can current MES function models be used as tool to evaluate MES products and environments? • What should the elements of an appropriate model be?
Demonstrate the validity of the newly developed MES model – as well as the validity of MES as concept – through a case study (DIAMES).	• How does DIAMES perform as a Manufacturing Execution System and what developments are required? • In which other ways can this model be used to analyze MES products and environments?

PROPOSITION 2:

The Industrial Engineer has a contribution to make, regarding MES

Objectives	Questions
Relate MES to Industrial Engineering by integration literature on Industrial Engineering.	• How are Industrial Engineers trained? • How are Industrial Engineers practically involved in industry? • Which roles are to be played in the MES arena and to which extent can Industrial Engineers fulfill these roles?
Initiate a research program for a research program for MES at the Department of Industrial and Systems Engineering (University of Pretoria).	• What other MES research initiatives exist? • What should be the focus and scope of such an initiative?

1. 3.1. CONTRIBUTIONS MADE THROUGH THIS RESEARCH

Through this dissertation, the following contributions are made, towards MES research:

- Current models and theories are evaluated, integrated and presented in a way that can be used as basis for further research on MES.
- A new model – to be used as MES evaluation tool – is developed and demonstrated.
- The role of the Industrial Engineer, regarding MES, is evaluated and explained.
- The foundation is laid for an MES research initiative at the Department of Industrial and Systems Engineering (University of Pretoria).

1. 3.2. STRUCTURE AND SCOPE

The questions asked to meet the objectives are answered in this dissertation, according to the structure of *Table 1*.

Table 1

The scope of this dissertation

GOAL	PROPOSITION 1 The concept of MES is valid	PROPOSITION 2 The Industrial Engineer has a contribution to make, regarding MES
Business Position	What are Manufacturing Execution Systems?	How are Industrial Engineers trained? How are Industrial Engineers practically involved in industry?
History	Where does the concept of MES originate and in which direction is it evolving?	What is an Industrial Engineer?
MES Functions and the development of MES Function Matrix	Can current MES function models be used as tool to evaluate MES products and environments? How should an appropriate evaluation model look?	Which of the MES functions are the concern of the Industrial and Systems Engineer?
Case Study	Does an evaluation exercise - using the newly development MES model - prove that the product DIAMES can indeed be marketed as a manufacturing execution system?	
MES Role Players: Developers	What is the view of South African developers? What is the role played by an MES developer?	To which extent can the Industrial Engineer fulfill the roles of developer?
MES Role Players: Integrators	What is the view of South African integrator? What is the role played by an MES integrator?	to which extent can the Industrial Engineer fulfill the role of integrator?
MES Role Players: Research	Which research initiatives, regarding MES, exists?	To which extent can the Industrial Engineer fulfill the role of researcher? What should the focus and scope be of an MES research initiative at the Dept. of Industrial Engineering (University of Pretoria)?
MES Role Players: User	In which industry sectors (and to which extent and with how much success) are MES implemented? To which extent is the concept of MES accepted by South African manufacturing industry?	What should the focus and scope be of such an initiative?

1. 4. RESEARCH METHODOLOGY

To conduct the research, MES information was *gathered* and *applied*.

1. 4.1. GATHERING OF INFORMATION

An extensive literature study (including interviews with industry experts) needs to be conducted. Through the literature study as much as possible information and opinions regarding MES – and related concepts - are integrated. Literature is studied to make it possible to position MES within a South African and Industrial Engineering context and to identify further areas of research where gaps or contrasting opinions exist. Where these gaps are identified, models and theories are combined or modified and ultimately evaluated against the case study.

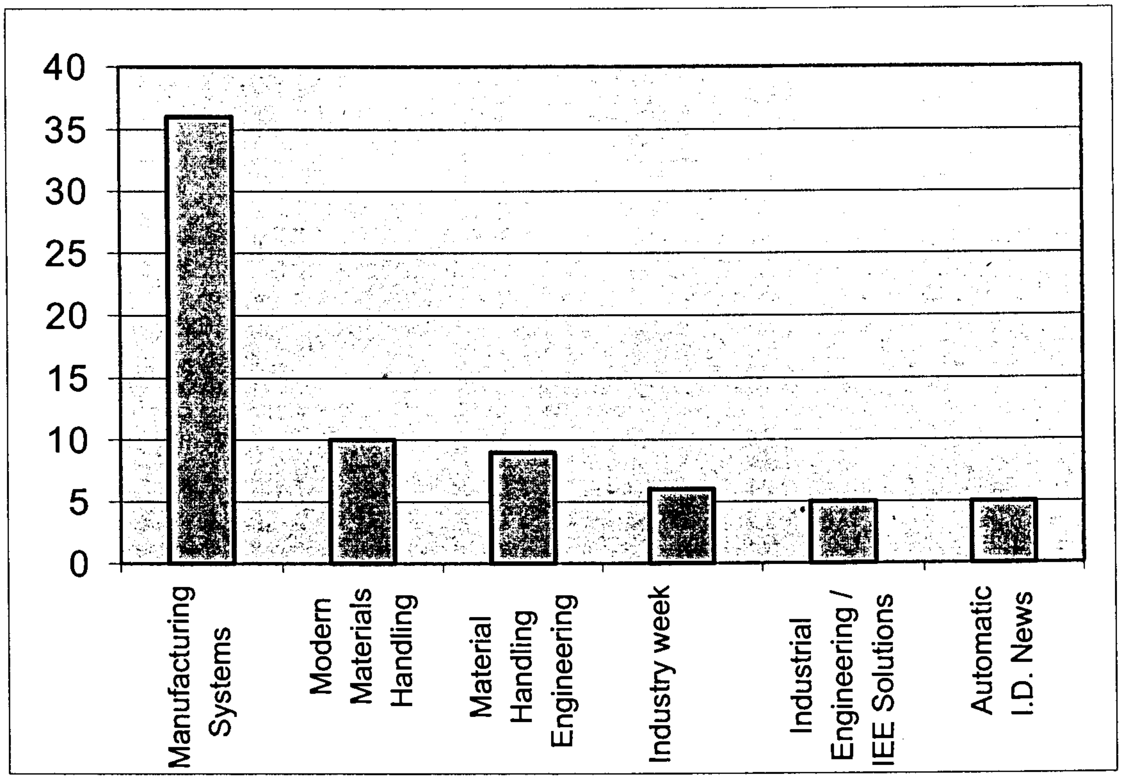
Information for this study is gathered from publications in textbooks, journals, publications on the World Wide Web as well as interviews and discussions with relevant MES developers and integrators from industry.

(a) INFORMATION GATHERING THROUGH PUBLICATIONS IN JOURNALS

References to 106 journal articles on Manufacturing Execution Systems, published before 1999 were identified. The first article appeared in 1991 (1 year after the term was coined). In the next year 16 articles were published and in 1993 the number of articles was 14. The largest number of articles was published in 1995 and 1996 (20 and 22 respectively). In 1997 sixteen MES articles appeared and in 1998 thirteen. Information on the journals in which these articles appeared is provided in *Figure 1* (on the following page).

Figure 1

Number of MES articles published in specific journals



All of these journals are concerned with business and manufacturing processes, rather than information technology. This is due to the fact that this research is not conducted from the viewpoint of an IT analyst. As noted earlier, the number of articles from IIE Solutions (the International Industrial Engineering Journal) implies a link between Industrial Engineering and MES, which is worth investigating.

(a) INFORMATION GATHERING THROUGH PUBLICATIONS IN BOOKS

Several information and operations management books were consulted. Information NOT given was of equal value than information given. The term Manufacturing Execution Systems has not been used in any of these books (publication dated varied from 1989 to 1997). Although the term MES is not used, MES functions – as identified by writers of journals and internet articles – are described in most of the books. Only one book was found, which focuses on MES: "Applying Manufacturing Execution Systems" (McClellan,1997).

The conclusion can be made from this that the concept of MES is an insignificant concept and do not deserve any attention. However, the wide acceptance of this term – as can be derived from publications in journals and the World Wide Web, as well as interviews – can not be ignored. The absence of literature on MES in books is, rather, considered as a signal that more research needs to be done.

(c) INFORMATION GATHERING THROUGH WORLD WIDE WEB (WWW)

The information gathered from the World Wide Web can broadly be categorized as either academic publications or promotional material.

- Academic material refers to articles, which are – apart from being published on the World Wide Web – published in official journals or course material. Publications from official research institutes are also considered as academic material. The integrity of this information is contemplated equal to information gathered from traditional publications in journals.
- MES developers and integrators provide promotional information to market their product or service. Due to the subjective nature of this information, this information is primarily used to identify trends.

(d) INFORMATION GATHERING THROUGH INTERVIEWS AND SURVEYS

An initial survey was conducted to determine the need for further research on MES in South Africa. The survey was directed – via e-mail – to South African research institutes, universities and software integrators MES. The focus was on the integrators and researchers of MES - rather than the users and potential users. This was done due to the necessity that respondents had prior knowledge regarding MES. The additional information and requests provided by the respondents was of greater importance than the statistical data obtained from answers. The positive reaction to the survey was a definite indication that there is a need to research MES in South Africa.

Interviews were conducted with representatives of companies concerned with the integration of Manufacturing Execution Systems. The outputs from these interviews are integrated throughout this report. Information from brochures of these companies is also used. The names of people interviewed and their involvement with MES are listed in *Table 2* (on the following page).

Table 2

Interviews held with persons from industry involved with MES

Schalk Claassen (Schalk_Claassen@voltex.co.za)	CSM Systems, representing DIAMES	February 1998 June 1998 January 1999 March 1999
Neville Searle	President of the South African MES Special Interest Group.	October 1998 April 1999
Kevin Archer	Director of Automated Systems Engineering Technologies and Member of the MES Special Interest Group	October 1998
André Brits ab3@isis.co.za	Account Executive of KEOPS ISIS	November 1998 April 1999 May 1999
Pieter Theron lt@isis.co.za	Project Manager at KEOPS ISIS	October 1998 November 1998 April 1999 May 1999
Henno Marais (chmarais@icon.co.za)	Webmaster and member of the South African MES Special Interest Group.	

1. 4.2. APPLYING INFORMATION

(a) DEVELOPMENT OF AN MES FUNCTION MATRIX

Based on information gathered, the need was identified to develop a new MES function model. This need is attended to through the development of an MES Function Matrix:

- Principles of value management are used to develop this matrix.
- The matrix is evaluated against criteria derived from criticism against existing models.
- The MES Function Matrix is validated through current function definitions.
- Possible applications of this matrix are discussed and some of these applications are illustrated throughout the dissertation.

(b) INITIATION OF A RESEARCH PROGRAM FOR MES

The following steps was followed to initiate a research program for MES at the Department of Industrial and Systems Engineering (University of Pretoria).

- Current institutes, which embark on MES research, were investigated.
- The extent to which an MES research program can contributes towards the missions of the Department of Industrial and Systems Engineering and University of Pretoria was evaluated.
- A mission statement for this initiative was compiled.
- A web site for this initiative was created.

(c) CASE STUDY

An independent project is conducted concurrent to this dissertation to evaluate DIAMES as an MES product. Relevant results from this project are presented, modified and expanded upon chapter 5.

(d) DISSERTATION DOCUMENT

Background on the position of MES within the business and the evolution of MES are given in Chapters 2 and 3, respectively. The need for a new MES function model is motivated and the development of the new model is explained in Chapter 4. The independent investigation on DIAMES and the development of the alternative model are integrated in Chapter 5. In the remainder of this dissertation the Industrial Engineer is evaluated with respect to the roles played in the MES arena. Chapter 6 is used to evaluate the roles of developer and integrator. The users of MES user are investigated in Chapter 7 and MES research initiatives are evaluated in Chapter 8. In Chapter 9 the research for purpose of this dissertation is concluded and evaluated regarding the goals set in this introductory chapter.

2. THE POSISION OF MES WITHIN THE BUSINESS

"Manufacturing Execution Systems (MES), are information systems that reside on the plant floor, between the planning system in offices and direct industrial controls at the process itself." (AMR Research: www.amrresearch.com*)*

MES functions, applications and concepts existed before the term was created and has also evolved since 1990. In this chapter current MES business models - established before and after 1990 - are evaluated.

CONTENTS OF THIS CHAPTER

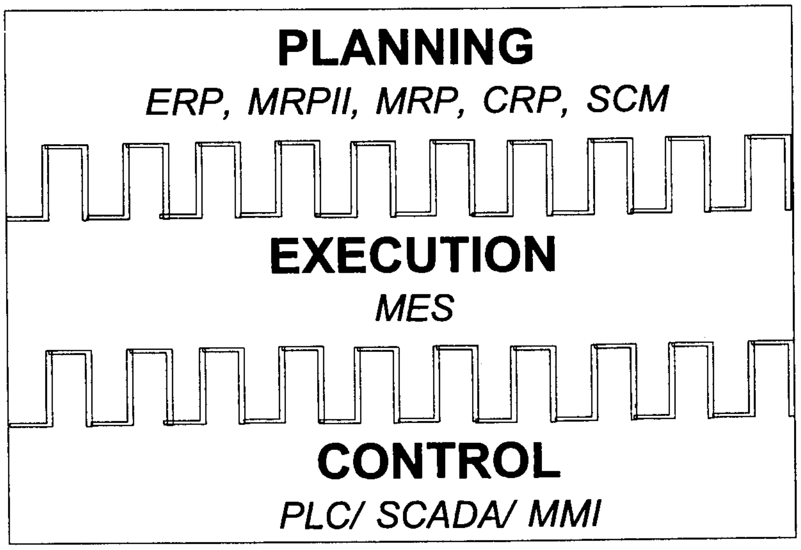
2. 1. CURRENT MES BUSINESS MODELS

AMR Research developed a simple model to explain the position of Manufacturing Execution Systems within a business (*Figure 2* on the following page). This model - called the Three-Layer-Model is used in the majority of MES literature. According to this model the three main activities within a business are related to three groups of information systems:

- The top layer comprises of systems such as Enterprise Resource Planning (ERP), Manufacturing Resource Planning (MRPII), Material Requirements Planning (MRP), Capacity Requirements Planning (CRP) and Supply Chain Management (SCM). Plans are send down in batch mode to the execution layer. Information on how the plans are executed is received from the execution layer.
- The execution layer acts as link between the control and planning layers. Communication between the execution and control layers occurs in real-time.
- Control is established through devices and systems such as programmable logic controllers (PLC), Supervisory Control and Data Acquisition (SCADA) and Man Machine Interfaces (MMI). Information from these devises is sent in real-time to execution layer. Work, process and maintenance instructions are sent back.

Figure 2

Three- Layer -Model by AMR Research



The statement was made that this business model is widely accepted. This is supported by the fact that MESA International[1] has not made any significant changes to this model. The model is only expanded: the types of systems within these layers - and its interfaces with MES – are modeled more specifically (as indicated in *Figure 3* on the following page).

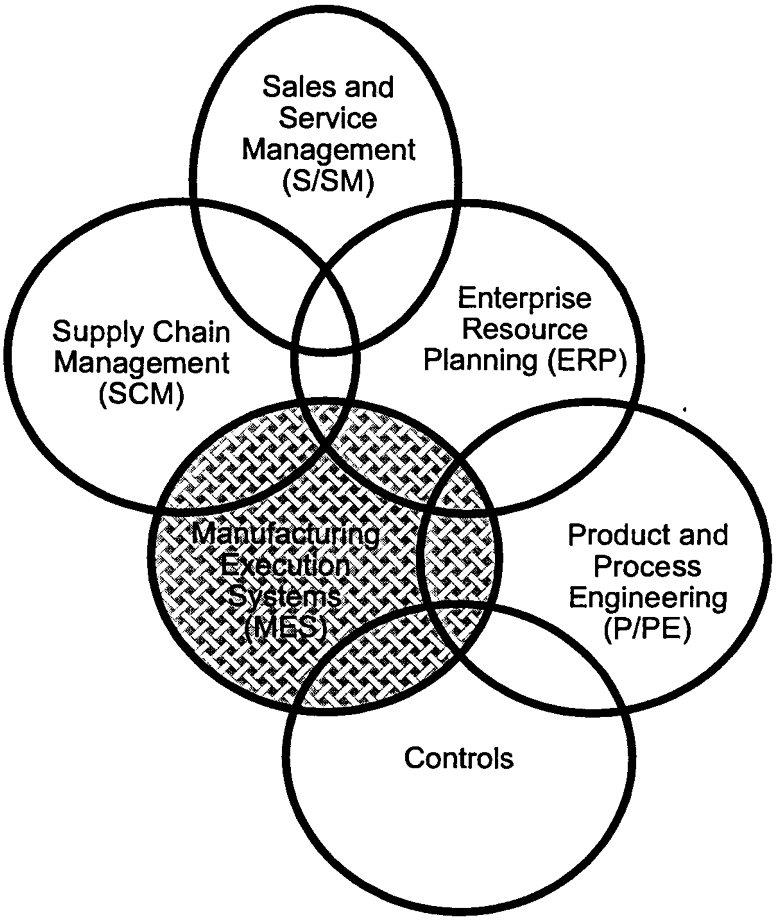
- Scheduling may be a component of both Manufacturing Execution Systems (MES) and Supply Chain Management (SCM).
- Labour management may appear in MES, Sales & service Management (SSM), and the Human Resource (HR) function of Enterprise Resource Planning (ERP).
- Document control can be a function of MES and Product and Process Engineering (P/PE). Both MES and Control can include process management. Degrees of overlap vary from industry to industry.

1
MESA International (Manufacturing Execution Systems Association) is a not-for-profit trade association providing a legal forum for competitors to work together to expand awareness and use of manufacturing technology, particularly MES and all the related products and services required by the modern manufacturing enterprise. (www.MESA.org)

Figure 3

The MES Context model by MESA International

(MESA International,1998:www.MESA.org/html/main.cgi?sub=5)



MESA International also uses the Three-Layer-Model to develop a model, which illustrates the flow of data to and from the execution layer. This is discussed in the next section.

2. 2. DATAFLOW BETWEEN MES AND NEIGHBOURING SYSTEMS

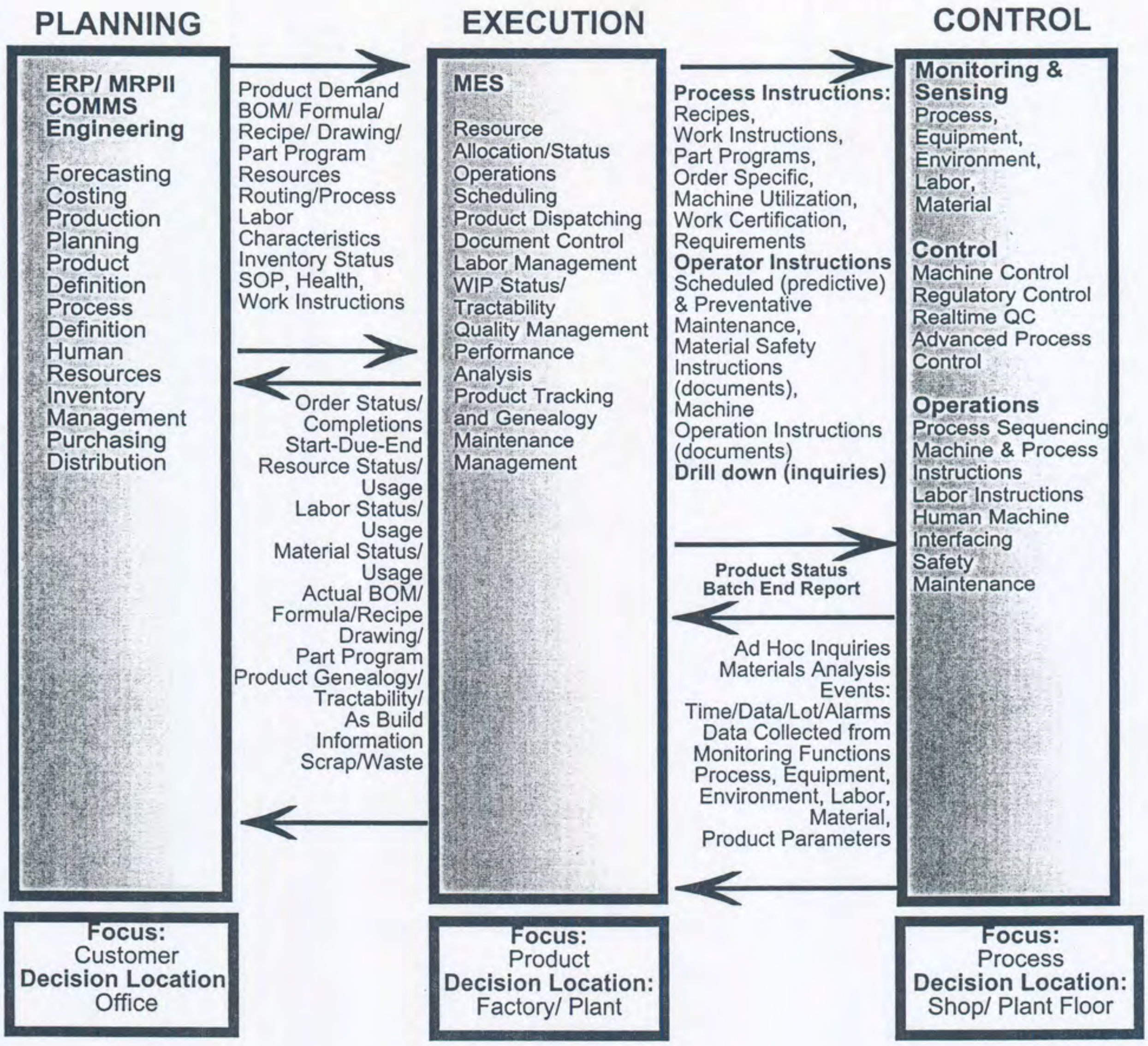
"The word "integration" is one of the most overused, abused, and misunderstood buzzwords in the lexicon of application software."

Luber (1991:298) made this statement with regard to Manufacturing Resource Planning (MRPII) systems. It is, however, just as applicable to MES. The difference between interface and integration is very much related to the underlying information technology. This is discussed at the end of this chapter. However, it is not an objective of this dissertation to define the difference between interface and integration. When the data flow between MES and neighboring systems is explained, the assumption is made that this data flow is established either by integration or through an interface.

The data flow model in *Figure 4* (on the next page) was developed by MESA International (1998:www.MESA.org/html/main.cgi?sub=5). This model is an expansion of the Three-Layer-Model of AMR Research. Although the layers are vertically orientated on this models, the way in which these layers interacts remains the same. Arrows indicate the data flowing to and from each of these layers, while the transformation of data is indicated within the boundaries of each layer. The flow of data from/ to the control and planning layers is discussed respectively.

Figure 4

The flow of data between MES and planning and control systems



2. 2.1. DATA FLOW BETWEEN MES AND CONTROL SYSTEMS

"A Control System is defined as being 'responsible for measurement, monitoring, and manipulation of production, people, products, and processes' within the environment of the process or shop floor."

(MESA International, 1998:www.MESA.org/html/main.cgi?sub=25).

According to the Object Management Group (1998:5), controls are usually hybrid hardware/software systems such as distributed control systems (DCS), programmable logic controllers (PLC), distributed numerical control (DNC), supervisory control and data acquisition (SCADA) systems designed to automate the way in which the product is being manufactured.

The focus of the control systems is on the process or operation itself.
The process is manipulated and rearranged by controls to assure

- that performance are kept within the defined tolerances,
- that continuous flow of material flow is maintained (as required by the process) and
- that resources is utilized optimally.

Inputs and output from and to the control layer can either be relayed and analyzed as they occur or stored in a database for later retrieval and analysis.

Forger (1997: http://www.manufacturing.net/magazine/mmh) explains technology - such as bar codes, radio frequency data communications, and radio frequency identification - is used to establish input and output to and from the control layer.

MESA International continues by explaining that the specific performance of a piece of equipment or person, is the concern of the control layer, rather than the execution layer. The results from these discrete operations are communicated to the execution system, after the results were converted together with process data.

The execution layer downloads instructions to the control layer. These instructions direct people and machines in the carrying out of the manufacturing operation. These resources monitor and control their own operations and act to comply with the requirements set out by the execution layer. This monitoring and control can include separate software and hardware products for quality, process control, data acquisition, safety and maintenance. Drill-down inquiries, or status indicators, from the execution layer can spontaneously access information created on an as-needed basis for process control. (MESA International,1995:www.MESA.org/html/main.cgi?sub=26)

2. 2.2. DATA FLOW OF MES WITH PLANNING SYSTEMS

The MES is the basic interface between planning and execution. Information is flowing bi-directionally. Factory floor information aids the office system (eg. ERP system) in job costing, payroll, lot control, inventory management and other factors on work actually being performed (and not the work planned to be performed).

According to MESA International (MESA International,1995: www.MESA.org/html/main.cgi?sub=26) the planning layer normally do not function in real-time, but rather in a batch mode. The planning layer notes product usage, customer orders, and materials requirements, and sends requests to the execution layer initiate the production of more, less or other products. The Manufacturing Execution System then perform the required transactions and send out the necessary instructions to enable the production of those products.

The Manufacturing Execution Systems often needs information, which not generally found in office and planning systems. Therefor, additional data elements are added to the Manufacturing Execution System the enable the organizing of manufacturing operations on a realistic basis. Based on this additional data, the Manufacturing Execution System send the appropriate data back to the planning systems to update material and capacity plans.

2. 3. THE REPAC MODEL

"In essence, the REPAC model takes the formal and informal systems in plants today and puts them in context. It has an eye to future systems that automate all plant activities. It is an extension of earlier models and it tracks the pragmatic way systems are implemented in factories today. More importantly, it identifies the holes in the architecture when using today's product categories."

(Swanton,1998: www.advmfg.com/repac*)*

AMR Research developed the REPAC model, by the end of 1998 as extension to the current Three-Layer-Model. In the remainder of this chapter the REPAC model is used to explain the interaction between MES and the supply chain. It is also demonstrated how the REPAC model can be used to contextualize business processes and systems currently used in businesses.

2. 3.1. THE RELATIONSHIP BETWEEN MES AND THE SUPPLY CHAIN

The expanding role of manufacturing information in the Total Supply Chain Management requires that MES evolve to easily integrate with enterprise systems. MES must also maintain the flexibility to provide customized integration for individual companies within different industries. The former dictates a set of off-the- shelf interfaces available to leading ERP suppliers. The latter entails a level of openness defined by accessibility to information via a broad range of application programming interfaces that facilitate customization.

*(Consilium,1998:*www.consilium.com/Publications/optv2n2/nexgen.htm*)*

The REPAC model is build upon the Supply Chain Operations Reference (SCOR) model (*Figure 5*) and is discussed as part of an attempt to place MES within context of the supply chain.

According to Hakason (1998:www.autoidnews.com), the SCOR-model (*Figure 5*) is based on four distinct management processes:

- plan,
- source,
- make and
- deliver

Each of these processes is explained in *Table 3*, following *Figure 5*.

Figure 5

The Supply Chain Operations Reference (SCOR) model

(Supply Chain Council:www.supply-chain.org/html/scor_overview.cfm)

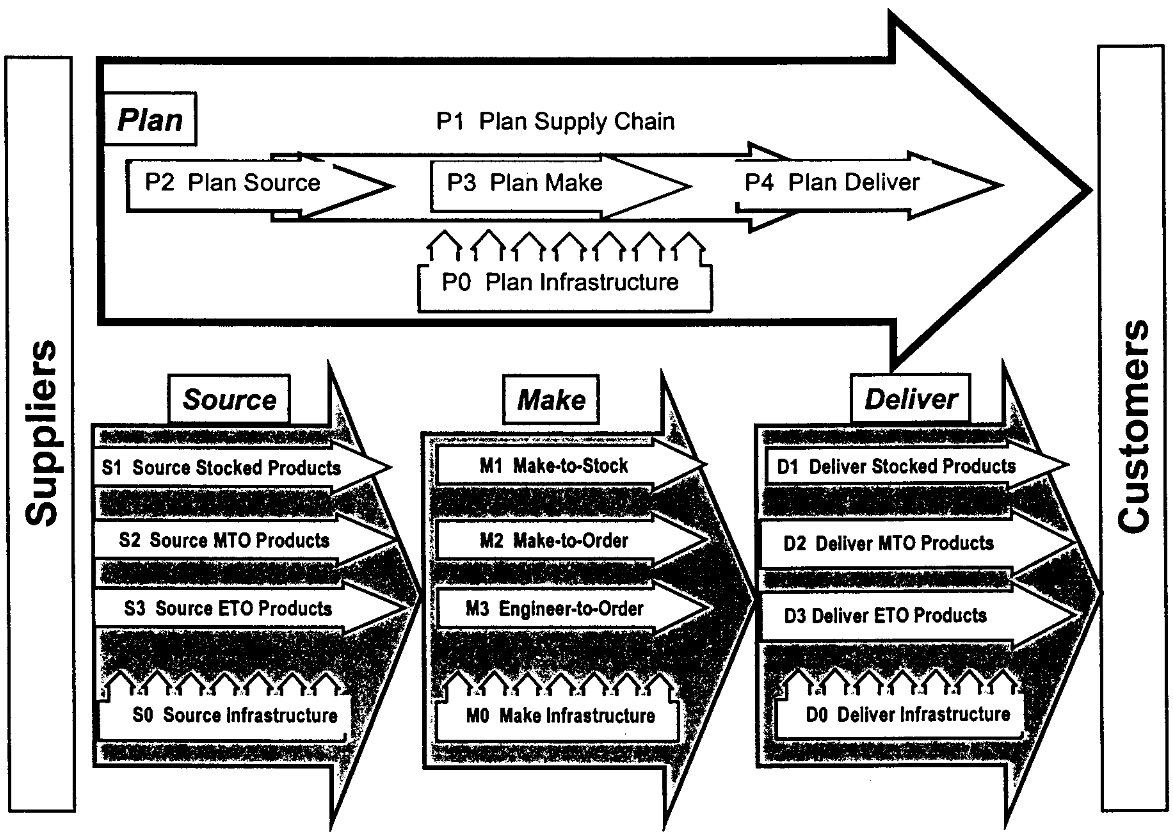


Table 3

Management processes within the SCOR model

Process	Description	Activities
Plan	Demand and supply planning and infrastructure management.	• Assess supply resources • Aggregate and prioritize demand requirements and plan - inventory - distribution requirements, - production, - material and rough-cut capacity for all products and all channels. • Manage infrastructure: - make/buy decisions, - supply chain configuration, - long-term capacity and resource planning, - business planning, - product phase- in/phase-out, manufacturing ramp-up, - end-of-life management and - product-line management.
Source	Sourcing and material acquisition and managing infrastructure.	• The - obtaining, - receiving, - inspecting, - holding and - issuing of material. • Monitor - sourcing quality, - in-bound freight, - component engineering, - vendor contracts and initiating vendor payments.
Make	Production execution	• Request and receive material. • Manufacture and test product. • Package, hold and/or release product. • Oversee - engineering changes, - facilities and equipment, - production status, - production quality, - shop scheduling/sequencing and - short-term capacity.
Deliver	Order management, warehouse management, and transportation and installation management	• Manage - channel business rules, - order rules deliver inventories and - deliver quality.

The REPAC model (*Figure 6*) focuses on the make process from the SCOR model. This model emphasizes the five fundamental business processes of a plant. The term REPAC is a concatenation of the first letter of each business process within the scope of this model (Heaton,1998:13).

- Ready
- Execute
- Process
- Analyze
- Coordinate as shown in *Figure 6*.

Each of these business processes are discussed in *Table 4*, on the following page.

Figure 6

The REPAC model

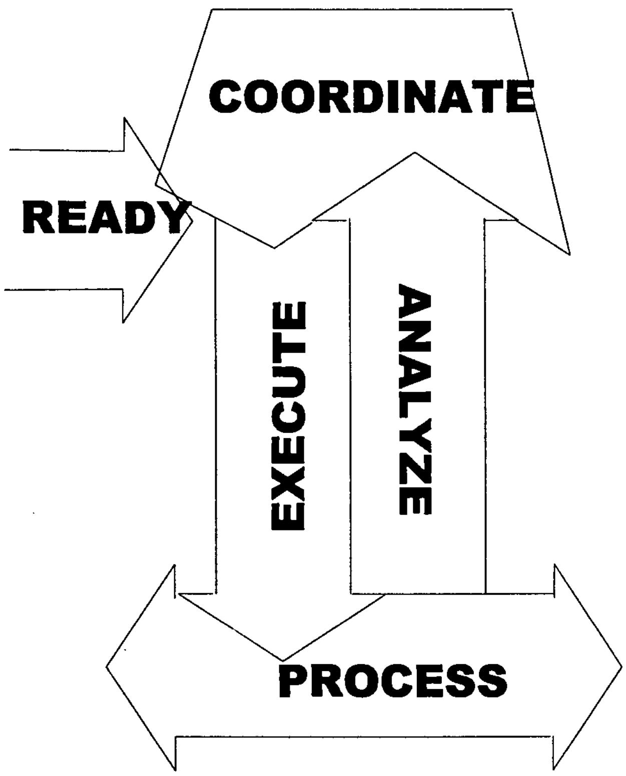


Table 4

Business Processes in the REPAC model

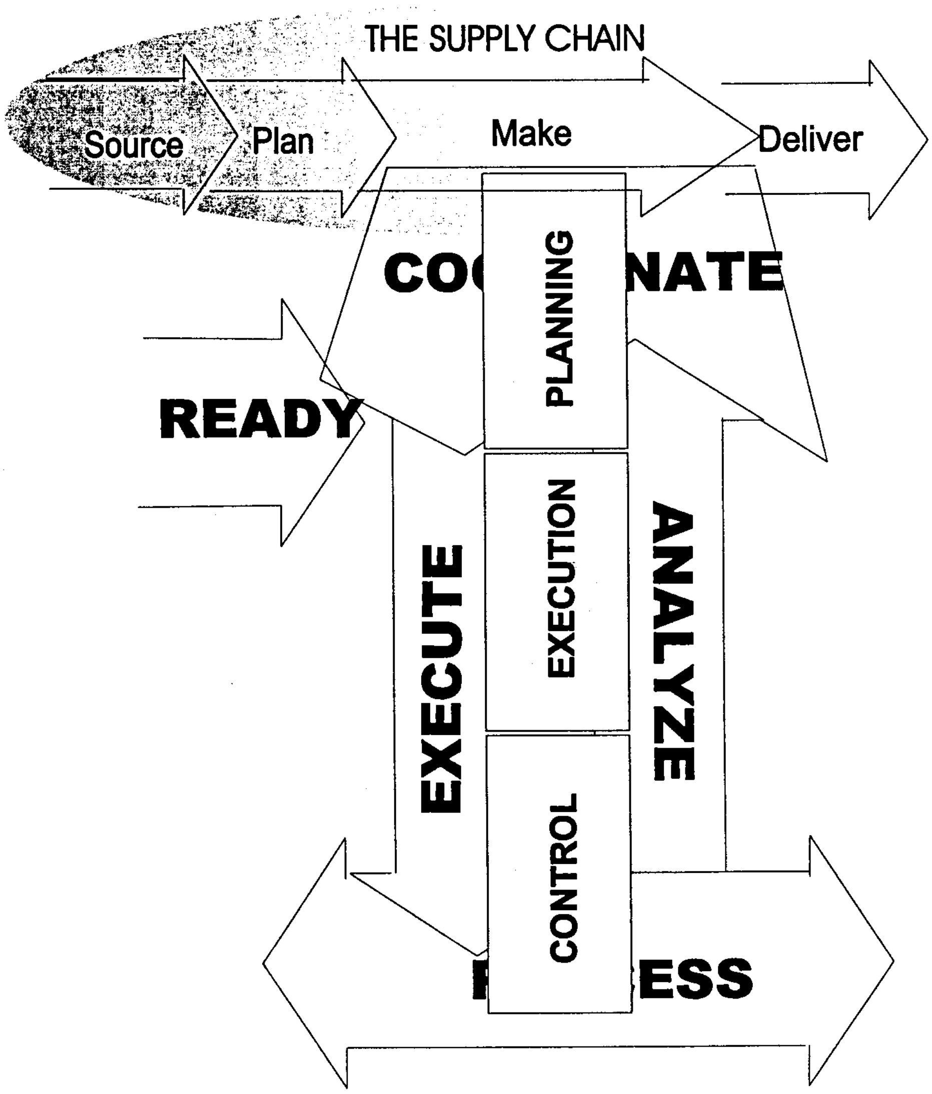
READY New Products for Production	With product lifecycles declining, plants must rapidly make new products ready for volume, high-yield production. This requires well controlled production processes, an automated, paperless process of new product introduction and engineering change, and integrated Quality Management.
EXECUTE Orders for Products	This process focuses on the execution of orders and processes. Similar to classic MES and WIP (Work-In-Process) Tracking, it manages the execution of a schedule within the plant, directing plant personnel, equipment, and recording actual progress.
PROCESS Capability Control and Management	This step corresponds to the existing process management and control infrastructure, including MMI (Man Machine Interface)/SCADA (Supervisory Control And Data Acquisition), PLC (Programmable Logic Controllers), DCS (Distributed Control Systems), and equipment with embedded controls. It focuses on the automation and control of Plant Systems. Process equipment is often expensive and complex, with sophisticated controls and extensive data collection.
ANALYZE Plant and Product Performance	This step focuses on identifying and using key performance information to further improve the process in a number of areas such as: quality and production improvement, calculating key performance indicators, summarizing data for supply chain planners, and assembling product information for downstream use. While plants may be a minor part of the overall supply chain, their models are complex with large volumes of data to manage.
COORDINATE the Plant Internally and With the Supply Chain	This final step is responsible for constantly updating the plant's schedule so everyone knows the best thing to be doing each time they start a new task. Since the plant is no longer isolated by inventory from the supply chain, a new mechanism is necessary to coordinate its operations. This process optimizes all of the activities in the plant, using status information from the *execute business process* and performance information from *analyze business process*. Coordination today is primarily an informal activity performed by managers with the odd finite scheduling application helping out.

The coordinate business process links with the supply chain, while the execute process links with MES. The relationship between MES and the supply chain is thus explained through a discussion of these two processes. This discussion is supported by *Figure 7*. This figure overlays AMR's original Three-Layer-Model, the REPAC model and a part of the SCOR model. The greatest overlap is with the execute and portions of the coordinate process arrows.

The business processes of the SCOR model as discussed in *Table 4* are also positioned on *Figure 7*, to show the integration between the coordinate process and the supply chain.

Figure 7

The REPAC model as link between the Three-Layer-Model and SCOR model



(a) COORDINATE : THE LINK WITH THE SUPPLY CHAIN

Swanton (1998:www.amrresearch.com/repac) explains that the integration with the supply chain is modeled through the *coordinate business process*:
"Since the plant is no longer isolated by inventory from the supply chain, a mechanism is necessary to coordinate its operations. This is primarily an informal activity performed by managers, with a finite scheduling application as support.
At its center the *coordinate process* is responsible for constantly updating the plant's schedule so everyone knows the best way to accomplish each new task. This process optimizes all of the activities in the plant, using status information from *the execute process* and performance information from the *analyze process*. These optimizations include the following:

- Exploding the high-level production requirements from the plan process into the detailed activities needed in the plant.
- Coordinating production with the actual status of incoming deliveries from suppliers arranged by the source process.
- Coordinating production with transportation in the deliver process.
- Sequencing operations in the plant to minimize cost while meeting external schedule commitments.
- Coordinating other plant activities including maintenance and engineering use of equipment."

(b) EXECUTE: THE RELATIONSHIP BETWEEN THE THREE LAYER MODEL AND THE REPAC MODEL

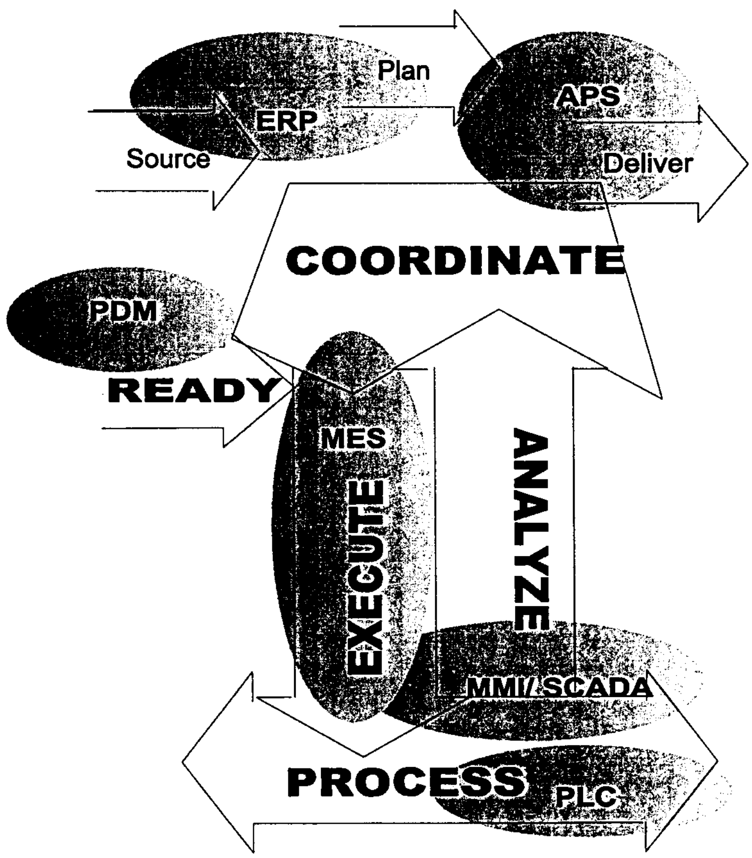
The relationship between the execute layer of the Three-Layer-Model and the REPAC model is explained as follow (Swanton,1998:www.amrresearch.com/repac/):

"Corresponding closely to classic MES and WIP tracking applications, the execute process manages the execution of a schedule within the plant. It communicates what needs to be done to the plant personnel and equipment, and it records what actually happens. Execute focuses on the transaction-processing portion of MES. It follows production and records any necessary data, including quality and abnormal condition information. Other workflow and reporting will be covered later, as transactional systems have proved incapable of meeting plant requirements in this area. The execute process is also simplified in that it does not try to optimize the execution itself; it uses a schedule created elsewhere (e.g., *the coordinate process*) and presents it to the operators.

2. 3.2. CONTEXTUALIZATION OF BUSINESS SYSTEMS

Figure 8 (Swanton, 1998: www.advmfg.com/repac) shows the coverage of the REPAC model in a typical enterprise architecture. Procurement (*Source*) and master planning (*Plan*) are handled by ERP while a demand-oriented APS handles distribution (*Deliver*) and coordinates factory schedules (*COORDINATE*). MES covers *EXECUTE* and PDM covers some but not all of the *READY* processes. MMI, PLC, and Computer Numerical Controls (CNCs) cover the *PROCESS*. Much of the rest, including all of *ANALYZE*, is not covered.

Figure 8
REPAC Model with centralized ERP/APS



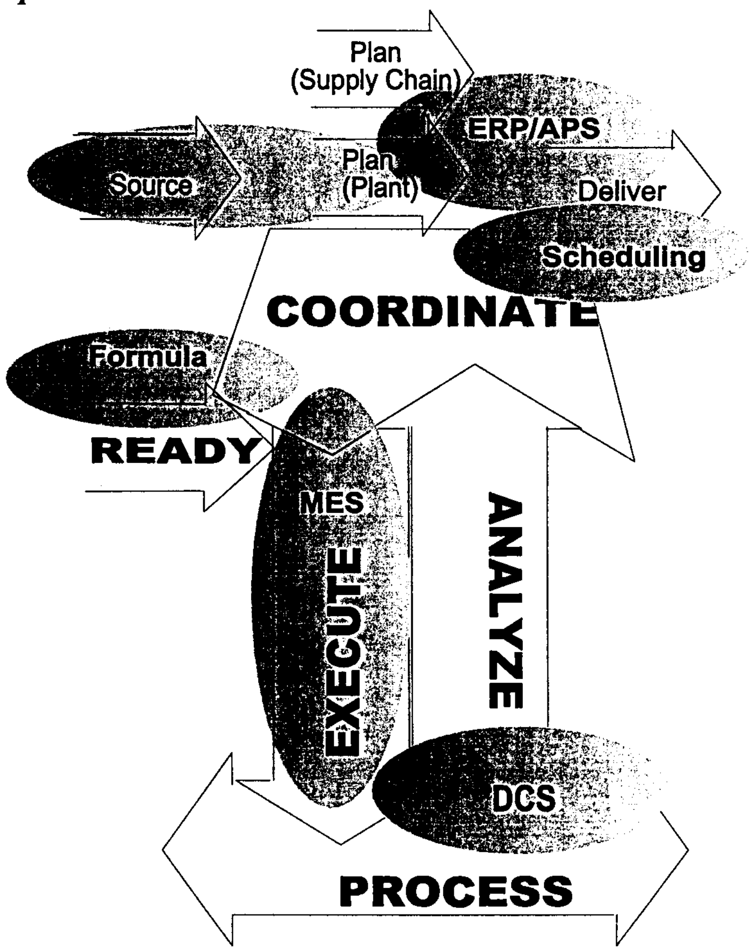
Origin (1999:2) makes the following comment in a marketing brochure:

"As Enterprise Resource Planning (ERP) and Control Systems vendors continue to expand their functionality to encompass that of MES, the MES layer is continuing to undergo changes. " The rest of the brochure is used to explain the a service provided by them to accomplish plant centric ERP.

Figure 9 (Swanton, 1998: www.advmfg.com/repac) shows an enterprise that has implemented ERP but that uses a plant-centric ERP to manage the batch process plant and sourcing of raw materials. A finite scheduling package sequences the batches, which are executed by an MES or batch execution package. The DCS handles the *PROCESS*. Again, much of the needed plant architecture is not covered by formal systems.

Figure 9

REPAC Model with plant centric ERP



2. 3.3. CONCLUSION

Hydrocarbon Online (1999: http://news.hydrocarbononline.com/info-tech/19980914-4955.html) concludes as follow on the REPAC explanation by Swanton:

"The key to this model, says Swanton, is that plant owners can choose what business systems occupy what parts of te overall process. A company with centralized ERP (that is, ERP being handled mainly at headquarters) could choose not to implement ERP at the plant level, and to keep planning and scheduling a corporate IT function. A company with "plant-centric ERP" could seek to integrate ERP modules on the plant floor, and to tightly link production and planning. 'Set an architectural direction for your plant,' Swanton advises, 'and then buy products on the basis of their fit with the architecture.' Swanton adds that this model guides the user to integrate various systems only as necessary to meet business goals.

Two other important issues are brought forward by the REPAC model:

1. There is great potential for the integration of MES with the supply chain and business models should reflect this.
2. MES business models and concepts are evolving at a high rate.

To achieve a better understanding of the second issue, the evolution of MES related concepts are investigated in the following chapter.

3. THE EVOLUTION OF MES

"Even before manufacturing execution systems (MES) became a defined category of industrial software used to control manufacturing operations, many manufacturers had been using some form of MES either manually or by computer point solution."
(Hakason,1996:26)

Factors, which influence the evolution of MES, are categorized (for purposes of this investigation) as follow:

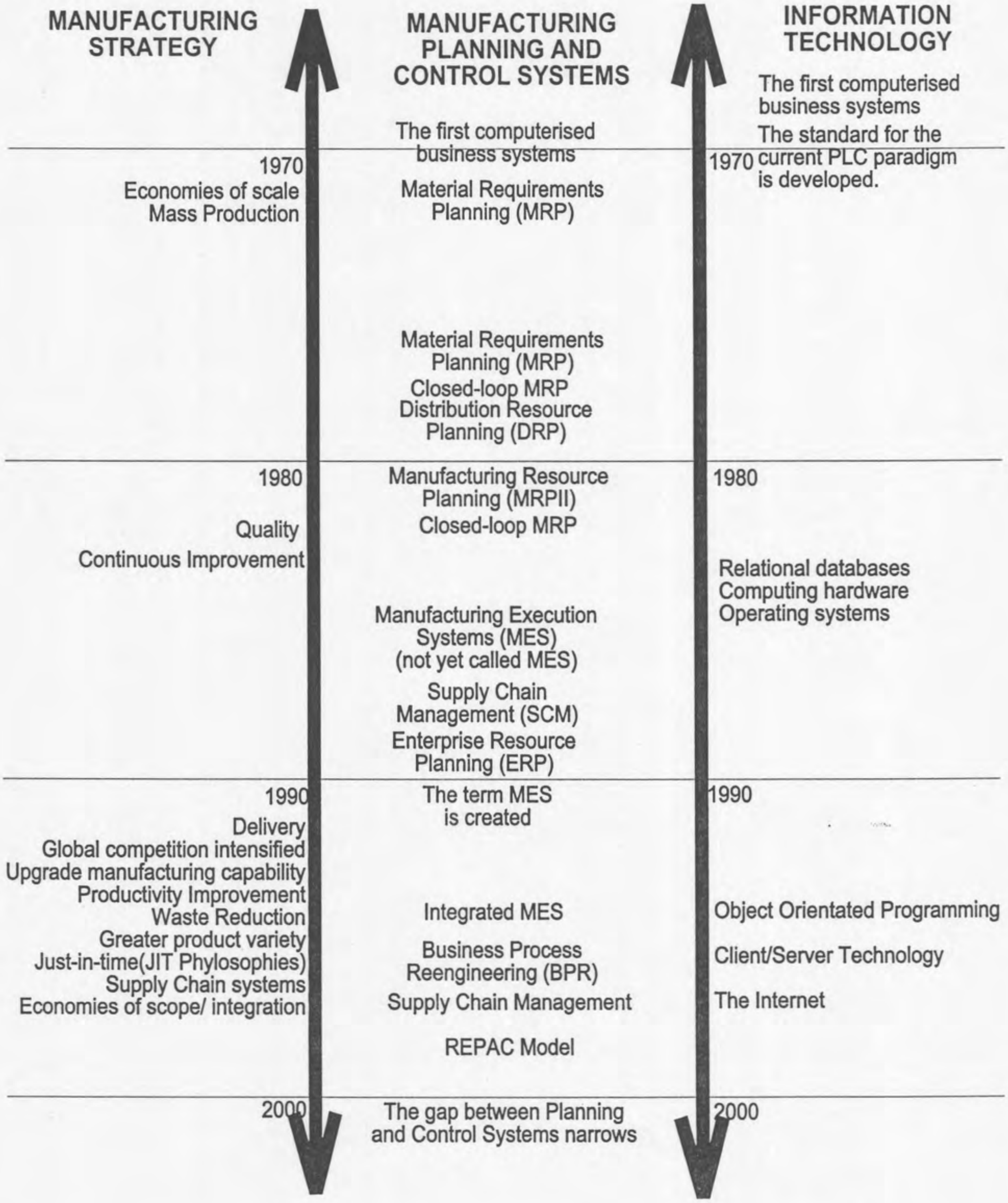
1. Manufacturing strategy
2. Manufacturing Planning and Control Systems
3. Information Technology

Trends within these categories are indicated on the same time scale in *Figure 10*. In this chapter each of these areas is discussed accordingly.

CONTENTS OF THIS CHAPTER

Figure 10

The evolution of concepts related to MES



3. 1. THE EVOLUTION OF MANUFACTURING STRATEGY

"Despite advances in manufacturing and computer software technologies, most manufacturers are basically managing their shop floor activities the same way they were twenty years ago. If you visited the computer rooms or looked over a planner shoulder, you'd find dated computer systems and timeworn management strategies, which simply don't fit the new realities of global manufacturing."

(MESA International,1997:www.MESA.org/html/main.cgi?sub=32)

Table 5 is an extract from a figure drawn by Chase (1998:41). MES can be positioned as an information technology based solutions to accomplish business integration, agile manufacturing and flexibility.

Table 5

Evolving Management Perspectives

	1920 – 1980s	1980 - 1990	1990 - 1995	1995 - 2000	2000 & beyond
	Mass production	**Lean production**	**Agile manu-facturin**	**Agile manu-facturin**	**Strategic agility**
Competitive priorities	Cost	Quality	Delivery	Flexibility	Knowledge factory
Process criteria	Scale efficiencies	Continuous improvement	Time/ quick response	Economies of scope/ integration	Mass personalizatio n/ economies of knowledge
Source of value added	Capital/ muscle power	Local infor systems/ work teams	Supply chain systems/ cross functional teams	IT enabled processes. Process expertise & relationships.	Intelligent systems/ communities of practice

According to Willis (1998:83), the dominant theme from the 1950s and into the 1970s was economies of scale using mass production. Large facilities built to produce huge quantities of goods required complex organizational structures for sufficient management and control. Conventional wisdom at the time dictated that low unit cost was achieved by spreading fixed costs over the largest possible volume of output. Quality was the dominant theme by the 1980s as US manufacturers were pressured to match the higher quality offerings of foreign producers. Statistical process control (SPC), employee involvement in quality assurance programs, and improved product design were key elements of quality improvement. Globalization (in the late 1980s and early 1990s) necessitated the upgrade of manufacturing capability.

3. 1.1. GLOBAL COMPETITION

The emphasis was placed on continuous improvement and waste reduction (as part of the JIT / TQM philosophies). More effective planning and control were required from planning systems, such as manufacturing resource planning (MRP II).

To survive companies have to adapt to rapidly changing markets. More suppliers are competing for the same customers with high quality, reasonably priced products. As part of the JIT philosophy, the emphasis has shifted towards partnerships with customers and suppliers. Since customers require more and more flexibility, manufacturers have to produce exactly what the customer wants, in a fraction of the time and at a fraction of the cost of the old methods. To be responsive and adaptive, organizations need to focus on the processes required to meet specific customer demands. (MESA International,1996:www.MESA.org/html/main.cgi?sub=32)

3. 1.2. AGILE MANUFACTURING

Flexibility, speed, and responsiveness to the customer are increasingly recognized as the critical order-winning criteria (and even order-qualifying criteria) for competing in the restructured markets. Agile manufacturing seems to be the solution to meeting customer demands for products in less time at lower costs.

Matthews (1996:www.atp.nist.gov/www/comps/briefs/95120024.htm) explains that lean production entails the enhancement of the mass-production (repetitive manufacturing) process, on the one hand, as well as the production of highly customized products, on the other hand:

- In the first instance, the elimination of inventory, defects, waiting and other forms of waste have shorter lead times, improved quality, and a higher level of customer service as result.

- Highly customized products are produced in an attempt to satisfy a wider spectrum of customers.

Lean production refer thus to the ability to deliver the right quantity of a unique product to the customer when and where required - all for a price equal to mass production conditions.

(Matthews, 1996:www.atp.nist.gov/www/comps/briefs/95120024.htm) continuos by arguing the agile manufacturing is a key to success, in particular for small and medium-sized companies, competing against lower-cost products from foreign producers. The weekly - or even monthly - batch generated production plans are not acceptable in the lean production environment. MES enable real-time (or near real-time) reaction to these plans and contribute accordingly to the lean production ability.

3. 1.3. CONCLUSION

- It does not come as a surprise that the term MES, MES definitions, business models and functional definitions are created and developed concurrent with manufacturing strategies.
- Valstar (1998:www.valstar.co.uk/MES/index.htm) remarks that because agile manufacturing became imperative in the fast-changing, global competitive environment, manufacturers increasingly make use of MES to improve the ability to respond to change.
- According to MacDonald (1998:www.consilium.com/Publications/roi.htm) manufacturers adopt integrated MES software packages for the same reason they turned to MRP II in the 1970s, namely to gain competitive advantage in world markets.
- MES products were first adopted in industries with high value products, complex or unstable processing, or heavy governmental regulations (eg. semiconductor manufacturers, prime contracts in the aerospace and defense industries and makers of pharmaceuticals). MES packages are gaining wider acceptance as

industries are faced with customers demanding better delivery performance and higher levels of quality at lower cost.

As manufacturing strategies evolves, so does the systems, plan and control manufacturing - as discussed in the remainder of this chapter.

3. 2. THE EVOLUTION OF MANUFACTURING PLANNING AND CONTROL SYSTEMS

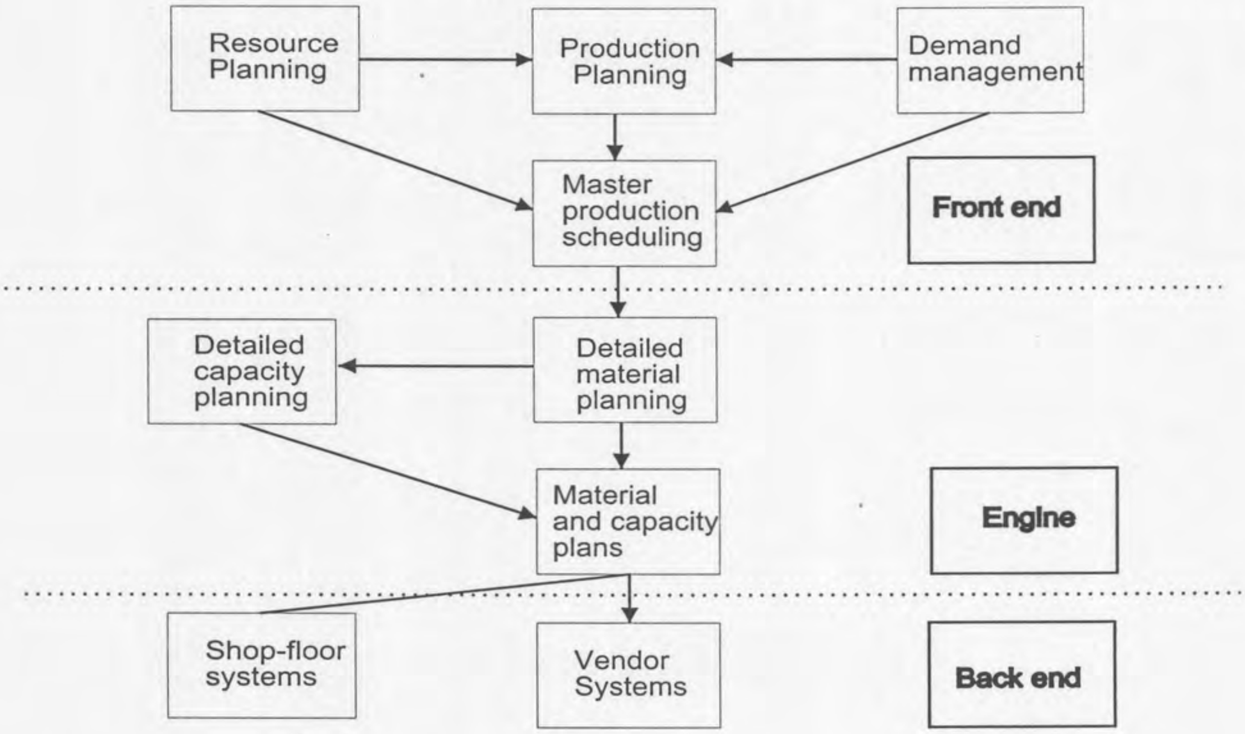
"MES applications are designed to integrate the manufacturing enterprise and empower production to play a strategic, competitive role. MES's strategic "fit" lies between corporate planning systems, like MRP II, and factory-floor equipment." (Valstar,1998:www.valstar.co.uk/MES/index.htm)

"As the information technology revolution was taking place MES grew up out of automated data collection systems, and like the evolution of MRP into MRPII, functionality was added bit by bit, until a functional critical mass established a clear point of differentiation."(Valstar,1998: www.valstar.co.uk/MES/index.htm)

Figure 11 (on the following page) indicates how the interaction of between planning and control was modeled before the term MES was created and integrated (Vollmann,1991:5).

Figure 11

Manufacturing Planning and Control model, before the creation of the term MES



Volmann (1991:4) explained this model as follow:

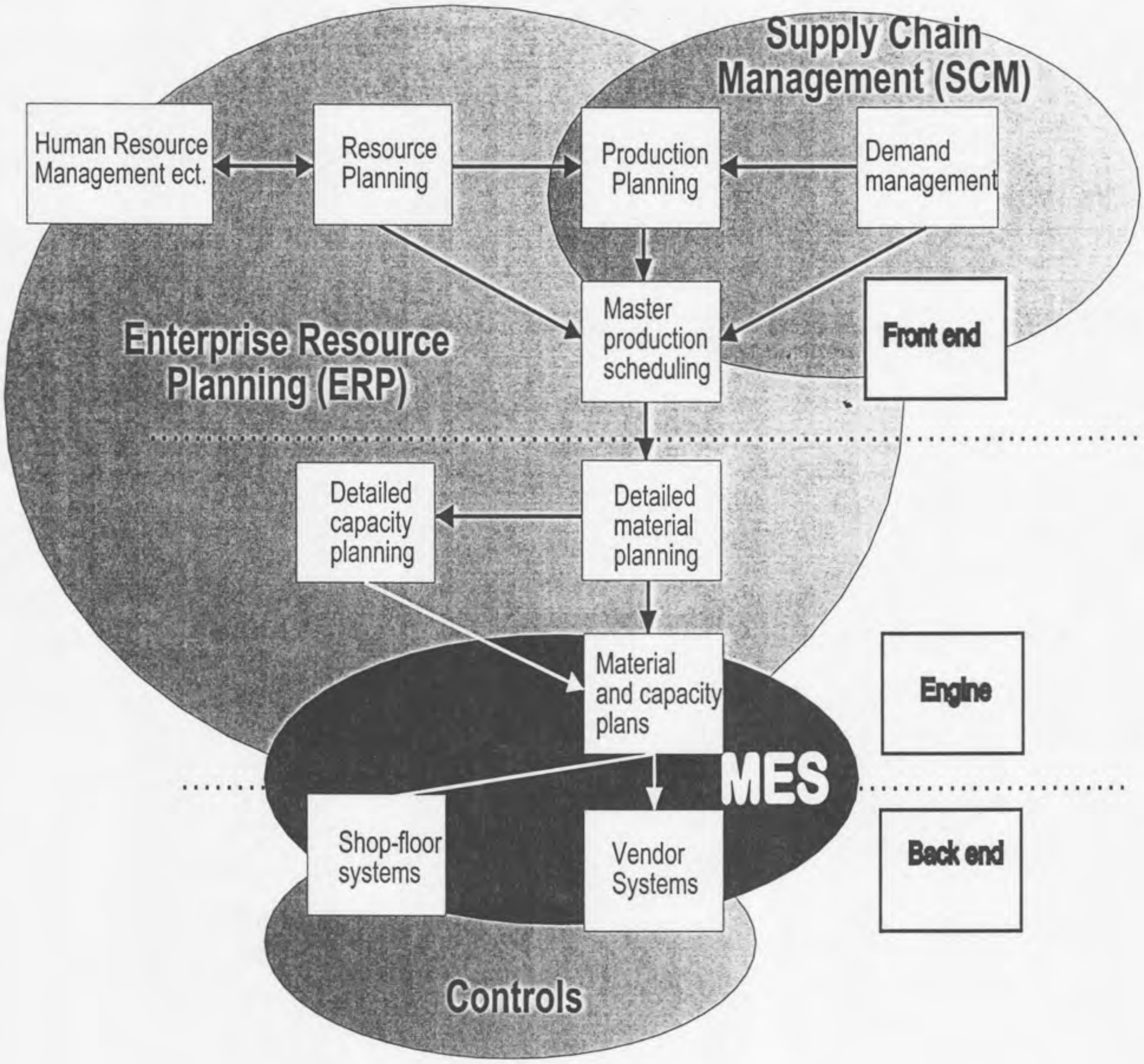
"In any firm, manufacturing planning and control encompasses three distinct aspects or phases:

1. Create the overall manufacturing plan for the manufacturing part of the company game plan.
2. Perform the detail planning of material and capacity needs to support the overall plans.
3. Execute these plans on shop floor and in purchasing."(Vollmann:1991:4)

Figure 12 illustrates the relationship between the Volmann model and the MES model from MESA International. The communication gap between the planning and control layers, as well as the lack of bottom-up communication is clear. To investigate the development of business models from the model of Volmann (*Figure 3*) to the Three-Layer-Model (*Figure 11*) the evolution of elements of these models are subsequently evaluated.

Figure 12

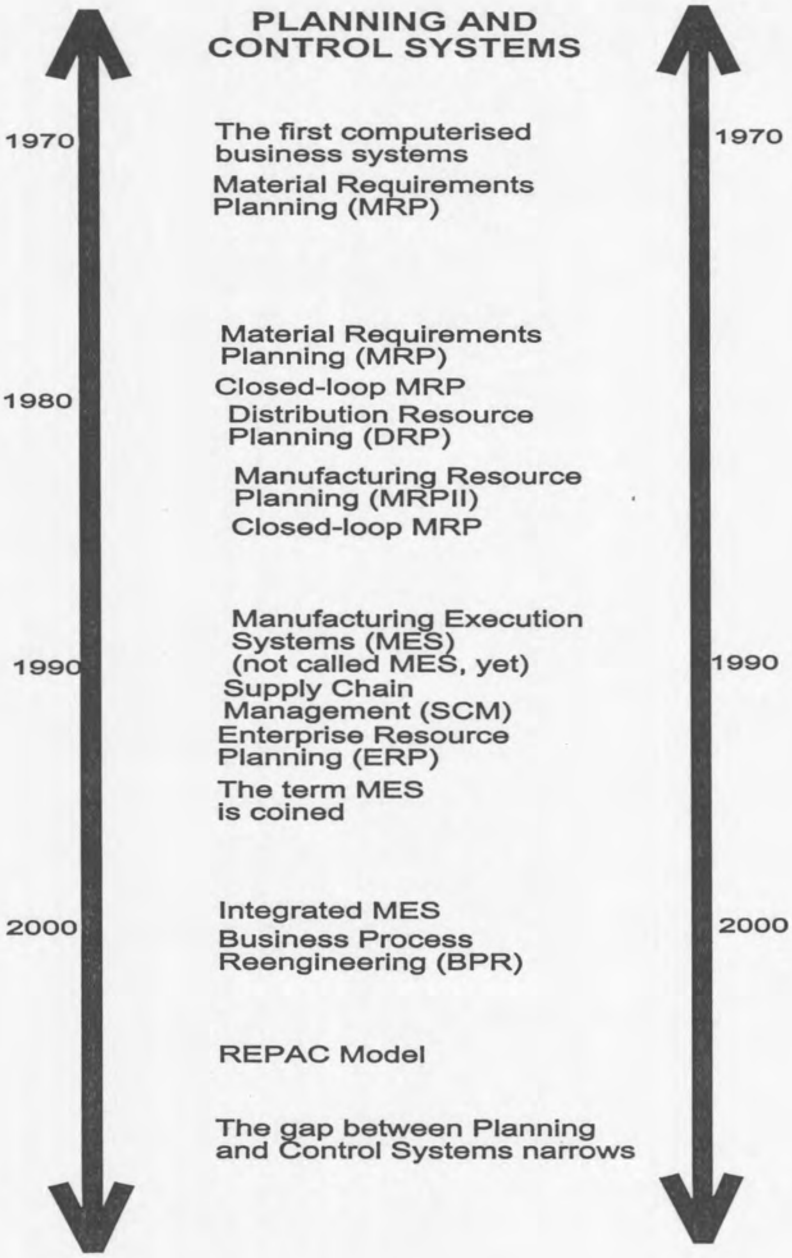
Business model before the coining of the term MES (Volmann) related to business model after the coining of MES (MESA International).



The evolution of manufacturing planning and control systems, since 1960's is illustrated in *Figure 11* on the following page. This evolution is discussed thereafter.

Figure 13

Overview on the evolution of Planning and Control Systems



1960s - 1970s

The first computerized business systems were used in accounting. By the late 1960's / early 1970's material requirements planning (MRP) evolved from these accounting systems. MRP was intended to help manufacturers better plan material availability. (MESA,1996:www.MESA.org/html/main.cgi?sub=32)

As far as the control layer is concerned, the development of Programmable Logic Controllers (PLC's) can be regarded as a milestone. Ross (Handbook,1992:1915) predicted that PLC technology will be incorporated more and more into the total control system. However, Marks,1997:www.industry.net/nmw97/MES1d.htm, draws attention to the fact that PLC technology did not develop by the same rate as computer automation in general: "The current PLC paradigm is based on a 1968 specification.The notation for programming was relay ladder logic, which was similar to electrician's notation for wiring diagrams. The PLC was the hardware platform PLC, a specialized computing device with very fast and deterministic logic solving capabilities for controlling machinery and devices in a safe and reliable fashion."

1970s – 1980s

Computers became were more powerful and capable of handling more data and being used interactively by more people. By the late 1970s and early 1980s MRPII (Manufacturing Resource Planning) evolved from MRP (Material Requirements Planning). MRPII systems have the additional ability to incorporate capacity constraints into the planning process. Other functions, such as shop floor reporting and purchasing are added to MRPII.

However, there were still business areas and processes, which were not covered by MRPII. Distributions Resource Planning (DRP) systems were developed to address the requirements in distribution, while certain shop floor solutions (such as quality control systems) emerged to manage the shop floor and react in real-time. A number of other unique, function-specific systems evolved as well. Specific business problems were solved with these systems. However, the advantage of data from other systems did not exist, since these systems were not commonly integrated.

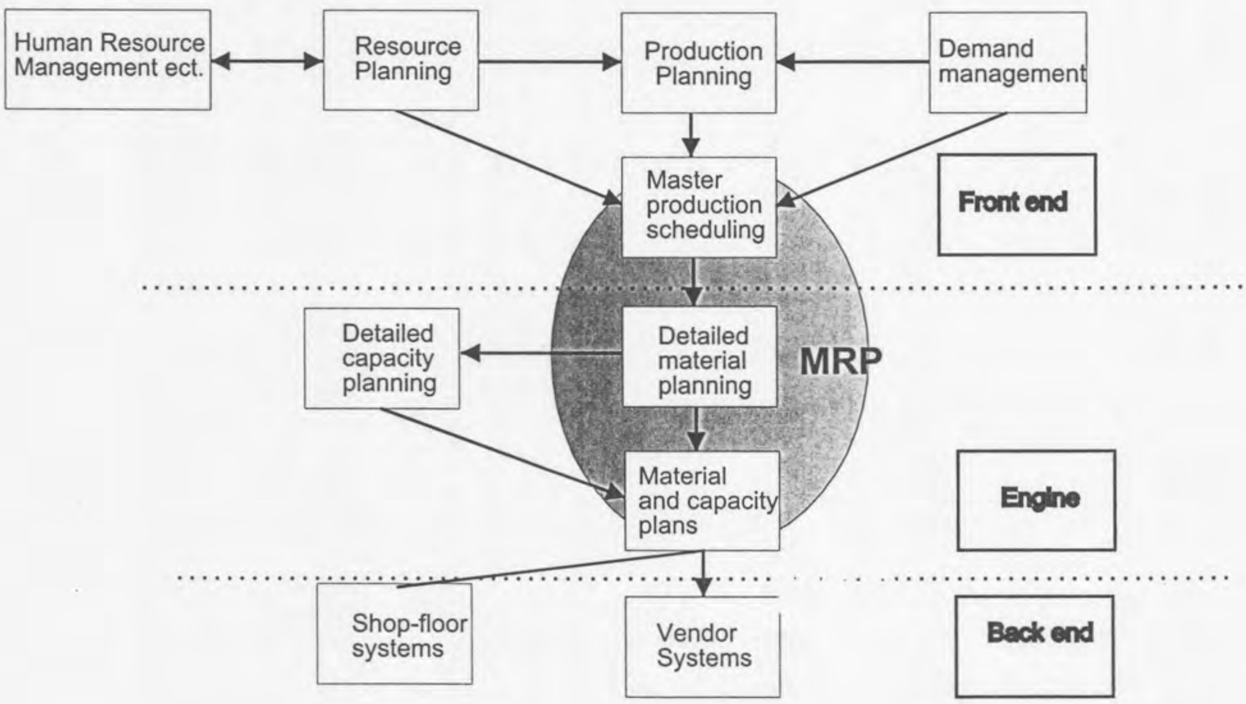
As far as the control layer is concerned, memory and processing capabilities of PLC's - as well as the number of instructions handled – by the PLC's – became more powerful. However, the software to manage and the communications between these devises did not develop at the same rate. Marks (1997:www.industry.net/nmw97/MES1d.htm) explains that the functions of control systems developed from a device control and safety perspective and not from a data management and information sharing perspective.

1980s - 1990s

In the late 1980s and early 1990s, another generation of systems became available. The aim of these systems was to establish total solution integration. (Thus solving the "islands of information problem"). Enterprise Resource Planning (ERP) developed accordingly from MRPII. Likewise Supply Chain Management developed from ERP and the shop floor solutions evolved into integrated MES. In all cases, solution-focused systems, such as quality or maintenance management, remained viable alternatives for companies which required more functionality that that available in the integrated solutions. (MESA,1996:www.MESA.org/html/main.cgi?sub=32)

3. 2.1. MATERIALS REQUIREMENTS PLANNING (MRP)

According to Vollmann (1992:15) the detailed material planning function in the engine portion. For firms preparing detailed material plans using MRP, this means taking a time-phased set of master production schedule requirements and producing a resultant schedule and material plan.



*"MRP is a set of techniques that uses bills of material data, inventory data, and the master production schedule to calculate requirements for materials. It makes recommendations to release replenishment orders for material. Further, because it is time-phased, it makes recommendations to reschedule open orders when due dates and need dates are not in phase." (APICS,1999:*www.apics.org/Dict/*)*

"MRP refers to the techniques of using a projected manufacturing productions schedule to figure out what supplied materials you will need (bills of material), and when you will need them. MRP is a simple technique, but does not take into account any constraints on the resources, or deviations from the schedule, and hence, when used in isolation can produces infeasible solutions." (Hicks,1995:14)

Chase (1995:588) explains that MRP systems determine the type and quantities of products as well as the raw material and components needed in a logical and easily understandable way. MRP also provides the time schedule specifying when each of these materials, parts, and components should be ordered or produced. The simplicity of these systems contributed to the universal installation of these systems in manufacturing companies.

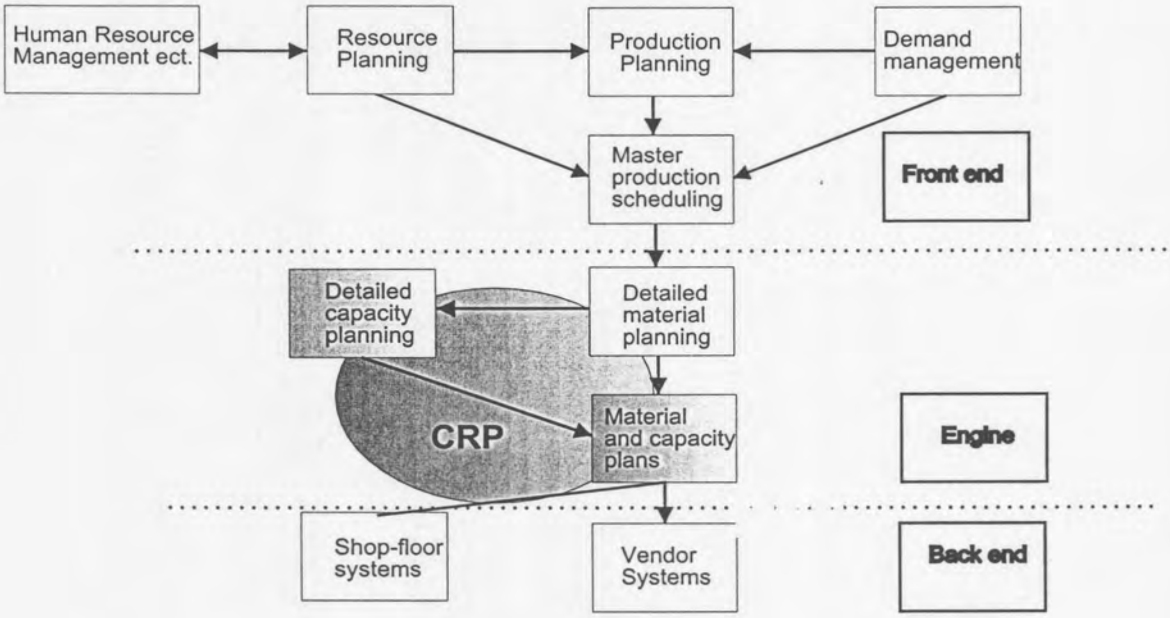
However, original MRP planned only materials. Thus, out of the original MRP systems, some enhancements were made, concurrent with advancements in Information Technology. The following functions were added gradually:

- order entry,
- forecasting,
- distribution requirements planning,
- resource requirements planning,
- master production scheduling,
- capacity requirements planning,
- shop floor control,
- purchasing and cost accounting.

When accounting and financial applications were added in the early 1980s, the name changed to MRPII to reflect these enhanced capabilities. (Marks,1998:www.industry.net/nmw97/MES1d.htm)

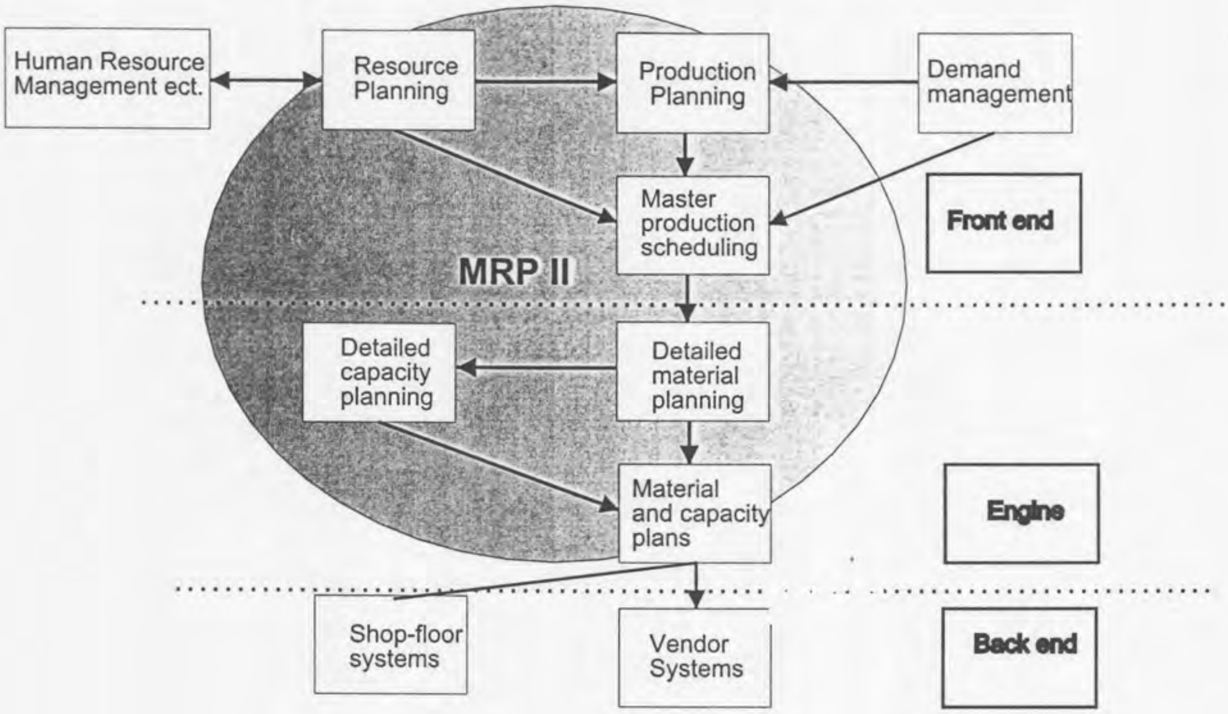
3. 2.2. CAPACITY REQUIREMENTS PLANNING (CRP)

"By tying in actual productions data and resource constraints MRPII is able to produce feasible productions plans to help stabilize and control manufacturing systems. Capacity planning tools typically perform a similar function: matching up production plans and schedules with available capacity." (Hicks,1995:14).



APICS (1999:www.apics.org/Dict/) explains that the CRP systems translates open shop floor orders and planned orders (from the MRP system) into hours of work by work centre by time period. This is done through the use of parts routings and time standards. The CRP systems may identify specific time periods of insufficient capacity, not anticipated by the rough-cut capacity plan.

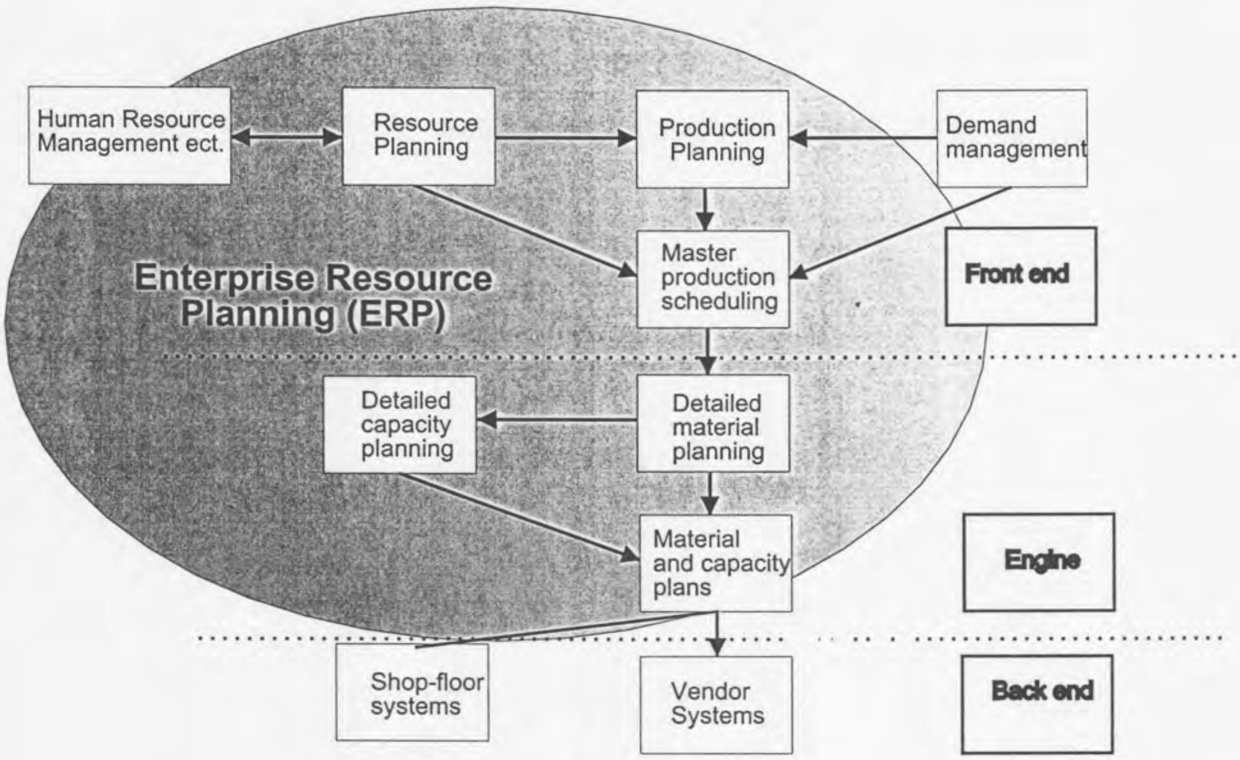
3. 2.3. MANUFACTURING RESOURCE PLANNING (MRPII)



"MRPII is a method for the effective planning of all resources of a manufacturing company. Ideally, it addresses operational planning in units, financial planning in dollars, and has a simulation capacity to answer "what if" questions. It is made up of a variety of functions, each linked together: business planning, sales and operations planning, production planning, master production scheduling, material requirements planning, capacity requirements planning, and the execution support systems for capacity and material. Output from these systems is integrated with financial reports such as the business plan, purchase commitment report, shipping budget, and inventory projections in dollars. Manufacturing resource planning is a direct outgrowth and extension of closed-loop MRP" (APICS,1999:www.apics.org/Dict/)

As shop floor control improved, attention was given to the creation of a viable master production schedule, as well as the maintenance thereof. The term "closed loop MRP " emerged as better master production scheduling was incorporated into MRP-based Manufacturing Planning and Control (MPC) systems. Additional enhancements of closed loop MRP included better capacity planning procedures at the front end, engine and back levels. It was now possible to include financial plans based on the detailed Manufacturing Planning and Control process. Simulation possibilities were added along with various ways to examine "what-if" scenarios. From this Oliver Wright coined the term Manufacturing Resource Planning (MRPII) (Vollmann,1991:15).

3. 2.4. ENTERPRISE RESOURCE PLANNING (ERP)



Controls

"Enterprise Resources Planning (ERP) consists of those systems that provide financial, order management, production and materials planning, and related functions. The modern ERP systems focuson global planning, business processes and execution across the whole enterprise (intra-enterprise systems), with an accrued recent importance of aspects like supply chain planning and the whole supply chain management aspects and extending to include the whole enter-enterprise supply chain." (Object Management Group,1998:5)

As manufacturing has grown to serve larger markets, so has the complexity of such coordination. In its current state of evolution, manufacturing resource planning requirements have been expanded to envelop the entire manufacturing enterprise. Although the enterprise requirements planning (ERP) model has succeeded in coordination of plans, it has fallen short in supporting the actual achievement of those plans. (Consilium,1998:www.consilium.com/Publications/gap.htm)

These systems include ability to manage multi-plant and multi-country operations, have preventive maintenance modules, advanced scheduling and planning, utilize expert system-based scheduling and artificial intelligence, and include enterprise logistics planning. These systems are now called enterprise resources planning (ERP) systems. (Marks,1997:www.industry.net/nmw97/MES1d.htm)

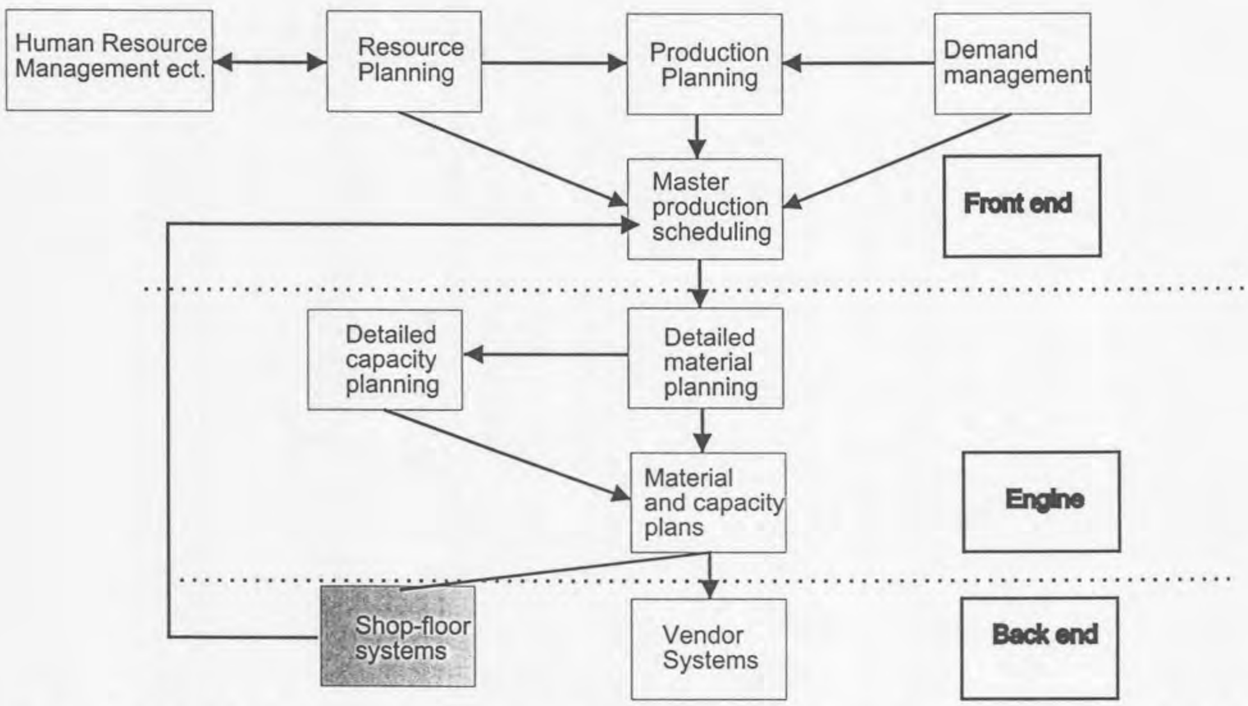
The focus and strength of MRP II or ERP is as a planning and accounting tool. Forecast inaccuracy, duality problems, capacity bottlenecks and inefficiency can undermine the best plans, leaving production scrambling. ERP doesn't make these problems visible until after they have occurred and does not provide sufficient information for correction or prevention. ERP cannot resolve these achievement gaps. Capacity, labour or overhead, and inventory must compensate for this lack of achievement. In addition, ERP does not plan overhead activity in support of manufacturing operations such as receiving, production set-up and qualification, neither for quality assurance. ERP can report that a batch of product was scrapped for inferior quality. Information regarding the cause exists completely outside the ERP planning and coordination model. Actual production configuration and processing measures are not available through ERP. (Consilium,1998:www.consilium.com/Publications/gap.htm)

Integration is the underlying foundation of successful ERP systems and is vital on several levels: ERP must transcend information technology boundaries to enable true data sharing across business disciplines; ERP must integrate with plant systems, and increasingly, ERP must integrate with advanced planning systems to achieve the decision support necessary in a world of closely linked suppliers and customers.

For manufacturers, the most urgent need is the integration of plant and ERP systems. For plant managers, the greatest benefit to be derived from extended ERP systems is the ability to generate feasible production plans that optimize manufacturing execution with customer demand. Sharing accurate data allows planners to achieve greater utilization of plant capacity and materials so that optimized manufacturing plans are created.(Mazzoni,1998: www.arcweb.com/arcsite/Search/search.asp)

The ERP system provides MES with manufacturing orders and receives status information from the MES. Other information must be shared such as part numbers, BOMs, and routings, with MES maintaining a higher level of detail than the ERP system. For example, ERP maintains a BOM for material planning, while MES maintains a detailed BOM containing all subassemblies, options and consumables for actual operation dispatching and control. An ERP routing can be limited to equipment classes or work centers for the purposes of capacity planning while the MES can maintain a much more detailed routing needed by manufacturing, equipment units, utilities, labouratories, staging areas, and maintenance. (Consilium,1998:www.consilium.com/Publications/gap.htm)

3. 2.5. PRODUCTION ACTIVITY CONTROL AND CLOSED LOOP MRP/MRPII



The function of shop floor control is to have activities performed as planned, to report on operation results, and to revise plans as required to achieve desired results. The shop floor control system also closes the control loop by measuring actual output and comparing it to plan. Thus, shop floor control systems is an essential component of closed loop MRP (Fogarty,1991:448).

Production activity control (PAC) concerns the execution of detailed material plans. It describe the planning and release of individual orders to both factory and outside vendors as well as detailed scheduling and control of individual jobs at work centers on the shop floor. Vendor scheduling is also the concern of PAC. An effective PAC system can

- reduce work-in-process inventories and lead time as well as
- improve vendor performance.

A key element of an effective PAC systems is feedback on shop and supplier's performance against plans (Volmann,1997:165).

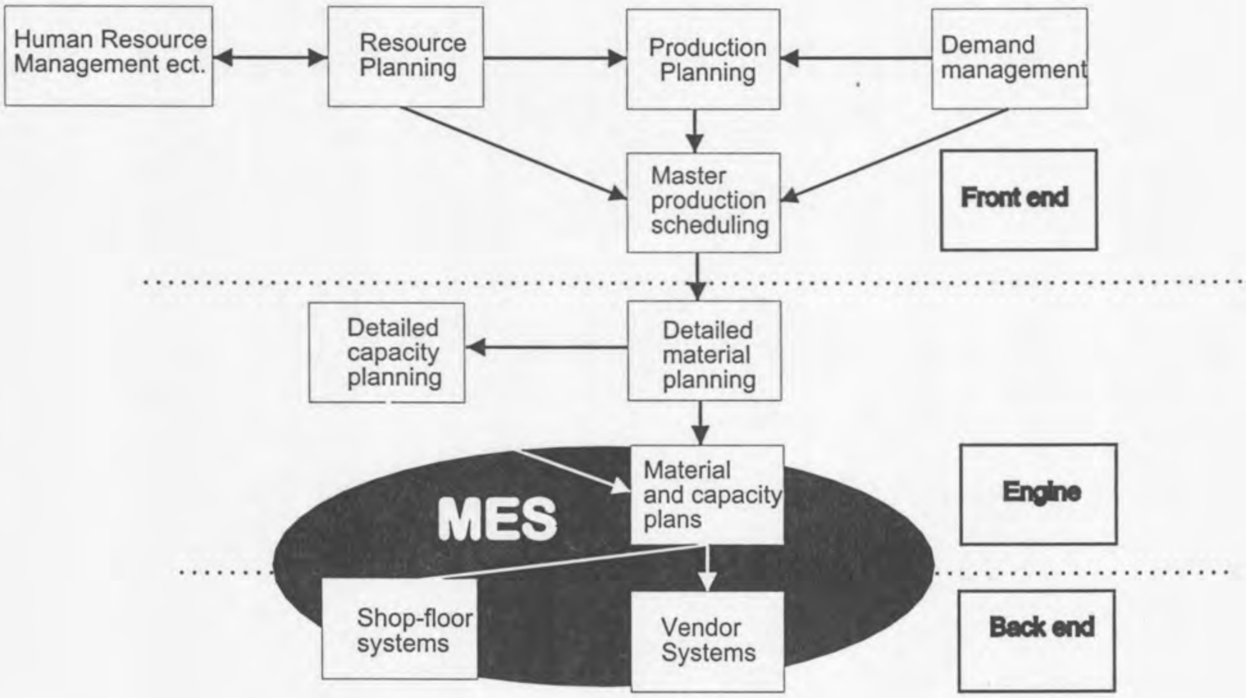
The extension of the definition of production activity control is accentuated by the growing use of computers on the shop floor and electronic data interchange (EDI) with vendors. As more and more traditional staff work is integrated into the basic manufacturing infrastructure, it will expand PAC as well (Volmann, 1997:167).

"Subsequent sophistication of MRP by adding feedback of actual results has led to closed-loop manufacturing resource planning (MRPII). Shop floor control and vendor control systems are added to the existing software so that revisions of dates and quantities will be taken into account in the next planning systems."
Degarmo,1997:1188).

The conclusion can be made that PAC is part of MES. PAC occurs, however, often in batch mode, while MES communicate with controls in real time.

3. 2.6. MES CLOSES THE LOOP IN REAL-TIME

"What ERP is to the top level of enterprise management, MES are to the intermediate level. MES concerns itself with the management of the locally owned facilities and with the coordination of centers of productivity, typically within the building. MES organizes the plant floor, tracks the plan, and as a result, improves productivity. ERP and MES, when coupled with real-time control on the factory floor (PLCs etc.), constitute the full communication and computer integration between all aspects of the enterprise." *(Morley,1998)*



Close-loop MRP/ MRPII seems to be a form of manufacturing execution. Closed loop MRP/ MRPII occur, however, in batch mode, while real-time reaction is an essential characteristic of MES. The type of reaction within MES is also of much more detail than with closed-loop MRPII.

Unlike material resource planning and enterprise resource planning that enable manufacturing planning, MES technology provides a real-time window into the shop floor thereby enabling manufacturing executives to control production more effectively

and see the product as it moves toward the customer.
(Hakason,1997:www.arcweb.com/arcsite/Search/search.asp)

MRPII and ERP

McClellan (1997:12) explains that these planning systems are in principle reactive. Changes are only detected and reported. These systems react to daily plant floor changes. However, the demand for a flexible business environment, entails pre-active systems that can anticipate changes. MRPII systems were essentially designed to integrate all the operational functions of a manufacturing organization, from engineering through production, and replace a reactionary management culture with top-down planning disciplines (Martin,1995:32). The replacement of the ability to manage reactively has, however, not replace the need to react on changes. Without replacing MRPII systems, MES is integrated to business systems, to enable the necessary bottom-up reactionary management.

Manufacturing Resource Planning (MRPII) and Enterprise Resource Planning (ERP) systems were taken on as system efforts that could close the production knowledge loop. These solutions offered the promise of having production respond to delivery commitments. Reynolds (1998:81-83) explains, however, that more detailed tracking and quality information are demanded by customers. Due to the gap caused by the lack of information from the plant floor, this demand cannot be addressed. Within this new manufacturing environment real-time systems is needed to plan, schedule and execute the operations strategy effectively and efficiently. (Willis,1998:84)

Capacity planning

Through MES manufacturers can gain real-time visibility to capacity constraints. Potential capacity problems or bottlenecks can be anticipated before they occur. Shop floor and support department activities can be coordinated so they execute work assignments as a synchronized operating unit. Capacity planning should still be done by the CRP system. MES should provide the management of value-added manufacturing activities on a minute-by-minute basis. (MESA International,1996)

3. 2.7. NARROWING OF THE GAP FILLED BY MES

(a) NARROWING OF THE GAP BY THE CONTROL LAYER

The MMI/SCADA functionality is more closely tied to control strategies than MES installations. But, where MES are installed in highly automated environments, the MES must be interfaced to the MMI/SCADA application to read and write to the tag database to access data in PLC registers. In fact, developing interfaces to MMI/SCADA systems provides access to the device PLC drivers within the MMI/SCADA packages so MES vendors need not develop their own PLC drivers. When considering MES functionality, it is important to realize that the functionality is dispersed across distinct, albeit converging and blurring markets - the MMI/SCADA market and the MES market.

Many of the MMI/SCADA vendors have MES products available through their sales channel. These products can include recipe and batch management modules, discrete MES modules, and others. It is important to understand that MMI/SCADA applications do add value to MES implementations by providing a graphical view of plant-wide operations, which many MES systems today cannot provide. (Marks,1997:www.industry.net/nmw97/MES1e.htm)

Major control companies are increasingly attempting to provide total industry solutions that may include control hardware and software, advanced control applications, material handling equipment, and production management software. Control companies are looking to enter this arena because of the potential market value of this adjoining industry. Market value is migrating away from hardware-based to software-based solutions. This is being driven by a decreasing proportion of manufacturer's capital budget spent on industrial equipment versus an increasing proportion spent on information technology (Automated Research Corporation,1998: www.arcweb.com/ARCsite/MktStudies/mktstudies.htm).

(b) NARROWING OF THE GAP BY THE PLANNING LAYER

Developers of planning systems are continuously adding MES functions to their products.

According to AIS (1999:http://www.aistech.com/workinp/workinp_wp_fm.html) changes in the Manufacturing Execution tools will be required for all ERP systems. For efficient shop floor operations the following in ERP systems are suggested by AIS and listed in *Table 6*. Many ERP vendors add similar (tradional MES) functions to their systems.

Table 6

Anticipated ERP changes

Traceability	Traceability requirements increase in a fast moving environment in keeping with the improved customer responsiveness. Almost every company needs some form of traceability whether it's the detail required by the government for medical devices production or it's the maintenance requirements of a pump manufacturer.	A preferable solution allows the enterprise to turn on Serial Control part way through the process, for historic traceability requirements. This would allow the factory to enter the serial number when the component is included in an assembly or when the finished product is received in inventory. Additionally, component traceability and the ability to relate work orders to sales orders, especially when the product cycle time exceeds one day, needs to be added. Traceability by transaction type, whereby users could select to trace by work order transaction but not by inventory move would be beneficial.
KANBAN Pull Techniques	These techniques of delivering only the goods necessary to manufacture a product when they are required means that the ERP system has to respond and coordinate this information. Triggers when the KANBAN reorder signal is issued need to inform the ERP system , which can then track and report on supplier information.	KANBAN replenishment is triggered by a signal from the shop floor. Physical replenishment will be handled by the visual signaling system. Computer tracking, via a fast and efficient interface, either code or dedicated terminal, keeps inventory and supplier information up to date. External replenishment, i.e. requesting a KANBAN from a supplier, is used to update Supplier Schedules in order to track of supplier performance.

Table 6 (continued)

Anticipated ERP changes

Supplier Schedules	Supplier Schedules in most ERP systems work well but need a lot of data maintenance to keep them current. Current Supplier Schedules functionality is not set up for Manufacturing Execution: there is too much focus on maintaining cumulative quantities to make them useful at the execution level. However, with some modification they could form the foundation of KANBAN signaling to suppliers.	Any solution needs to recognize a consumption signal that triggers the KANBAN replenishment. Supplier performance is measured by response to KANBAN signals rather than adherence to a delivery schedule. This also indicates a change in the way supplier performance is reported. The same kind of functionality could also be used to signal KANBAN replenishment between cells in a production line.
Available To Promise	The basis for calculation of ATP shifts in the Manufacturing Execution environment from a product focus to a capacity focus. Most ERP/MRP systems currently calculate ATP by product. In order for a user in a Manufacturing Execution environment to be able to promise an accurate delivery date to a customer, ATP needs to be determined by a two step process. First, the capacity availability of the environment must be determined and second, the components availability is determined.	In order to help sales team, an access window from the sales order entry module should be available. In this manner, the sales team has quick and reliable access to the ATP information as the sale order is being entered.
Product Configuration	As part of the drive to meet customer needs, product options will increase in number. Product Configuration is an important function and must respond to marketing and production needs. Current Product Configuration functionality does not meet the requirements of a Manufacturing Execution enterprise.	Other manufacturing policies, such as Product Postponement, influence the timing of final assembly and change how products are planned, produced and shipped. The planning and execution tools need to address alternate configuration and assembly options.
Sales Order coupling/integration with Daily Production Schedule	In a Manufacturing Execution environment, items are only produced in response to specific demand, which includes Customer Orders and Finished Goods replenishment orders.	The link between the demand and production needs to be maintained right through to Finished Goods inventory.

Table 6 (continued)

Anticipated ERP changes

Backflushing in real-time	Backflush performance is an issue in a fast moving environment. The requirement to backflush all operations at the end of the line can create a record locking situation which degrades system response times.	The Demand Flow model calls for the use of flat Bills of Materials; all subassemblies and phantoms are eliminated. Adoption of shallow BOMs would enable backflushing to be processed more rapidly. Alternative backflushing procedures are necessary to optimizing performance.
Demand Smoothing	A visual interface to a Detailed Execution Schedule makes demand smoothing viable in a fast moving environment. Ideally, forecast and demand over a number of time buckets can be seen and updated on a single screen. This interface should enable evaluation of alternate schedules to calculate the effect on resource and material requirements.	The production planning for a Manufacturing Execution environment requires daily, weekly, and monthly planning, instead of the 6-12 month planning most factories use. The ERP/FM software needs to allow for smaller increments of time for scheduling and planning.

3. 2.8. CONCLUSION

Models and theories around MES as well as the MES market, vendors and integrators will evolve. The way by which manufacturing (and services) is planned and controlled will also change.

McClellan (1997:ix) states that MES are specific only in concept.
The CONCEPT of MES is well established and is integrated inextricably within planning and control systems. Further discussion on the integration of enterprises through information technology is done in the remainder of this chapter.

3. 3. THE EVOLUTION OF INFORMATION TECHNOLOGY

3. 3.1. COMPUTER INTEGRATED MANUFACTURING (CIM)

"A CIM system is commonly thought of as an integrated system that encompasses all the activities in the production system from the planning and design of a product through the manufacturing systems, including control. CIM is an attempt to combine existing computer technologies in order to manage and control the entire business." (Degarmo,1997:1190)

According to Cuttica (1998,www.icsmagazine.com/soft0598.htm) intense competition and time to market imperatives are driving the need to integrate all of the computing systems in a manufacturing enterprise into a comprehensive information technology (IT) structure. Value are added to a business, if the IT architecture and data exchange are understood. The same can be applied to MES. "It is the IT architectures that help MES to enable true enterprise-wide, plug-and-play interoperability among multiple applications."

Before the creation of the term MES, Theodore J. Williams of Purdue University (Handbook,1991:674) described CIM as future trend: *"Plant-wide computer control, computer integrated manufacturing (CIM) and hierarchical computer control systems are all terms describing the expected future trend in all large scale manufacturing (overall optimization, scheduling, coordination and dynamic control of the entire plant by means of a multi -element, distributed yet totally integrated computer system."*

The term MES was created to describe the suite of software that integrates planning and control systems, to establish exactly what Williams described. The conclusion can be made from this that both MES and CIM are attempts to accomplish enterprise integration through information technology. Some investigation is needed to determine whether MES is only an element of CIM or whether it is a concept with its own right of existence.
"Although CIM and MES are very similar concepts, there was significant development during the past few years" (McClellan,1997:ix).

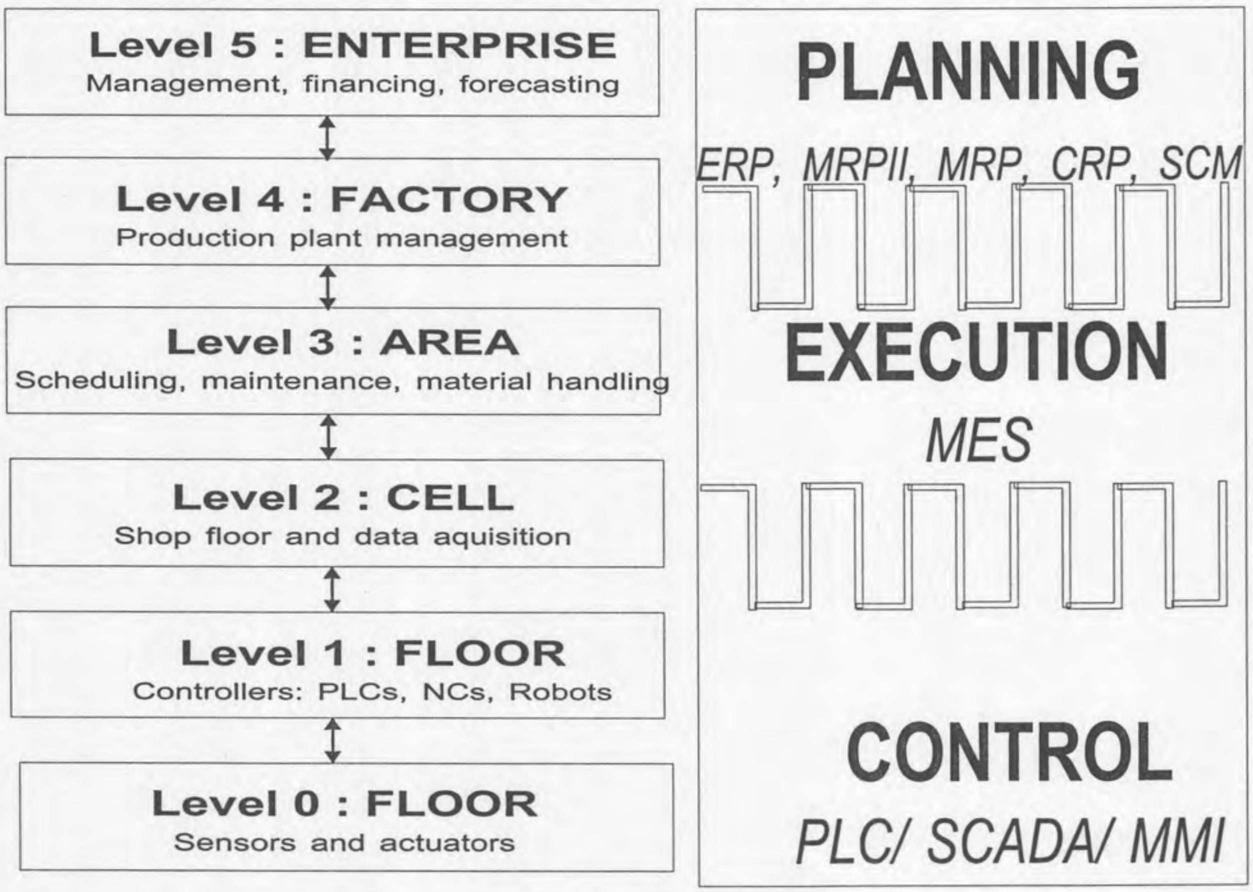
The differences between MES and CIM are related to business models as well as underlying technology. The most significant differences between the business models of MES and CIM are the following:

- The scope of CIM include the entire model, while MES is only represented by the middle layer.
- The CIM-model is more complex and consists of double the amount of layers as indicated in *Figure 14*. Systems based on this model is, thus, much less flexible and reactive.

3. 3.2. BUSINESS MODELS OF MES AND CIM

Figure 1

CIM compared to MES, through business models



3. 3.3. UNDERLYING TECHNOLOGY

MES has taken on broader and, in some cases, totally different meaning, providing the infrastructure that CIM never had. Instead of custom designing software programs on a contract-by-contract basis, MES are based much more on standard reusable application software. The results include lower costs and shorter implementation time (McClellan,1997:ix). Based on the technology of the day MES was modeled in 1993 by AMR Research as a group of functions around a relational database with wired communication connections to Materials Requirements Planning (MRP) and controls.

Swanton (1998:www.amrresearch.com/repac) declared, however, that the way by which MES are using information technology has changed rapidly over the past few years: "*Integration through a common data model on a relational database proved impossible in the plant systems market. No vendor had all the parts, and no one could agree on a common model. The lack of a common data model meant sky-high integration costs.*"

This information technology, doomed by Swanton, is also the basis for CIM: *"Computer-integrated manufacturing systems as basically a network of computer systems tied together by a single integrated database".* This may one of the reasons for the low success rate of CIM – as explained by Degramo(1997:1190): *"CIM is an approach that very few companies have adopted at this time, since surveys show that only 1%-2% of U.S. manufacturing companies have approached a full-scale use of FMS and CAD/CAM let alone CIM systems."*

According to McClellan (1997:ix) several application disappointment is to blame for the fact that CIM has fallen in total disuse. A detail study of underlying information technology does not fall within the scope of this dissertation, nor has the author the authority to comment on this. It is, however, clear from the study of CIM that information technology and management needs to be considered.

" The removal of production bottlenecks increases the effectiveness and efficiency of manufacturing processes. Through native drivers or ODBC and OPC interfaces, MES can directly connect the computing environments, allowing real-time decisions to influence the running of the business. And through Internet/intranet tools, production managers can view production trends or other plant information from anywhere in the world. Finally, some MES tie into existing email systems, and can use this technology to generate alarms and provide production updates to selected personnel.

(Guttica, 1998:www.icsmagazine.com/soft0598.htm)

3. 3.4. THE INTERNET

According to CIMx (1998:www.cimx.com) the explosive growth of Internet is encouraging the use of Internet technology to build Intranets in large companies. The growing need for major improvements in manufacturing productivity creates an opportunity to achieve breakthroughs in the use of these new information technologies for next generation products and services. Technology now enables large scale implementation of inexpensive distributed networks of personal computers and network computers for manufacturing firms where only expensive workstations were previously used. Installations can take place over time to suit the customer. Each cluster can be fully justified economically and functionally before proceeding with the next phase of the plan. This increases productivity, decreases the time for positive return on investment, and greatly reduces the risk associated with a large project.
Growing interest among manufacturers in Web browsers, Internet-enabled applications, viewing tools, and home pages is fueled by the need for inexpensive, scaleable, enterprise-wide integration.

Wingate (1996:40) states that the Internet has rewritten the rules on connectivity. Intranets, in a sense, are small, private Internets within individual companies. Intranets can span the globe, but the emphasis is on providing access and data sharing within a homogeneous unit. Both the Internet and Intranets exploit the power of browser technology, which effectively changes the world of distributed computing that the classic client/server compution architecture created. User desktop access remains, in essence, a client connected across the Internet/ Intranet bridge but the desktop browser fetched both the program and the information each time it stars a new computing work task. This enables software upgrading in one place at one time and ensures consistent data accuracy with little overhead.

Although it is believed that many companies remain hesitant about committing to the Internet due to security concerns and other issues, Fulcher (1996:40-46) predicts that more will be implementing standard Web browsers and server software on their own intranets. The most common of these in-house applications include "Web visualization" tools, which provide various real-time diagnostic capabilities from remote locations using Internet browsers. Managers, supervisors, and other technicians gain access to mission-critical data, and in some cases, full monitoring and control capabilities.

Clouther (1999:www.arcweb.com/arcsite/Search/search.asp) predicts that the Internet will increasingly be used for inter-company communication:
Internet browsers and Java applications provide the mechanism whereby a business application can intelligently access and retrieve data across the Internet/ intranet/ extranet. This is prevalent in the growing number of businesses moving into electronic commerce involving business-to-business and customer-to-business scenarios. The browser works across the horizontal business layer from suppliers to customers. For example, purchasing uses the Internet to search for suppliers of specific products, prices, availability, specifications and delivery dates. With contracted suppliers, or partners, the Internet allows them to access the inventory levels of every plant or location that stocks their products worldwide, and initiate a restocking order to be delivered from the nearest facility before the item is stocked out.

These technologies provide a clean connectivity not previously available, but no intelligence is related to the actual transferring of information. Therefore, they cannot truly be defined as integration. These technologies will, however, definitely enhance the intergration of Manufacturing Execution Systems.

3. 3.5. OBJECT ORIENTATED PROGRAMMING AND CLIENT/SERVER TECHNOLOGY

"MES are essentially an integrating set of functions - providing links between planning and control, design, product execution, sales force and delivery mechanisms, and customers and supply capabilities. For this reason Application Programmer Interfaces (API) and data transport or communications mechanisms are in some ways a center piece of MES functionality and not just an incidental technical detail."(Theron,1998)

Wibberley (1998:www.adroit.co.za/press/art04.html) explains that a dominant effort in software development over the past few years has been the use of object oriented technology. This methodology has become widely accepted as the as the most effective way of designing and implementing software that is robust and flexible enough to meet future and as yet unforeseen requirements. Both the SCADA, MES, ERP layers are now working off the following common threads: a common operating system, applications designed with objects in mind and all developers have common binary interfacing standards to work from. Thus the ability to expose and interface relevant inter-application objects' properties along a distributed technology backbone is now and will become ever more possible.

By utilizing SQL and ODBC database connectivity standards, these point solutions can be integrated with existing MES systems and ERP systems to add needed functionality. (Marks,1997:www.industry.net/nmw97/MES1d.htm)
What the data processing establishment could never achieve on mainframes and midrange systems was now possible through client/server technology. "Plug and play" concepts, as well as open systems architecture, allowed companies to build distributed applications that provided true Enterprise Resource Planning (ERP) and Computer Orientated Manufacturing Management Systems (COMMS) capabilities. The low cost of communications technology, combined with easily configurable local area networks (LANs) and wide area networks (WANs), enabled flexible, scaleable, distributed systems, as well as Computer Integrated Manufacturing (CIM) to become a reality. Most recently on the manufacturing scene is MES which allows planning execution, and control activities to be linked together. (Martin,1995:34)

3. 3.6. CONCLUSION

Developing an understanding of data exchange with respect to an enterprise's IT architecture, then using that understanding to enable the exchange, is the key to unlocking huge unrealized business value. It is the IT architectures that help MES to enable true enterprise-wide, plug-and-play interoperability among multiple applications. (Guttica,1998:www.icsmagazine.com/soft0598.htm)

Information Technology evolves even faster than the MES concept and has a direct influence on the way MES are established.

4. THE FUNCTIONS OF MES

"Once the term MES was established, many organizations offered solutions for specific narrow areas in manufacturing and had call them manufacturing execution systems. Statistical Process Control (SPC) has been called MES. Tracking work orders through production routing steps has been called MES. Data collection systems have been called MES, leaving most users confused asking, "What is a Manufacturing Execution System?" (McClellan:1997:2)

MESA International published a functional model in 1997. This set of MES functions is most frequently used by MES vendors and integrators. McClellan (1997:5,6) (the author of the only published book on MES) defined another set of MES functions. The contents of these functions, as well as the principle of defining MES through a set of functions - are not as widely accepted as the business models described in the previous chapters.

In this chapter

- the above mentioned sets of function definitions are discussed,
- gaps regarding these definitions are evaluated and
- a new function model is developed to address these gaps.

THE CONTENTS OF THIS CHAPTER

4. 1. FUNCTION MODEL FROM MESA INTERNATIONAL

The functional model by MESA International (MESA International,1998: www.mesa.org) appears in *Figure 15*. This model is only an expansion of the business model described in Chapter 2 (*Figure 3*). The integration between the various MES functions and planning and control systems respectively, is indicated on this model. Each of these functions is discussed in *Table 7* on the following page.

Figure 15

MES Functional Model (MESA International)

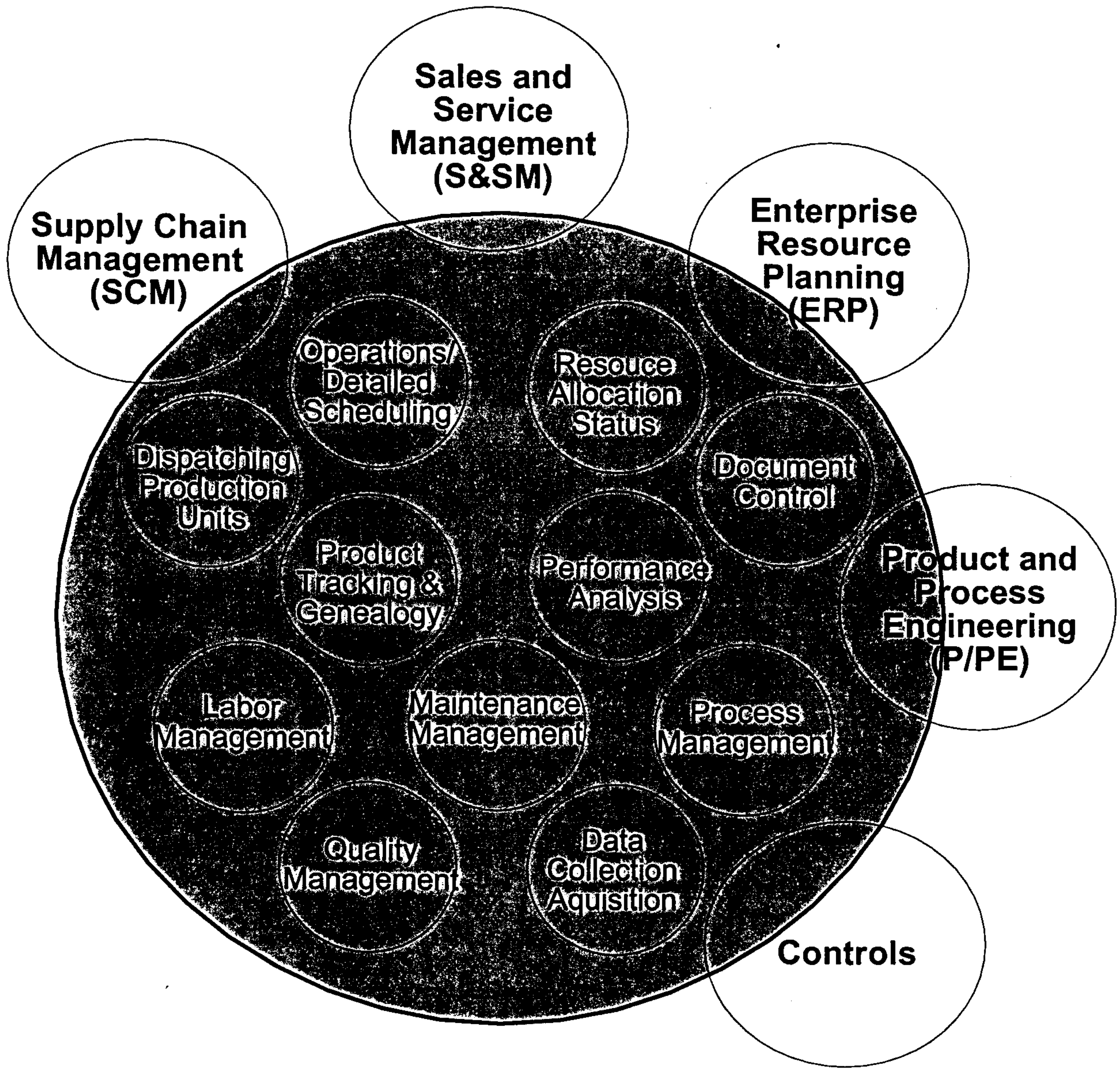


Table 7

Definition of MES functions by MESA

	Definition by MESA (MESA International, 1998, http://www.MESA.org) Organization
Resource Allocation and Status	Manages resources including • machines, • tools, • labour skills, • materials, • other equipment, and • other entities such as documents that must be available in order for work to start at the operation. It provides detailed history of resources and insures that equipment is properly set up for processing and provides status in real-time. The management of these resources includes reservation and dispatching to meet operation-scheduling objectives.
Operations/ Detail Scheduling	Provides sequencing based on • priorities, • attributes, • characteristics, and/or • recipes as associated with specific production units at an operation such as - shape, - color, - sequencing, or - other characteristics that, when scheduled in sequence properly, minimize set-up. It is finite and it recognizes alternative and overlapping/parallel operations in order to calculate, in detail, exact time of equipment loading adjusted to shift patterns.
Dispatching Production Units	Manages flow of production units in the form of • jobs, orders, • batches, • lots, and • work orders. Dispatch information is presented in the sequence in which - the work needs to be done and - changes in real-time as events occur on the factory floor. It has the ability to alter the prescribed schedule on the factory floor. Rework and salvage processes are available, as well as the ability to control the amount of work in process at any point with buffer management.
Quality Management	Provides real-time analysis of measurements collected from manufacturing to assure proper product quality control and to identify problems requiring attention. It may recommend action to correct the problem, Including correlating the - symptom, - actions and - results to determine the cause. May include SPC/SQC tracking and management of off-line inspection operations, and analysis from a labouratory information management system (LIMS) could also be included.

Table 7 (continued)

Definition of MES functions by MESA

Maintenance Management	Tracks and directs the activities to maintain the equipment and tools to insure their availability for manufacturing and insure scheduling for periodic or preventive maintenance. Also provides the response (alarms) to immediate problems. It maintains a history of past events or problems to aid in diagnosing problems.
Document Control	Controls records/forms that must be maintained with the production unit, including • work instructions, • recipes, • drawings, • standard operation procedures, • part programs, • batch records, • engineering change notices, • shift-to-shift communication, as well as the ability to Edit "as planned" and "as built" information. It sends instructions down to the operations, including providing data to operators or recipes to device controls. It might also include the control and integrity of environmental, health and safety regulations, and ISO information such as Corrective Action procedures. Storage of historical data is provided.
Data Collection/ Acquisition	Provides an interface link to obtain the inter-operational production and parametric data that populate the forms and records that were attached to the production unit. The data may be collected from the factory floor either manually or automatically from equipment in an up-to-the-minute time frame.
Labour Management	Provides status of personnel in an up-to-the-minute time frame. Includes time and attendance reporting, certification tracking, as well as the ability to track indirect activities such as - material preparation or - tool room work as a basis for activity based costing. It may interact with resource allocation to determine optimal assignments
Process Management	MONITORS production and - either automatically corrects or - provides decision support to operators for correcting and improving in-process activities. These activities may be • inter-operational and focus specifically on machines or equipment being monitored and controlled, as well as • intra-operational, which is tracking the process from one operation to the next. It may include alarm management to make sure factory personnel are aware of process changes that are outside acceptable tolerances. It provides interfaces between intelligent equipment and MES, possibly through Data Collection/Acquisition

Table 7 (continued)

Definition of MES functions by MESA

Product Tracking and Genealogy	Provides the visibility to where work is at all times and its disposition. Status information may include • who is working on it; • components, • materials by supplier, • lot, • serial number, • current production conditions, • and any alarms, • rework, or • other exceptions related to the product. The on-line Tracking function creates a historical record, as well. This record allows tractability of components and usage of each end product.
Performance Analysis	Provides up-to-the-minute reporting of actual manufacturing operations results along with the comparison to past history and expected business results. Performance results include such measurements as - resource utilization, - resource availability, - product unit cycle time, - conformance to schedule and - performance to standards. It may include SPC/SQC. Performance Analysis draws on information gathered from different functions that measure operating parameters. These results may be prepared as a periodic report or presented on-line as current evaluation of performance

4. 2. McCLELLAN FUNCTION MODEL

McClellan (1997:5) explains the relationship between the function model of MESA International and the McClellan function model as follow:

"Although this list includes the same system functions as indicated by MESA International, it is based more on specific software divisions within a systems and will be described using outlines from currently available software system products. These functions are divided into core functions, which are directly associated with managing production, and support functions, which include what might be called peripheral or support activities" (McClellan,1997:5).

The core functions of McClellan (1997:5,6) are explained in *Table 8*.

Table 8

MES Core Functions by McClellan

Planning System Interface	This describes the connection with the planning layer
Work Order Management	This function manages work orders, including scheduling, for all orders in the systems
Workstation Management	This function is responsible for implementing the direction of the work order plan, workstation scheduling, and the logical configuration of watch workstation.
Inventory Tracking and Management	The inventory tracking function develops, stores and maintains the details of each lot or unit of inventory
Material Movement Management	The movement of material, manual or automated is managed and scheduled through this function.
Data Collection	This segment acts as the clearinghouse and translator for all information that is needed and/or generated on the plant floor.
Exception Management	This function provides the ability to respond to unanticipated events that affect the production plan.

As far as support functions are concerned, the following is only a representation of possibilities; they do not constitute an exhaustive list of what is available or what will be on the market in the future. The ability to "plug and play" support systems should be provided (McClellan, 1997:6). The current most popular functions include:

- Maintenance Management
- Time and Attendance
- Statistical Process Control
- Quality Insurance
- Process Data/Performance Analysis
- Document/ Product Data Management
- Genealogy/ Product Tractability
- Supplier Management

4. 3. EVALUATION OF THESE MODELS

The following gaps were identified regarding the function definitions of MESA International and McClellan:

- Business models build around functions create the risk of "functional silo mentality".
- The opportunity to abuse the term MES for marketing purposes is created.
- Ambiguity may occur.
- New functions emerge as MES evolve and need to be accommodated.

Each of these gaps is subsequently discussed.

4. 3.1. FUNCTIONAL SILO MENTALITY

Swanton (1998:www.amrresearch.com/repac/) - in support of the REPAC model - criticized the whole concept of modeling according to functions.

"Models, such as the MES Functional Model published by the Manufacturing Execution Systems Association (MESA) in 1997, retain this functional silo mentality. The functions are laid out like a traditional software package, screen by screen and task by task, rather than like a complete business process that the plant personnel follow."

A product may be able to perform ALL the functions expected from an Manufacturing Execution System, but when these functions are not integrated over the complete business process, the MES can not be regarded Manufacturing Execution SYSTEM.

4. 3.2. THE OPPORTUNITY TO ABUSE THE TERM MES FOR MARKETING PURPOSES IS CREATED

According to MESA International (1996:www.MESA.org/html/main.cgi?sub=29) MES software can be complex because it involves the integration of multiple functions and these functions may not be available from a single vendor. Low level MES functionality can be delivered using MMI/SCADA platforms, assuming that the MMI/SCADA architecture can accommodate the application data requirements, networking, system performance, and relational database connectivity requirements. What will be missing, however, are some critical MES components: finite capacity scheduling, work dispatch lists, standard reports, and interfaces to ERP systems (Marks,1997:www.industry.net/nmw97/MES1d.htm).

Due to the efforts of some MES related non-profit research institutes (of which MESA is the most significant) the concept of systems, which execute manufacturing, gained wide acceptance and the benefits of MES are generally well understood. MES are not necessarily one product or system but more often a number of integrated products. Some vendors market their product as complete MES, while only some of these functions are fulfilled - or even partially fulfilled.

4. 3.3. AMBIGUITY MAY OCCUR

It may happens that an activity is related to more than one function. An example of such an activity is statistical process control (SPC). This can be part of either the quality management function or process management. If the Manufacturing Execution System is treated as a set of independent functions, ambiguity like this will influence the quality of the system.

4. 3.4. NEW FUNCTIONS EMERGE AS MES EVOLVE

Some authors suggest functions in addition to those defined by MESA International. Examples of these are listed in *Table 9* on the following page. As manufacturing management and information technology develop some functions may be added to this list. Different environments are also requiring different functions. The model from MESA International does not accommodate new functions. McClellan (1997:7) take care of this problem by discriminating between core functions and support functions. Although the contents of the core functions remains the same, new support functions can be added or current support functions can be modified.

Table 9

Proposed additional MES functions

Deviation and Abnormal Situation Management	Using incident management functions available in some MES systems allows identification of manufacturing problems, communication of problems to necessary personnel, and can enable speedy resolution to minimize the work disruptions and ensure product quality.
Integrated Reactive Planning and Scheduling and Real-time Decision Support	The historical data functions of MES systems can be used to determine true manufacturing capabilities based on actual product mix and work order makeup through the manufacturing process. Comparing SPC data with this analysis can help determine where process improvements or design changes can be implemented to reduce product defects and increase first time process capability.
Logistics Execution and Supply Chain Visibility to Customers	ERP (Enterprise Resource Planning) is currently regarded as the link between the enterprise and the supply chain through supply chain planning. Integration between MES and supply chain through supply chain execution is suggested.
Simulation	Simulation tools are excellent for modeling manufacturing workflows, establishing throughput and process capability baselines, and setting up critical work cells and associated cycle times. Using simulation tools and MES data to identify bottlenecked operations can help determine buffer sizes and assist in establishing pull signals or triggers for release of new work to the floor based on progress of jobs through key manufacturing operations.
Data Integrity and Reconciliation	Reconcile data as it is entered. Update data automatically to ensure integrity and keep track of revisions.

4. 4. ALTERNATIVE FUNCTION MODEL

To address the gaps identified, regarding current MES function models, an alternative MES function model is developed. In the remainder of this chapter

- the development of the MES Function Matrix is explained,
- the MES Function Matrix is evaluated against the previously given criticism and
- the the function definitions of MESA International and McClellan are related to the MES Function Matrix to validate the MES Function Matrix.

4. 4.1. DEVELOPMENT OF THE MES FUNCTION MATRIX

The purpose of this model is to determine what MES does by defining its functions. The second phase of the value management[3] think plan is concerned with exactly this: to determine the function of a product/ system by asking what it does. The second phase of the value management think plan is therefor used as the basis for an alternative MES function model. The value management think plan is indicated in *Table 10* (Value Management Services,1995:18).

Table 10

The value management think plan

1	Information	What is it?
2	***Function***	**What does it do?**
3	Creation	What else will do it?
4	Evaluation	How will that work?
5	Investigation	How best can that be accomplished?
6	Recommendation	What is required to change?
7	Implementation	How is change implemented?
8	Audit	How effective was that change?

Most value management texts recommend that the function of an item or system be expressed in as concise phrase as possible, ideally one comprising just a verb followed by a noun. (Kelly,1993:91).

Using the specifications of value management the function of manufacturing execution systems is simply to:

EXECUTE MANUFACTURING

The product of all the elements of manufacturing and all the elements of execution will comprise all of the functions of MES, in terms of a verb and a noun. To accomplish this, a matrix (with the elements of manufacturing on the one axis and the elements of execution on the other axis) is drawn up. The vertical axis of the matrix is defined according to the definition of MANUFACTURING, while the horizontal axis refer to the EXECUTION of manufacturing. The functions of MES ("What do MES do?) are defined at the intersections of these axis.

(a) ELEMENTS OF MANUFACTURING (Y-AXIS)

According to (MacDonald,1998:www.consilium.com/Publications/roi.htm)

"manufacturing is the processing of materials on equipment, aided directly or indirectly by labour based on work instructions within a facility."

Manufacturing elements can be identified according to this definition:

- Material/parts/products
- Work centers/Equipment/tools/fixtures
- Labour/personnel
- Work instructions/specifications/procedures
- Facilities

This list is used as point of departure to define the elements of manufacturing for purposes of the MES Functional Matrix. Two alterations are made to this list:

3 Value Management is an overall strategy in decision making in all areas of technology, commerce and administration to achieve performance improvement

REMOVE THE ELEMENT "FACILITIES"

An important characteristic of an Manufacturing Execution System is the fact that decisions can be made and there can be react upon in real-time. It is physically impossible to change facilities in real-time. Scheduling of other resources within and between different facilities falls within the scope of MES, but will be part of the other elements, such as work centres/ equipment and material. "Facilities" is thus not regarded as an element of manufacturing as far as MES are concerned.

ADD AN ELEMENT " WORK ORDER"

The element "Work Order" represents the routing, tracking and scheduling of raw material, work-in-progress or finished products amongst the manufacturing resources and throughout the supply chain. Each of the remaining four elements of manufacturing represents to a large extent the vertical integration between the planning systems and the control systems. "Work Order" is added to compensate for the horizontal integration provided by MES. Some of the functions of MRPII and ERP are to coordinate work orders, and may thus overlap with MES, if this element of manufacturing is added. The fundamental difference between the scope of MES and these planning systems is that MES operate in real-time. The focus of this element, for purposes of the MES Function Matrix, is thus the real-time execution of work orders.

The elements of manufacturing used on the y-axis of the MES functional matrix is:

- Material/parts/products
- Equipment/tools/fixtures
- Labour/personnel
- Work Instruction/specifications/procedures
- Work Order

(Marks,1997: www.industry.net/nmw97/MES1.htm) explains the execution of manufacturing through MES as follow:
"MES provides synchronization of the following as they are used to make the product:

- Labour
- Machinery & Equipment
- Tooling
- Resources, e.g. Power, Raw Material, WIP"

This definition is supporting the proposed element breakdown:

Proposed elements of Manufacturing	**Definition by Marks, E et al (1997)**
Materials/ parts/ products	Resources, e.g. Power, Raw Material, WIP
Equipment/ tools/ fixtures	Machinery & Equipment & Tooling
Labor/ personnel	Labor
Work instructions/ specifications/ procedures	Resource (implying information needed)
Work order	....provides synchronization...

(b) ELEMENTS OF EXECUTION (X-AXIS)

To execute is to "perform in accordance with a prescribed design" (Grolier, 1981)

To execute is to "carry out fully, put completely into effect. Do what is provided or required by. To make or to produce, especially by carrying out a design." (Longman, 1984)

According to Schaeffer (1998:www.arcweb.com/arcsite/Search/search.asp) *"manufacturing execution systems deliver information that enables the optimization of production activities from order launch to finished goods. Using current and accurate data, manufacturing execution systems*

- *guide,*
- *initiate,*
- *respond to and*
- *report on plant activities as they occur."*

From this definitions the following three elements of "to execute" were identified:

- guide
- initiate
- react

The criticism on the traditional MES model, as provided by AMR Research in support of the REPAC model, was also evaluated. The execute process is the greatest overlap between the traditional Three-Layer-Model and the REPAC model. The earlier model looked narrowly at the direct labour functions in the plant and ignored the indirect tasks of Analyze, Ready, and Coordinate. (Heaton,1998:14)

The ready and coordinate business processes are represented by initiate and guide elements, respectively. Analyze is added as fourth element of execution to compensate for it absence in the traditional model. The elements of "to execute" for purposes of the MES Function Matrix are thus:

- Guide/ Coordinate
- Initiate/ Ready
- Analyze
- React

Each of the 20 functions (in terms of a verb and noun) are indicated on the MES Function Matrix (*Table 11* on the following page). The contents of this matrix are discussed in the remainder of this dissertation.

Table 11

The Basic MES Function Matrix

	GUIDE/ COORDINATE	INITIATE/ READY	ANALYZE	REACT
MATERIAL/ PARTS/ PRODUCT	(Guide/ coordinate) (Material/ parts/ products)	(Initiate/ ready) (Material/ parts/ products)	(Analyze) (Material/ parts/ products)	(React) (Work orders)
LABOUR/ PERSONNEL	(Guide/ coordinate) (Labour/ personnel)	(Initiate/ ready) (Labour/ personnel)	(Analyze) (Labour/ personnel)	(React) (Labour/ personnel)
EQUIPMENT/ TOOLS/ FIXTURES	(Guide/ coordinate) (Equipment/ tools)	(Initiate/ ready) (Equipment/ tools)	(Analyze) (Equipment/ tools)	(React) (Equipment/ tools)
WORK INSTRUCTIONS/ SPECIFICATIONS/ PROCEDURES	(Guide/ coordinate) (Work instructions/ specifications/ procedures)	(Initiate/ ready) (Work instructions/ specifications/ procedures)	(Analyze) (Work instructions/ specifications/ procedures)	(React) (Work instructions/ specifications/ procedures)
WORK ORDERS	(Guide/ coordinate) (Work orders)	(Initiate/ ready) (Work orders)	(Analyze) (Work orders)	(React) (Work orders)

4. 4.2. EVALUATION AND VALIDATION OF THE MES FUNCTION MATRIX

The MES Function Matrix is developed in reaction to criticism given against existing function definitions. The extent to which this matrix has overcome such criticism, is evaluated in *Table 12* (on the following page).

Table 12

Evaluation of MES Function Matrix according to critic on other function definitions

CRITIC	Evaluation of MES Function Matrix
Business models build around functions creates the risk of "functional silo mentality".	The interrelationship between all the functions is clear, due to the matrix format. The process can be followed through the guiding, initiation, checking and reaction to all manufacturing activities.
The opportunity to abuse the term MES for marketing purpose is created.	This risk still exists. Through presenting the functions in matrix form, it is easier for the user to determine the gaps within the system and whether or not this function is integrated. This matrix can also be used to establish the specific need within an organization and evaluate a product or a combination of products regarding the extent to which this need is fulfilled.
Ambiguity may occur	The discipline of defining a function by only a verb and a noun allows an exact statement of the function, which is readily understood. (Kelly, 1993:91)
New functions emerge and MES evolve	The matrix is providing only a framework for the definition of the functions. As part of the validation of this matrix, current function definitions are related to this matrix. This can be used as guideline when defining the functions for a specific situation and environment. It is, however, essential that this framework is completed by someone with proper knowledge of the environment as well as manufacturing systems.

4. 4.3. THE VALIDATION OF THE MES FUNCTION MATRIX

Existing MES models and definitions are used to validate this model.

(a) FUNCTION DEFINITIONS OF MESA INTERNATIONAL AND McCLELLAN RELATED TO THE MES FUNCTION MATRIX

The MES Function Matrix is validated through the mapping of the contents of the definitions from MESA International (*Table 13*) and McClellan (*Table 14*) to this model. The assumption is made that the models of MESA International and McClellan are indeed valid models of MES. Although this assumption is not proved in this dissertation, it is supported by the fact that the models of McClellan and MESA International do not contradicts each other.

The descriptions given by these models are allocated to the appropriate block on the MES matrix. All of the blocks of the MES Function Matrix are filled by comments from both MESA International and McClellan and all of the descriptions made in the existing models are allocated on the MES Function Matrix. The conclusion can be made that the MES Function Matrix is a valid method of modeling the functions of MES. It is another way of presenting the functions of MES and no changes are brought to the contents of these functions.

Table 13

MES Function Matrix related to the function definitions of MESA

	GUIDE/ COORDINATE	INITIATE/ READY	ANALYZE	REACT
MATERIAL/ PARTS/ PRODUCT	Reserve materials that must be available in order for work to start at the operation.	Dispatch materials that must be available in order for work to start at the operation. Dispatch information is presented in sequence in which the work needs to be done. MES has the ability to control the amount of work in process at any point with buffer management.	Provides real-time analysis of measurements collected from manufacturing to assure proper product quality control. MES includes alarm management to make sure factory person(s) are aware of process changes which are outside acceptable tolerances. Provides real-time analysis of measurements collected from manufacturing to assure proper product quality control.	Dispatch information changes in real-time as events occur on the factory floor. Provides up-to-the minute reporting of actual manufacturing operations results along with the comparison to past history and expected business benefits.
LABOUR/ PERSONNEL	Reserve labour skills that must be available in order for work to start at the operation. Labour skills and other entities such as documents that must be available in order for work to start at the operation. It may interact with resource allocation to determine optimal assignments of labour.	Dispatch labour skills and other entities such as documents that must be available in order for work to start at the operation. Provides operations data to personnel.	Provides status of personnel in and up - to - the - minute time frame. Includes time and attendance reporting, certification tracking, as will as the ability to track indirect activities such as material preparation or tool room work as a basis for activity based costing.	It may interact with resource allocation to determine optimal assignments. Provides up-to-the minute reporting of actual manufacturing operations results along with the comparison to past history and expected business benefits. Either automatically corrects or provides decision support operators for correcting and improving in - process activities.
EQUIPMENT/ TOOLS/ FIXTURES	Recognizes alternative and overlapping / parallel operations in order to calculate in detail equipment loading. Reserve tools, fixtures and other equipment that must be available in order for work to start at the operation.	Dispatch tools, fixtures and other equipment that must be available in order for work to start at the operation. MES insures that equipment is properly set up for processing. Provide recipe information to device controls. Tracks and directs the activities to maintain the equipment and tools to insure their availability for manufacturing and insure scheduling for periodic or preventive maintenance. Provide the response (alarms) to immediate problems. Provides interfaces between intelligent equipment and MES possible through Data Collection / Acquisition.	MES provides status real-time. Monitors production. Data may be collected from the factory floor either manually or automatically from equipment in an up - to - the - minute time frame.	Either automatically corrects or provides decision support to operators for correcting and improving intra operation activities (focus on machines or equipment). It may recommend action to correct the problem, including correlation the symptom, actions and results to determine the cause. May include SPC / SQC tracking and management of off - line inspection operations and analysis in labouratory information management system (LIMS) could also be included.

Table 13 (continued)

MES Function Matrix related to the function definitions of MESA

	GUIDE/ COORDINATE	INITIATE/ READY	ANALYZE	REACT
WORK INSTRUCTIONS/ SPECIFICATIONS/ PROCEDURES	Reserve entities such as documents that must be available in order for work to start at the operation	MES sends instructions down to the operations. It maintains a history of past events or problems to aid in diagnosing problems. Ensure integrity of environmental, health and safety regulations, and ISO9000 information such as Corrective Action procedures. Controls records/forms including work instructions, recipes, drawings, standard operation procedures, part programs, batch records and engineering change notices.	Provides up - to - the - minute reporting of actual manufacturing operations results along with the comparison to past history and expected business result. Draws on information gathered from different functions that measure operating parameters. .	Rework and salvage processes are available. These results may be prepared as a report or presented online as current evaluation of performance. Control integrity of environmental, health and safety regulations, and ISO9000 information such as Corrective Action procedures
WORK ORDERS	.	Manages flow of production units in the controls records/forms including shift-to-shift communication of jobs, orders, batches, lots, and work orders. Provides sequencing based on priorities, attributes, characteristics, and/or recipes. Manages the flow of production in the form of hobs, orders, batches, lots and work orders.	Provides the visibility to where work is at all times and its disposition. Information may include who is working on it; components materials by supplier, lot, serial number, current production conditions, and any alarms, rework, or other exceptions related to the product. The on - line tracking function recognizes alternative and overlapping / parallel operations in order to adjust to shift patterns. This record allows tractability of components and usage of each end product.	It has the ability to alter the prescribed schedule on the factory floor and to change the priorities of work orders in real-time.

Table 14

MES Function Matrix related to the function definitions of MESA

	GUIDE/ COORDINATE	INITIATE/ READY	ANALYZE	REACT
MATERIAL/ PARTS/ PRODUCT	The MES should have stored in its database or available on-line whatever information is necessary to choose a specific inventory site, (current location, date received, lot number, quality information and in-process inventory information.) Assign/ Unassign inventory to work orders. Connect to vendors, receive quotes, approve purchases, manage purchasing and receives functions for maintenance items.	Notify material handling system that specific material is required at a specific workstation. Request and manage delivery of inventory, tooling and data in response to bill of material requirements. Execute commands to move the required items to the planned workstations. Provide a specific item of inventory to a workstation in response to the order sequence.	Statistical process control (SPC) is a quality control method that focuses on continuous monitoring of a process rather than the inspection of finished products, with the intent to achieve control of the process and eliminate defective products. Tracks spare part inventory usage, stock quantities, and physical location. In-Process Inspection through on-line access to work-in-progress. Compile detailed supplier reports consolidation receiving, non-conformance, and corrective action information.	Although many planning systems have extensive inventory information capabilities, the local inventory data must either be on the MES or immediately available on-line when events cause any change to plant floor priorities. Mark an order for material shortage. Use genealogy information for warranty information.
LABOUR/ PERSONNEL	Interface with most payroll, human resource, and planning-level packages.	Maintains employee master file with employee name, number, plant, department, default schedule, work center/group, direct/indirect, permanent/temporary, reporting assignment, accrued vacations time and sick time.	Full Screen access to one or more department groups via unique password for employee review, override and reporting. Performs employee review on a daily and/ or weekly basis. Track human resources by individual and by craft.	Generates standard supervisor reports.
EQUIPMENT/ TOOLS/ FIXTURES	Maintains a complete history for each piece of equipment, including technical data, spare parts information and running records of all maintenance performed on each equipment item. Generates every scheduled maintenance task for every piece of equipment. Establish which workstations can do which operations.	Maintains a picture of the workstation resources that are currently available and their backlog of assigned work. Matches the routing for the required part number to develop shop load by operation. Establish which workstations can do which operation or operations. Assign operation codes to work cells and work stations. Retrieve and download programs to plant floor devices.	Using statistical process control methods, the system tracks dynamic equipment data such as vibrations, temperature or electrical load. Tracks every scheduled maintenance task for every piece of equipment. All preventative tasks are assigned and tracked.	If a resource becomes unavailable, the MES should respond automatically to reschedule work into other available resources. Use on-line scheduling revisions as part of exception management that responds to unplanned resource interruptions to help predict equipment failure and prevent downtime.

Table 14 (Continued)

MES Function Matrix related to the function definitions of MESA

	GUIDE/ COORDINATE	INITIATE/ READY	ANALYZE	REACT
WORK INSTRUCTIONS/ SPECIFICATIONS/ PROCEDURES	.	Download process recipes to equipment on request or automatically. Store and show part number, quantity, routings, time standard, process data and que for each operation. Manage product structure and configurations and bills of material. MES should locates and retrieves all supporting material information in response to the production plan (Create production messages for reports and filing, drawings or other technical information, tooling and fixtures, specific labour skills).	Validates transactions at the time of entry. Analyze maintenance data and generate reports. Monitor quality assurance information and adjust machines and processes to conform to specifications.	Define and control changes to product configuration, part definitions and other product data. Activate engineering change orders on an immediate global basis.
WORK ORDERS	Following the schedule that indicates the sequence of work for each workstation, the MES can automatically retrieve information and direct that information to the specific workstation to match the sequence of work orders. Maintains a database of active work orders. Develop the shop load by operation. If an operation is available at more than one workstation, rules within the model determine the loading accordingly. Simulation or "what if" queries. Supports single, batch, and multiple operations in process. Set up schedule for work orders.	Accepts (automatically / manually) information that identifies what is to be produced, quantity, the requested completion data and prioritizing method. Release orders to productions and establishes a current order priority list based on sequencing rules or other schedule-production methods. Assign and unassign inventory to work orders. Maintains a constant real-time view of the work orders in the current backlog and the status of each order. By knowing the part number, quantity, routings and time standards for each order, the que for each operation is established.	The logic in the MES follows the operation steps on the routing and matches those steps to actual workstation with the capability to perform those operations. It is possible to have sequencing rules for each workstation and/or to do a quick simulation analysis to determine the optimum sequence for work in the current que.	Respond to sudden changes in resource availability (schedules, quantity, routing) by automatically rearranging the work order priority list, presenting productions management with alternatives and/or provide decision support. Combine orders into larger lot size. Place an order or hold or some other status.

(b) THE THREE LAYER BUSINESS MODEL RELATED TO THE MES FUNCTION MATRIX

An attribute of the model by MESA International is the way by which the interfacing and integration between the functions and application within other layers are modeled (*Figure 15*). The data flow model discussed in Chapter 2 (*Figure 4*) is mapped to the MES Function Matrix (*Table 15*). It is proved through this that the MES Function Matrix also accommodates the modeling of interfaces/ integration with MES.

From this matrix it can be seen that the MES-ERP interface is related to the GUIDE-COORDINATE element of execution, while the MES-CONTROL interface is related to the ANALYZE element of execution. Both the ERP-MES and MES-CONTROL interfaces are facilitated by the READY element. The REACT element seems to be unique with regard to MES.

Table 15

Data flow between MES and the Planning and Control layer related to the MES Function Matrix

	GUIDE/ COORDINATE	INITIATE/ READY	ANALYZE	REACT
MATE-RIAL/ PARTS/ PRODUCTS	Receive from ERP System: Product Demand/ Inventory Status	Send to ERP System: Material Status/ Usage/ Scrap/ Waste. Send material safety instructions to control.	Material data collected from monitoring functions	.
LABOUR/ PER-SONEL	Receive from ERP System: Resources Routing/ Labour Characteristics	Send to ERP System: Resource Status/ Usage. Send machine operation instructions to controls.	Labour data collected from monitoring functions	.
EQUIP-MENT/ TOOLS/ FIXTURES	Receive from ERP System: Resources Routing	Send to ERP System: Resource Status/ Usage. Send order specific machine utilization to controls	Equipment data collected from monitoring functions	.
WORK INSTRUC-TIONS/ SPECIFI-CATIONS/ PROCEDUR	-	Send to ERP System: Actual BOM/ Formula/ Recipe.	Environment data collected from monitoring functions. Send work certification Requirements to controls.	.
WORK ORDERS	Receive from ERP System: Resources Routing	Send to ERP System: Order Status/ Completions/ Start-Due-End/ Product Genealogy/ Tractability	-	.

4. 5. CONCLUSION

"What does MES do?" is a question often asked. Several attempts are made to answer this question. A MES Function Matrix is developed in an effort to improve on current attempts. This MES Function Matrix is not a checklist or an Manufacturing Execution System module breakdown, but rather a framework to contextualize MES. The following possible applications are given in *Table 16* on the next page. The models of McClellan and MESA do not contradicts each other and neither is contradicted by the MES Function Matrix.

Apart from the general application possibilities explained in this table, the MES Function Matrix is also used in the subsequent chapters of this dissertation to:

- Relate the expertise of the Industrial Engineer to MES.
- Explain the value of MES as tool to accomplish continuous improvement.
- Explain the accomplishment of ISO9000 compliance through MES.
- Evaluate DIAMES as an Manufacturing Execution System product.

In Chapter 5 an investigation from Willemse (1999) on a specific MES product is used as case study to demonstrate the MES Function Matrix as tool to evaluate MES products.

Table 16

Potential applications of the MES Function Matrix

Identify the strengths, weaknesses, opportunities and threats regarding a specific MES product.	When the abilities of a specific product are allocated to the relevant a matrix block, the manufacturing elements executed well by that specific product can be identified. The definitions of MESA and McClellan would not allow the identification of a specific element of manufacturing or executions, but only abilities – such as document control. This information can be used to identify an industry with specific needs regarding that element or by investigating the feasibility of adding functionality, where the existing product is lacking.
Identify the areas in a business not benefiting optimally from MES and relate the benefits of MES in terms of return on investment (ROI).	When a business consider the implementation of an Manufacturing Execution System, the current performance regarding the areas on the matrix can be accessed and indicated on the matrix. From this specific areas – such as the analyzing of and reaction to equipment or the coordination and initiation of specifications – which can benefit from MES, can be identified. This can serve as basis to determine the return on investment or to devise an implementation strategy. It is easier to relate a function such as initiate, coordinate and analyze material to ROI than a function such as Quality Management given by MESA International.
Identify common MES attributes related to certain industries and environments.	In chapter 8 the characteristics on MES approaches associated with specific industries, is discussed. This MES matrix can be used as a framework from which a checklist can be created to enable companies in specific industries to evaluate MES products. Elements of manufacturing as well the initiation, coordination, analyzing and reacting to these elements has similar characteristics related to industries. It is, thus, easier to devise such a checklist from this matrix than from the function definitions of MESA International and McClellan.
Explain the relationship between MES and other business applications and functions	Existing models explain the relationship between planning, execution and control systems very simple and neatly. However, this models does not necessarily enable the personnel manager or storeroom clerk to understand the influence of MES on them an visa versa. The specific areas on the MES Function Matrix related to them and the interaction explained.

5. CASE STUDY: THE MES FUNCTION MATRIX AS TOOL TO EVALUATE DIAMES

"DIAMES, is a UNIX (IBM AIX open system) based application which provides features to optimize the usage of available human and technical resources on the shop-floor level. DIAMES combines a MRP application with the production equipment on the shop-floor." (CSM Systems, 1999:http://www.csmsystems.com)

When AMR Research created the term MES at the beginning of this decade, it was to categorize (for purposes of research and development) information systems - which focus on the execution of manufacturing. Even before the term MES was created, manufacturing execution systems existed. DIAMES is an example of such a system.

MES surfaced as a research topic due to an attempt to create and interface between SAP (as Enterprise Resource Planning system) and DIAMES. The feasibility to develop DIAMES into a complete Manufacturing Execution System is investigated in an independent project (Willemse,1999). In this chapter the investigation by Willemse (1999) is used as case study on the evaluation of MES. Willemse (1999) studied the environment of DIAMES in the first instance and compared it to other MES in the second place. The MES Function Matrix from Chapter 4 is demonstrated as an MES evaluation tool, on grounds of the conclusions by Willemse (1999).

CONTENTS OF THIS CHAPTER

5. 1. BACKGROUND ON DIAMES

DIAMES is owned by Computer Supported Manufacturing Systems of Switzerland (CSM AG:www.csmsystems.com). This company promotes DIAMES as follow:

"DIAMES, is a UNIX (IBM AIX open system) based application which provides features to optimize the usage of available human and technical resources on the shop-floor level. DIAMES combines a MRP application with the production equipment on the shop-floor. A real-time based management by exception approach enables immediate workflow interventions if differences between planning and actual work-in-progress, quality standards etc. exceeds predefined limits. The information circle from production planning to the activities on the shop floor and reporting back of work in progress to the planning system is automatically closed by this system. The basic information flow between the DIAMES system and the individual manufacturing processes (operations) is practically human-independent and continuous. Definable set-up functions enable a flexible behavior of the DIAMES system to meet specific customer's demands."

According to Willemse (1999) DIAMES is currently used in eight South African plants owned by Aberdare Cables (Pty) Ltd. Development on DIAMES started at the early 1980's to enable more control on the shop floor. More and more functions were added to enhance the execution of manufacturing. This product was initially called COMIS, but the name was changed, once the term MES became more accepted within manufacturing industry.

5. 2. THE EVALUATION OF DIAMES

The study by Willemse (1999) is twofolded:

- The environment of DIAMES is studied in the first place. For purposes of this case study, the conclusions regarding the interfaces of DIAMES is highlighted.
- Secondly Willemse (1999) used the Functional Model by McClellan (1997:6,7) to compare DIAMES with two other products marketed as MES.

5. 2.1. DIAMES AS PART OF THE MES AT ABEDARE CABLES (THE INTERFACES OF DIAMES)

Willemse (1999) explains on grounds of *Figure 16* (on the following page) that the Manufacturing Execution Systems at Abedare Cables consists of a combination of products:

- As new orders are received, they are entered into the MRPII system. The MRPII system performs daily runs to calculate material requirements, capacity requirements and the like to generate a first-iteration production schedule.

- The "Job-adder" then optimises the production schedule for maximum throughput by arranging similar orders (with similar attributes such as colour) in sequence. This is done by assigning priorities to each work-order. An example is the frequent sequencing by the colour of the cable's sheath. All the work-orders for a certain period with similar critical attributes such as gauge thickness and colour would be scheduled back-to-back since this would enable maximum throughput with the least time lost to set-ups, etc.

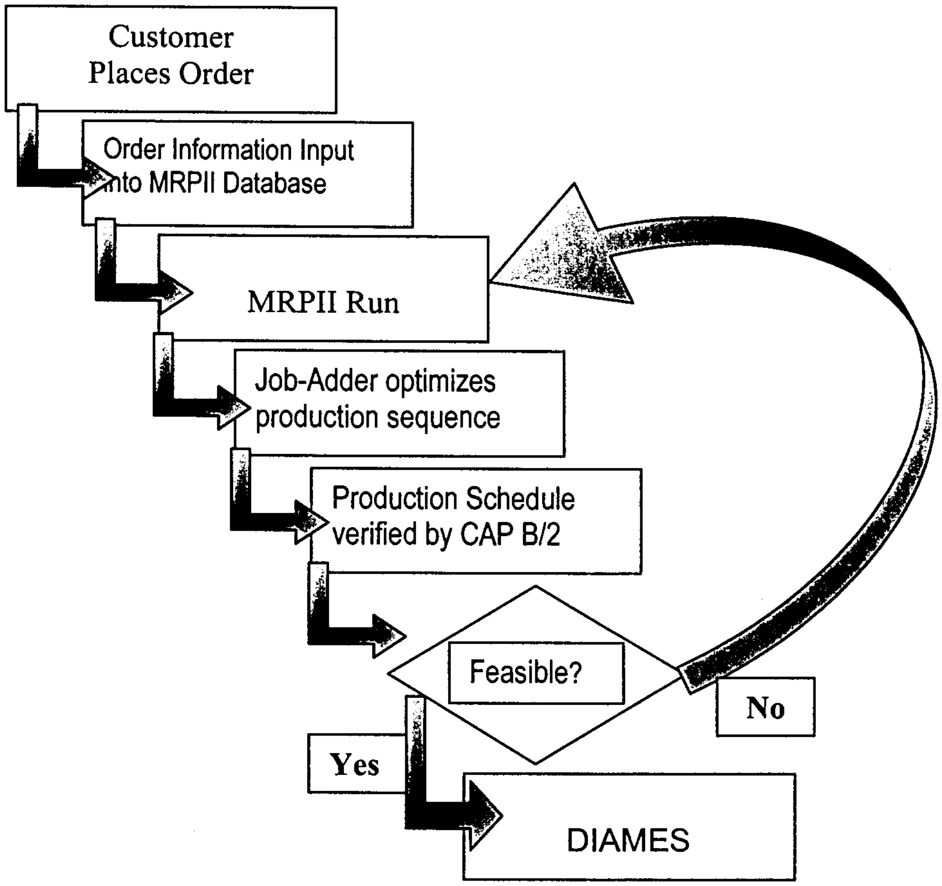
- This "second-iteration" production plan is then fed into the CAP B/2 finite capacity scheduler to check the feasibility of the plan against the current resource availability. If the plan is not feasible the planning sequence is repeated, otherwise the final production plan is passed onto the DIAMES system for communication down to the shop floor.

- The DIAMES system possesses the capability to manually reschedule some work-orders but this is used only in case of a production failure or some other exception such as a change to a work order. The final production plan is communicated to the shop floor via Machine Information Centres (MICs). The MIC's provide information regarding the product that have to be made, production times, production rates, product quantities and required material.

Some flexibility is provided by the "pool-system" that allows an operator to choose from one job in a pool of up to 15 scheduled jobs to adapt production for current shop-floor conditions.

Figure 16

Production Planning Process in Aberdare Cable



5. 2.2. DIAMES COMPARED TO OTHER MES

After Willemse (1999) investigated the interfaces with MES, he used the function model from McClellan (1997:6,7) - as explained in Chapter 4 - to compare DIAMES to three other products that are promoted as an Manufacturing Execution System:

- Factory Suit 2000 (http://www.wonderware.com)
- Workstream Open (http://www.consilium.com/products/weapon.htm)
- RtPM (http://www.hilco.com/products/rtPM/rtPMIntro.html)

Background on these products is in given in *Table 16* on the next page.

Willemse (1999) compared these three products with DIAMES against each of the functions defined by McClellan (1997:6,7):

Core functions

- *Table 17*: WORK ORDER MANAGEMENT
- *Table 18* : PLANNING SYSTEM INTERFACE
- *Table 19*: INVENTORY TRACKING AND MANAGEMENT
- *Table 20* : MATERIAL MOVEMENT MANAGEMENT
- *Table 21* : WORK ORDER MANAGEMENT
- *Table 22* : DATA COLLECTION
- *Table 23* : EXCEPTION MANAGEMENT

Peripheral functions

- *Table 24* : MAINTENANCE MANAGEMENT
- *Table 25* : TIME AND ATTENDANCE
- *Table 26* : STATISTICAL PROCESS CONTROL
- *Table 27* : QUALITY ASSURANCE
- *Table 28* : PRODUCT DATA MANAGEMENT & DOCUMENTATION
- *Table 29* : PROCESS DATA & PERFORMANCE ANALYSIS
- *Table 30* : SUPPLIER MANAGEMENT
- *Table 31* : GENEALOGY / TRACTABILITY

Table 16
Products used in comparative DIAMES study

Name of product	**Factory Suit 2000**	**Workstream Open**	**RtPM (Real-time Production Management)**
Information obtained from	Wonderware,1999: http://www.wonderware.com	Consilium,1999: http://www.consilium.com/products/weapon.htm	Hilco Technologies, 1999: http://www.hilco.com/products/rtPM/rtPMIntro.html
Background	Wonderware products are distributed locally by Futuristix through more than 50 qualified Systems Integrators. Some components of this suite boast as many as 75,000 successful installations worldwide.	Workstream Open is an integrated MES designed to give the user strategic control over manufacturing operations. Developed to meet the needs of semiconductor, electronics, aerospace and defence manufacturers, the system enables Best Practices Manufacturing by monitoring and controlling operational performance.	rtPM (Real-time Production Management) is locally distributed by Hilco South Africa. Recent international clients include British Steel and Austin Foods as well as South African Breweries. rtPM makes information regarding process parameters, materials, scheduling and production readily available and easy to use.
Features	- FactorySuite 2000 runs in a Windows NT v.4 environment. - Since it is based on Client-Server technology, all FactorySuite 2000 modules can be implemented on a scale from one node to a site wide installation with hundreds of users. - Factory Suite 2000 has been applied in the following industries: - Automotive, electronics and medical devices. - Food / Beverage, metals and fibres. Petroleum, chemical etc.	- Workstream Open runs on leading UNIX platforms such as IBM's AIX, Hewlett-Packard's HP-UX and Sun Microsystems' Solaris. - Since it runs in a UNIX environment, Workstream Open enjoys the excellent scalability characteristics inherent to UNIX systems. - Workstream Open have been applied in the Pharmaceutical and Electronics industries.	- It enables other supply chain systems, such as Enterprise Resource Planning, by providing accurate and timely information about the plant status, which, in turn, leads to better plans and more efficient control of materials. - rtPM transforms management by prediction into management based on real-time data

Table 17

Evaluation of MES products: WORK ORDER MANAGEMENT

The MES accepts manual or automatic information inputs that describe what is to be produced and how much. This is usually done by using work orders that designate the work order number, part numbers, quantities, completion date and method of prioritizing. *This module manages changes to work orders, establishes and maintains schedules and a prioritized production sequence. It can also assign and de-assign inventory to work orders.* Although the capability to schedule work orders and resources seems redundant (already provided for in most planning systems) it is an integrated part of a successful MES. Since conditions on the shop floor change continuously (resource and material availability) and because work orders are frequently changed (additions, quantity changes etc.) the validity and optimality of the production plan needs to be verified. The planning system considers these changes only when re-planning, which may occur only once every day. The MES must have this information available on-line to automatically take these changes into account and re-plan or to present foremen and production planners with viable alternatives. At the very least exception-messages should draw the attention of foremen and production planners to the situation.			
DIAMES Exception messages draws the attention of planners who can reschedule or re-route work orders manually. Changes to quantities and extra information can easily be accommodated.	**Factory Suite 2000** Alarms draw the attention of planners to situations such as breakdowns and alternative routings are suggested. Changes to work order details are easily accomplished.	**Workstream Open** Alarms draw the attention of planners to situations such as breakdowns to re-route or reschedule work orders. Current shop floor conditions are considered before dispatching a lot for production. Production lines can be balanced manually by considering current circumstances. Changes to work order details are easily accomplished.	**RtPM** Scheduled items may be initiated manually or by an external automatic event. The Process Manager's event scheduler may be used to automate dispatches. Alarms draw the attention of planners to situations such as breakdowns to re-route or reschedule work orders. Changes to work order details are easily accomplished.

Table 18

Evaluation of MES products: PLANNING SYSTEM INTERFACE

There need to be a bi-directional link between planning systems (ERP / MRPII) and MES so that relevant information can be shared between these two type of systems. This is necessary to inform planning systems of changing conditions on the shop floor that might have an impact on planned delivery. The MES need to be informed if some aspect of a work orders change such as delivery date, quantity etc. *Due to the large variety of installed planning systems, this interface is usually custom-developed software that fits the specific planning system and MES.*			
DIAMES interfaces with planning systems via custom-developed Application Program Interfaces (APIs). A completed SAP R/3 API is available.	**Factory Suite 2000** is built around Wonderware's Industrial SQL Server which in turn, is based upon Microsoft's SQL Server. Interfacing with Windows NT based planning systems is facilitated by using ODBC drivers in custom-developed APIs.	**Workstream Open** interfaces with planning systems, CAD, CAE and CAPP systems via custom-developed APIs.	**RtPM** Operates in a Windows NT environment, rtPM utilizes ODBC drivers in APIs to interface with planning systems.

Table 19

Evaluation of MES products: INVENTORY TRACKING & MANAGEMENT

This function develops stores and maintains the details of each lot or unit of inventory used in production. Inventory includes every thing that is necessary for production including tooling, fixtures, raw materials, work-in-progress (WIP), special labour skills, drawings etc.

This function should:

- Manage. Direct and control all raw material and WIP inventory.
- Locate and retrieve all supporting material and information.
- Maintain and provide access to detailed information for each inventory item.

This function is especially relevant in regulated industries such as the Food and Pharmaceutical industries.

DIAMES	**Factory Suite 2000**	**Workstream Open**	**RtPM**
WIP is tracked throughout the complete production process and raw-material lots can be identified via unique inventory identification numbers.	Apart from raw material usage, WIP and shop floor inventory is also tracked in real-time. The InTrack module displays support materials such as work and maintenance instructions and other reference documents. Inventory movement may be automated by using recipes.	WIP and inventory movement is tracked in real-time and relevant work instructions and supporting information can be displayed.	Material status, batch/lot identification, vendor and storage information are recorded. Materials transformation and movement are also tracked during production. Automated material movement can be achieved by using recipes.

Table 20

Evaluation of MES products: MATERIAL MOVEMENT MANAGEMENT

This part of a MES causes the materials to move towards the workstations where it is needed. It may be accomplished by issuing commands to people or by communicating directly with equipment.
Typical uses range from issuing move tickets to forklift drivers to opening control valves and starting pumps in order to deliver fluids to a specified location.

DIAMES	**Factory Suite 2000**	**Workstream Open**	**RtPM**
These functions are not explicitly formalized in DIAMES but it may be possible to issue release orders with Machine Information Centers (MICs).	Material movement can be automated by using recipes from the InBatch module.	Automated materials movement is possible through the usage of scripts. This is handled by the Script Controller and the Material Handling System Server.	All material movement records are stored in the batch record. Material movement is controlled via recipes. Automated movement is possible by executing these recipes and manual movement via issued orders. The Process Manager module co-ordinates the transfer of all materials.

Table 21

Evaluation of MES products: WORKSTATION MANAGEMENT

Time and money are scarce resources. The investment of each has to be justifiable and carefully planned. Expensive equipment must be used efficiently and work orders must be delivered on time. To accomplish these goals, workstations' production time must be scheduled carefully.

For a MES to effectively schedule workstations' time and at the same time remain highly configurable to each customer's operation requires the building of a logical model of the facility. Such a model lists all departments, workstations and their capabilities and operations in the facility. Each workstation's capabilities have to be compared with every work order's requirements to find a suitable match. Routing information and time standards are used to determine the loading of every workstation to request and manage the delivery of materials, tooling and data.

This part of a MES should:

- Assign work order operations to suitable workstations.
- Optimize work order sequences for each workstation.
- Provide current and planned loading information of every workstation based on routing and time standard information.
- Retrieve and download programs to plant floor devices.
- Maintain a current map of workstation and operation availability.

DIAMES The matching of workstation's capabilities to work orders and the scheduling of workstations does not occur in DIAMES and is performed in part by CAP B/2. Work order sequences can be optimized manually by changing work order priorities. Current and planned loading can be viewed per workstation.	**Factory Suite 2000** The plant is modeled in the "Process Model" by defining the physical plant, the equipment processing capabilities and the material transfer capabilities. Short term scheduling involves prioritizing and scheduling batches based on the master schedule. Work orders can be edited and re-routed to alternative workstations if necessary. The processing sequence at each workstation may be modified by changing priorities. Equipment are acquired and released before and after processing work orders and is automatically configured to suit the work order's requirements. This includes the automatic retrieval of programs. A picture of planned and current equipment availability, loading and utilization is provided by the InTouch module.	**Workstream** Operator qualifications, materials and set-ups are verified before production can proceed. Capacity planning is supported by what-if scenario planning. Recipe management is automated by the Recipe Management Server which also downloads recipes to equipment. Line balancing is possible with current equipment and materials status. Alarms notify planners of any problems A picture of planned and current equipment availability, loading and utilization is available.	**RtPM** Each unit and cell has a schedule that determines the order that product recipes will be executed. The Process Model" identifies equipment according to their attributes and processing capabilities. Equipment are organized by site, are, cell etc. as specified by the ANSI-S88 standard. Set-up, materials etc. are checked before plans are executed. A picture of planned and current equipment availability, loading and utilization is available. Individual workstation's processing sequence may be manually rearranged.

Table 22
Evaluation of MES products: DATA COLLECTION

This function is literally the "eyes and ears" of the MES and helps it to remain current by collecting real-time data from equipment. Data may be collated and passed on to applications where it will be used to manage the operation. Data sources may range from manual data entry to bar code scanners and from radio frequency (RF) transmitters to time and attendance systems.			
DIAMES DIAMES has a well-developed "data net". Data is collected through bar code scanners and is also keyed in via MIC. Real-time machine information is captured via sensing devices attached directly to MICs	**Factory Suite 2000** SCADA like interfacing is possible through the InControl and InTrack modules. A comprehensive library of supported I/O devices facilitates an easy direct link-up with most equipment	**Workstream Open** Automatic data collection is controlled by the Script Controller and collected data belongs to the Station Controller which is responsible for data distribution.	**RtPM** The Production Status Monitor displays real-time information on production status, which is also recorded in the integrated manufacturing database.

Table 23

Evaluation of MES products: EXCEPTION MANAGEMENT

Work order changes and machine breakdowns are just some real-life occurrences that affect the production plan daily. The MES should notify its users of such events and preferably solve it by itself or provide decision support and indicate alternative solutions. At the very least alarms and exception messages should draw the attention of MES users and production planners to these events.			
DIAMES Exception messages are relayed to DIAMES users and foremen via e-mail and (through Page-X) pagers.	**Factory Suite 2000** Exceptions are flagged. In the case of machine breakdowns is automatic resolution via alternative routings possible by using recipes.	**Workstream Open** Exceptions are flagged. Automatic resolution via alternative routings is also possible by using scripts. Alternative routings can also be simulated before they are implemented	**RtPM** Exceptions are brought to the attention of system users. Automatic resolution is possible since alternative routings are stored in the process module. This is matched to the requirements stored in the product module.

Table 24

Evaluation of MES products: MAINTENANCE MANAGEMENT

Maintenance management (MM) is an important part of effectively managing a manufacturing facility. Resource availability should be maximized and costs kept to a minimum. Although this may seem obvious production schedules are frequently developed without taking resource availability into account. Maintenance management has developed into such a specialized field that the core MES should, in our view, only supply dedicated MM systems with the relevant data to plan and execute preventative maintenance plans. The MM system in turn should inform the MES of planned machine downtimes.			
DIAMES Maintenance work orders for preventative as well as corrective maintenance can be issued by the DIAMES system. Machine and process data is also accessible to dedicated MM applications.	**Factory Suite 2000** Machine specific data may be used to plan maintenance. Dedicated maintenance management packages may interface directly with FS2000 for data gathering.	**Workstream Open** Machine specific data may be used to plan maintenance. Dedicated maintenance management packages may interface directly with Workstream Open for data gathering.	**RtPM** Machine specific data may be used to plan maintenance. Dedicated maintenance management packages may interface directly with rtPM for data gathering.

Table 25

Evaluation of MES products: TIME & ATTENTANCE

The collection of time and attendance information can be used for payroll, costing etc. as well as operator screening in certain processes where specific qualifications is necessary.			
DIAMES Some time and attendance functions have been added to DIAMES and include operator screening. This is accomplished by magnetic swipe cards.	**Factory Suite 2000** "Who, what, when, where and how" information is captured during every phase of production and may be used for time and attendance purposes.	**Workstream Open** Labour is tracked to help with the identification of cost drivers.	**RtPM** Comprehensive records are kept for personnel involvement in each production lot.

Table 26

Evaluation of MES products: STATISTICAL PROCESS CONTROL

SPC is another specialized part of production where product parameters are monitored as the parts are produced. Products' "performance" to specifications are plotted on numerous charts and data is analyzed by applying statistical methods to determine trends in the production process. The core MES should provide dedicated SPC applications with the necessary product and process data to succeed in its goals.			
DIAMES DIAMES has no SPC capability but could capture SPC-relevant data and supply it to SPC applications.	**Factory Suite 2000** Apart from built-in trending applications, the optional **SPC Pro** is also available from Wonderware to perform SPC functions.	**Workstream Open** On-line statistical charts are available for real-time production monitoring. Quality data can be analyzed by using machine or material history as basis	**RtPM** Process and equipment data may be analyzed by third party SPC

Table 27

Evaluation of MES products: QUALITY ASSURANCE

This function may or may not be tied to SPC and ISO 9000. Some aspects include: ▪ Receiving inspections ▪ Non-conformance ▪ Supplier rating ▪ Calibration control ▪ In-Process inspection ▪ Serialized inspection			
DIAMES Batches may be put on hold for non-conformance reasons.	**Factory Suite 2000** Data on product quality, non-conformance and deviations can be extracted from the Industrial SQL Server database for analysis.	**Workstream Open** On-line alarms draw attention to statistical violations. Specifications verify materials, processes and operators before operations can begin. Operators are provided with a range of options in the case of quality violations.	**RtPM** "rtPM brings the quality function from the lab to the line". The Quality Record retains all information from quality tests. Analysis are easily accomplished by interrogating the Quality Record

Table 28

Evaluation of MES products: PRODUCT DATA MANAGEMENT & DOCUMENTATION

This part of a MES should enable free access to relevant information on products and the production process. Some possibilities include:

- Standard Operating Procedures
- Time standards
- Product drawings
- Regulatory requirements
- Routings
- Process recipes
- ISO standards etc.

Relevant information can be supplied to wherever it is needed (including the shop floor) to inform and educate where necessary.

DIAMES	Factory Suite 2000	Workstream Open	RtPM
No formal support is provided for this function.	The InTouch module displays work instructions, maintenance instructions and other relevant documents. Operators may view historical information on run conditions.	Work instructions can be displayed when necessary.	No formal support is provided for this function.

Table 29

Evaluation of MES products: PROCESS DATA & PERFORMANCE ANALYSIS

This function can capture and process data for time and cost variation or in more detail in a SCADA-like manner. It should be customizable to accommodate the measurement of unique Key Performance Indicators (KPIs).

DIAMES	Factory Suite 2000	Workstream Open	RtPM
A large range of custom reports is available for almost any KPI. The users of these reports are responsible for the analysis thereof	Data analysis can be accomplished by using the "Trend" database client. Detailed management reports can be generated by using Crystal Reports. These reports may focus on subjects such as deviations from plan, utilization, scrap, product or material variation etc	Performance for every Key Performance Indicator may be measured by interrogating the history database. These include yield and scrap levels as well as maintenance information such as Mean Time To Repair and Mean Time Between Failures.	The Production Status Monitor displays real-time and historical data about production status and pre-defined KPI's. Production is monitored against specifications and deviations are reported before it is too late.

Table 30

Evaluation of MES products: SUPPLIER MANAGEMENT

This part of a MES should provide information on upstream linkages in the supply chain. Information on supplier's production processes such as current work order status and planned delivery dates should be available as input into the planning system.

DIAMES	Factory Suite 2000	Workstream Open	RtPM
There is currently no support for this function.	There is currently no support for this function.	There is currently no support for this function.	There is currently no support for this function.

Table 31

Evaluation of MES products: GENEALOGY / TRACTABILITY

This function provides the capability to trace all raw materials, labour and equipment involvement in the production of a specific item or lot. It would be possible to determine, for instance, who supplied the raw materials for batch 433, when it was bought, any linked quality information on that batch etc. This would also include when production was started, on what equipment and by whom etc. This type of information is usually required in regulated industries such as the Food and Pharmaceutical industries.			
DIAMES Complete genealogy records are kept per work order and batch for each phase of the production process.	**Factory Suite 2000** Real-time lot specific and batch specific information are available. It captures and keeps a comprehensive product history and material genealogy	**Workstream Open** Workstream provides complete visibility of the shop floor. Detailed records in the database yield genealogy information when interrogated.	**RtPM** Ancestry can be identified from any point in the process. This includes WIP movement and raw materials used. Material details such as actual parameters, tests performed and test results, attributes etc. can be assessed. Recipe details show useful manufacturing details such as machines involved, times and dates of production etc

5. 3. THE MES FUNCTION MATRIX AS MES EVALUATION TOOL

The McClellan (1997:6,7) function model is used by Willemse (1999) to evaluate DIAMES as MES. In this section the MES Function Matrix is used as tool to evaluate the DIAMES product. The following applications of the MES Function Matrix are demonstrated:

1. MES Function Matrix as tool to contextualize MES product combinations.
2. MES Function Matrix as tool to identify gaps and support make/buy decisions.
3. MES Function Matrix as tool to indicate interface or integration.
4. MES Function Matrix as tool to analyze industry specific MES functions.
5. MES Function Matrix as tool to compare various MES products with each other.
6. MES Function Matrix as tool to support other MES models

The conclusions and suggestions by Willemse (1999) are integrated throughout this discussion.

5. 3.1. MES FUNCTION MATRIX AS TOOL TO CONTEXTUALIZE MES PRODUCT COMBINATIONS

Although DIAMES as such do not perform all of the traditional MES functions, all of these functions are performed by one of the products used at Aberdare Cables. Willemse (1999) states that the Manufacturing Execution System at Aberdare Cables is constituted of a combination of products (of which DIAMES is only one). This statement is supported through the mapping of these products on the MES Function Matrix. The relevant functions of each of the products used at Aberdare Cables (as discussed earlier by Willemse (1999)) are described in the MES Function Matrix (*Table 32* on the following page). The extent to which these products perform the MES functions is not clear from the matrix. It can be seen, however, that the "traditional" MES functions - not performed by DIAMES - is performed by other products, such as the job-adder and CAP B/2.

5. 3.2. MES FUNCTIONAL MATRIX AS TOOL TO IDENTIFY GAPS AND SUPPORT MAKE/ BUY DECISIONS

The MES Function Matrix can also be used to identify the absence of certain traditional MES functions. Development or purchase decisions can be based on this:
From *Table 32* it is clear that a gap exists regarding the real-time analyzing of elements of manufacturing, since very few attention is given to this element of execution. A graphical presentation product (CX-View) is currently used to present data gathered by DIAMES in a graphical fashion. The graphical presentation by CX-view contribute towards the analysis of manufacturing and fits at first glance in the open spaces in *Table 32*. CX-View is, however, not integrated with DIAMES and uses data only used in batch mode to create management reports. This is the reason why Willemse (1999) did not discuss CX-View as one of the MES products at Aberdare Cables. Through the MES Function Matrix the opportunity is identified to add MES functions through the integration of this product with DIAMES. It can be used in a similar fashion to make other make/ buy decisions.

Table 32

MES at Abedare Cables

	GUIDE/ COORDINATE	INITIATE/ READY	ANALYZE	REACT
MATERIAL/ PARTS/ PRODUCT	**DIAMES** maintains all operation information (events, quantities, times and other production or quality related data).	The "second-iteration" production plan is fed into the **CAP B/2** finite capacity scheduler to check for the feasibility of the plan given current resource availability.	**DIAMES** compares individual parameters with the on-line collected production date	**DIAMES** immediately notifies the person in charge when any exceptional conditions occur during production.
LABOUR/ PERSONNEL	**DIAMES** maintains all operation information (events, quantities, times and other production or quality related data).	The "second-iteration" production plan is fed into the **CAP B/2** finite capacity scheduler to check for the feasibility of the plan given current resource availability.		**DIAMES** immediately notifies the person in charge when any exceptional conditions occur during production.
EQUIPMENT/ TOOLS/ FIXTURES	**DIAMES** maintains all operation information (events, quantities, times and other production or quality related data). DIAMES receives an electronic list of planned operations for each attached workcenter. Such workschedules are eitehr issued by the productions planning and controlling system or manually created.	The "second-iteration" production plan is fed into the **CAP B/2** finite capacity scheduler to check for the feasibility of the plan given current resource availability.		**DIAMES** immediately notifies the person in charge when any exceptional conditions occur during production.
WORK INSTRUCTIONS/ SPECIFICATIONS/ PROCEDURES	**DIAMES** maintains all operation information (events, quantities, times and other production or quality related data).			**DIAMES** immediately notifies the person in charge when any exceptional conditions occur during production
WORK ORDERS	**DIAMES** maintains all operation information (events, quantities, times and other production or quality related data).	**"Job-adder"** program optimises the production schedule for maximum throughputs by arraging similar orders in sequence by assigning priorities to each work order.		The **DIAMES** system possesses the capability to manually reschedule some work orders in case of a production failure or other exception. The operator is allowed to choose from one job in a pool of scheduled jobs to optimise production for current shop-floor conditions.

Willemse (1999) remarks as follow on the option to expand the functions of DIAMES to comprise a whole MES:

"Since DIAMES supports the basic MES requirements, its existing capabilities can be expanded to transform it into a fully integrated Manufacturing Execution System. If this avenue is chosen, development should be focussed in the areas of

- *real-time decision support and*
- *reactive scheduling,*
- quick and easy data analysis, *and*
- *closer interfacing with planning and control systems.*

This suggestion correlates with the gaps left by DIAMES as derived from *Table 32*.

5. 3.3. MES FUNCTION MATRIX AS TOOL TO INDICATE INTERFACE OR INTEGRATION

According to Luber (1991:298-300) the word integration (or integrated) is one of the most overused, abused and misunderstood buzzwords in the lexicon of applications software. He defines an integrated software solution as one that has all of the following characteristics:

- The individual application modules share a common database, eliminating the need for redundant data files.
- The individual modules have a common "look and feel", i.e. a common user interface.
- The system is border-less; namely, it is not necessary to perform an intermediate step (such as returning to a main menu) to go from one module to another.

Based on the criteria by Luber (1991:299) it can be said that the MES products used at Aberdare Cables are interfaced, but not integrated. In *Table 32* thick lines are used to separate the functions performed by individual products, if products are not integrated. Where integration exists the line should be removed. When no lines are present on the MES Function Matrix, the MES can be considered to be an integrated MES.

5. 3.4. MES FUNCTION MATRIX AS TOOL TO ANALYZE INDUSTRY SPECIFIC MES FUNCTIONS

Willemse (1999) suggested that DIAMES should not be developed into a whole MES. The reasons for this suggestion are listed below:

- The current departure from a monolithic MES architecture in favor of one that is more granular and based on interfacing compatible components from one or more developer.
- The relatively small local market for MES that is already being fiercely contended for by numerous well established products.
- The time and resources that is necessary to develop DIAMES into an integrated MES are limited.
- Planning and Control Software developers are increasingly adding MES capabilities to their software products, encroaching on the already hazy division separating planning, execution and control systems. DIAMES will also have to compete with these products for market share.

However, according to Willemse (1999) the development of DIAMES into a whole MES will be more feasilible when focussed upon industries related to the cable industry: *"With its background in the continuous cable manufacturing industry, DIAMES may be adapted to serve as a MES in similar markets such as textiles, wire manufacturing and possibly metal extrusion. Alternatively it can be applied with a little adaptation to the discrete manufacturing environment for example electrical appliances, electrical plugs, etc."*

The MES Function Matrix can be used to analyze industry requirements, regarding MES. This statement is discussed in Section 7.1.4. as part of the discussion of MES in different types of industries.

5. 3.5. MES FUNCTION MATRIX TOOL TO COMPARE VARIOUS MES PRODUCTS WITH EACH OTHER

The attributes of another MES product (Workstream Open) are also mapped on the MES Function Matrix (*Table 33* on the following page). It is important to note that the information is subjective, since it is based on promotion material.

Table 33 can be used in a similar way to evaluate Workstream Open as is *Table 32* used to evaluate the MES products at Aberdare Cables. The MES Function Matrix provides a common structure to evaluate more than one product. However, the MES model by McClellan (1997:6,7) proved to be a better tool to compare various MES products with each other. Willemse (1999) used the McClellan model as structure to compare DIAMES with other products.

Table 33

Workstream Open evaluated as MES products on grounds of the MES Function Matrix

	GUIDE/ COORDINATE	INITIATE/ READY	ANALYZE	REACT
MATERIAL/ PARTS/ PRODUCT	Workstream Open puts you in control by giving you complete visibility of the plant floor, including operation status, in-process queues, and work-in-process (WIP) levels.	Workstream Open gives you the detailed and comprehensive planning tools you need to avoid expediting.	The system tracks inventory, labour, and critical activity indicators like yields and scrap levels, to identify cost drivers and reduce product costs. WorkStream Open delivers powerful tools for capturing and analyzing data on products and processes. WorkStream Open collects detailed manufacturing quality data at all major processing points, and integrates it with the lot history and equipment history to allow analysis by material and equipment.	A variety of standard and site-specific statistical process control (SPC) charts can be generated on-line to provide immediate feedback to users about process, product, and equipment status. By providing operators with a full range of corrective actions to take in the event of an error, the system empowers your employees to take responsibility for product quality.

Table 34 (continued)
Workstream Open evaluated as MES products on grounds of the MES Function Matrix

	GUIDE/ COORDINATE	INITIATE/ READY	ANALYZE	REACT
LABOUR/ PERSONNEL	WorkStream Open ensures that operators are provided correct, current instructions.	WorkStream Open ensures that operators are provided correct, current instructions.	The system tracks inventory, labour, and critical activity indicators like yields and scrap levels, to identify cost drivers and reduce product costs.	WorkStream Open ensures that operators are informed of changing conditions during processing.
EQUIPMENT/ TOOLS/ FIXTURES	The Equipment Performance Tracking module helps users manage the usage of valuable resources by incorporating an advanced alarm conditions capability, which drives preventive maintenance schedule management.	The system considers all the factors that affect the schedule, such as delivery date, available capacity, routing, and equipment maintenance schedules.	WorkStream Open collects detailed manufacturing quality data at all major processing points, and integrates it with the lot history and equipment history to allow analysis by material and equipment.	A variety of standard and site-specific statistical process control (SPC) charts can be generatedon-line to provide immediate feedback to users about process, product, and equipment status.
WORK INSTRUCTIONS/ SPECIFICATIONS/ PROCEDURES	Specifications verify materials, processes, and operator qualification before processing begins.	Specifications verify materials, processes, and operator qualification before processing begins.	WorkStream Open processes and validates transactions online so that operations are performed according to a pre-defined model or plan.	
WORK ORDERS	Because it is a real-time system, WorkStream Open considers current lot and equipment status when dispatching a lot for processing. The system allows you to balance production lines based on current material and equipment status, improving throughput and on-time shipments.	The system considers all the factors that affect the schedule, such as delivery date, available capacity, routing, and equipment maintenance schedules. Rule-Based Dispatching allows you to define production priorities, by lot, based on the unique characteristics of your process and products.	WorkStream Open delivers powerful tools for capturing and analyzing data on products and processes.	And you can generate a variety of standard and site-specific statistical process control (SPC) charts on-line to provide immediate feedback to users about process, product, and equipment status.

5. 3.6. MES FUNCTION MATRIX AS TOOL TO SUPPORT OTHER MODELS

From the previous section it is clear that the MES Function Matrix should not replace other MES models. Certain models are more appropriate for specific purposes. Not only have Willemse (1999) use the MES model by McClellan (1997:6,7) as structure to evaluate DIAMES against other MES products (*Table 17-Table 31*), but also are conclusions drawn based on the structure from McClellan. In *Table 34* (on the following page) the recommendations by Willemse (1999) regarding the development of DIAMES into a total integrated system are listed in the first column. In the second column the support as derived from the MES Function Matrix (*Table 32*) is given.

5. 4. CONCLUSIONS

5. 4.1. CONCLUSIONS REGARDING THE PRODUCT DIAMES

From a development perspective, Manufacturing Execution Systems generally falls into one of two categories. It is either one large integrated product from the same developer encompassing all the owner's anticipated needs, or it is a mixture of components (not necessarily from the same vendor) that is assembled to the owner's profile of requirements. DIAMES may be developed in either direction depending on a decision from the system's owners.

Willemse (1999) identified six development alternatives accordingly. These suggestions is listed below:

- Development as a comprehensive, integrated MES.
- Development as a component of a MES solution, addressing some of the functional requirements.
- Development as a budget MES, supporting only the "core" functions.
- Development as a Decision Support System
- Development as a shop floor information feedback loop
- Development as a data agent for third-party applications.

Table 34

Recommendations for the development of DIAMES into a complete integrated MES

Recommedations by Willemse (1999) based on MES model from McClellan	**Support of recommendations, based on the MES Function Matrix**
Support detailed scheduling (preferably dynamically related to changes on the shop floor) of all the resources receiving inputs from the Master Production Schedule. (i.e. schedule machines, tools, labour skills, materials and documents.) The dispatch sequence should change in accordance with events on the factory floor in order to maximize throughput and on-time delivery.	The function of detailed scheduling is part of *the guide/ coordinate* element of execution. From *Table 32* it can be seen that DIAMES only maintains operation information and update scheduling plans from the MRPII system. Detail scheduling is thus lacking.
Optimized work order sequencing (preferably automatic and reactive to changing conditions) based on priorities linked to due-dates or other factors, product attributes or characteristics and similarity in recipes.	The *initiate/ ready* element of execution for *the work order* element of manufacturing is not being performed by DIAMES, but by another software product (the "Job-Adder"). There exists no integration between DIAMES and this product. It can expected from a complete integrated MES to *initiate/ ready work orders.*
Support the control and availability of critical documents such as Standard Operating Procedures, other instructions etc.	Although DIAMES maintains all operation information events no product is catering for the *initiat*ing/ getting *ready* of *work instructions/ specifications/ procedures*.
Provide decision support and alternatives to foremen and operators in the event that an unforeseen event influences shop floor conditions.	DIAMES only **notifies** the person in charge when any exceptional conditions occur - in *react*ion to the elements of manufacturing. No decision support is provided, as could be expected from a complete integrated MES.
Expand the ability to analyze operating performance. Support creation of custom Key Performance Indicators (KPIs) to supplement standard KPIs such as utilization, yield etc.	The gap, regarding the *analyze* element of execution is obvious.
The potential of a Graphical User Interface should be exploited to transform DIAMES into a more intuitive system that is easier to use and understand. This is especially the case for read-only users such as managers who would such as to be able to generate automatic reports. Self-populating templates could be used to accomplish this.	The possibility of integrating the existing CX-View graphical product with DIAMES was already discussed earlier.

5. 4.2. CONCLUSION REGARDING THE USE OF THE MES FUNCTION MODEL AS MES EVALUATION TOOL

The MES Function Model is not just a theoretical outline of the functions of MES. It is also a very useful tool to evaluate MES products and to support decisions on how the products should be implemented. The MES model from McClellan (1997:6,7) provide for some purposes a more appropriate structure. The MES Function Matrix can, however, still support conclusions based on the McClellan model.

5. 4.3. FINAL CONCLUSION

In the introductory chapter two propositions were set for this dissertation:

1. The concept of MES is valid (The concept of MES is used by and useful to manufacturing industry).
2. The Industrial Engineer has a contribution to make, regarding MES

The first proposition is supported through the initial literature study, the development of the MES Function Matrix and the case study application. The remainder of this dissertation document is primarily used to support the second proposition

6. THE INDUSTRIAL ENGINEER IN THE MES ARENA

"The real success of Industrial Engineering is not in developing a creative and effective recommendation for a system, or in arranging the most effective operation of this system after installation. It is in effectively bringing together the necessary people, organizations, and resources for developing the system specifications and operating arrangements to increase significantly the likelihood that the most effective recommendations will be adopted and implemented." (Handbook, 1991:4)

To investigate the role of the Industrial Engineer within the MES arena, the general nature and scope of Industrial Engineering are discussed in the first instance and then applied to roles played within the MES arena.

CONTENTS OF THIS CHAPTER

6. 1. THE INDUSTRIAL ENGINEER

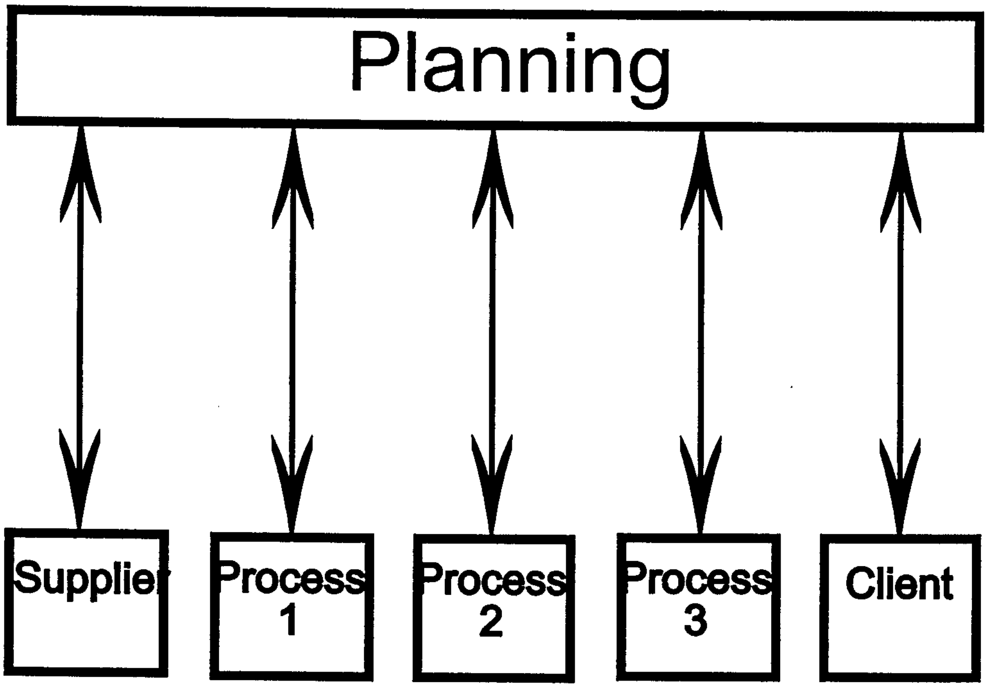
"The proliferation of engineering branches resulted a century ago from a lack of efficiency and integration of all factors into an effective total system. As the technologies needed to cope with these problems started to emerge, the Industrial Engineering profession developed." (Handbook, 1991:4).

6. 1.1. THE INDUSTRIAL ENGINEER AND MES

The role of the Industrial Engineer in the MES arena has emerged together with the evolution of MES technology and the need for MES integration. Vertical integration between control and planning layers is established through the development and implementation of MES by electronic engineers and information technologists (as indicated in *Figure 17*).

Figure 17

Vertical integration between planning and control



According to Digital Basestar (1998: www.asia-pacific.digital.com/info/manufacturing/integr.htm), real-time data collection from shop floor devices and personnel, real-time data processing and validation, real-time data sharing, and real-time application interoperability suffer, even in the most automated plants, from the islands of automation syndrome. In *Figure 17* it is shown how vertical integration may occur, while no integration is established between these "islands of automation".

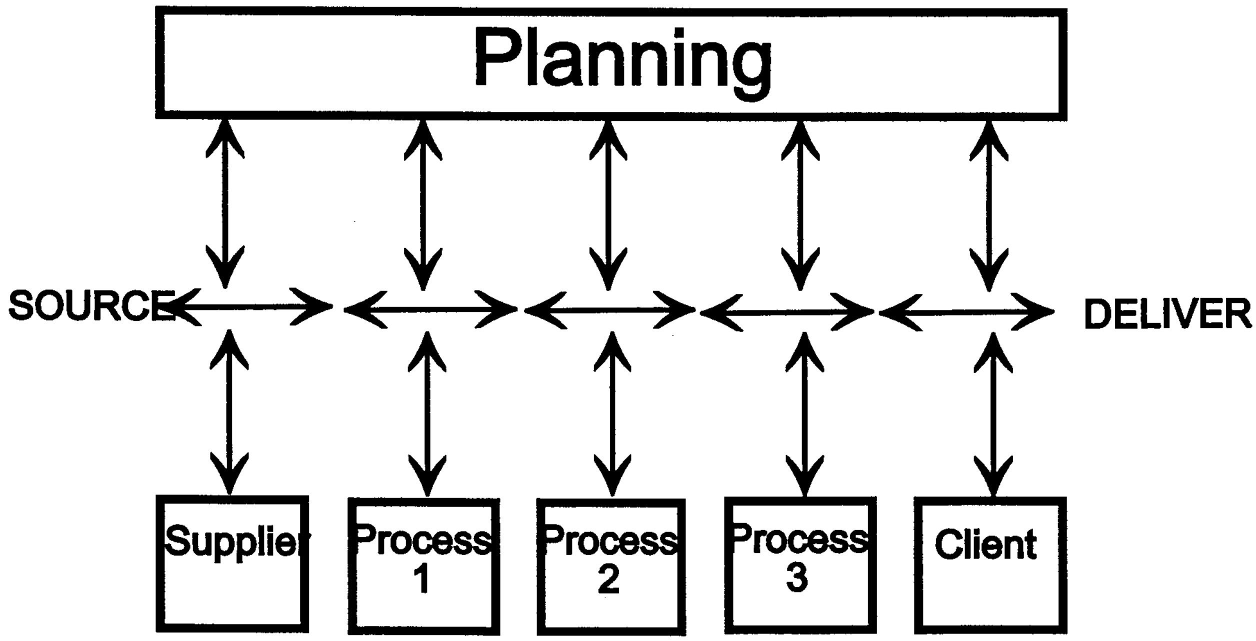
The Object Management Group (1998:6) supports the need for horizontal integration between workstations and plants:

"Many machines and controllers are standalone and are not networked or integrated with other systems. Manufacturing facilities are seeing the need to network these controllers and machines, as businesses need to become more flexible to business directions and organizational changes. In most cases, controllers at this time are unable to understand each other's constraints, targets and assumptions to ensure the control model is valid."

The role that the Industrial Engineer has to fulfill is becoming increasingly important, as the technologies to enable vertical and horizontal execution integration throughout the enterprise and supply chain evolves (*Figure 18*).

Figure 18

Vertical and horizontal execution integration throughout the enterprise



6. 1.2. THE INDUSTRIAL ENGINEER AND MES IN SOUTH AFRICA

The development of the Industrial Engineering profession within the MES arena is portrayed in statistics of two of the leading MES developers and integrators in South Africa as indicated *Table 35.*

Table 35

Industrial Engineers within South African MES companies

Name of company	Background on company	Industrial Engineers within company
KEOPS-ISIS	The following background is given on the homepage of Keops Isis (www.keopsisis.co.za): "Keops Isis Industrial Information Systems (Pty) Ltd.: (Keops Isis) is a leading South African systems developer and systems integrator that specializes in providing solutions for Manufacturing Execution Systems (MES). Keops Isis is vendor independent. Thus they do both MES development and integration.	When this company emerged in the MES field a few years ago, the project team member consisted out of electrical and mechanical engineers as well as information technologists. In 1999 the second Industrial Engineer was appointed, which increases the percentage of Industrial Engineers in relation to other engineers to 20%. Approximately the same number of Information Technologists as Engineers is employed at this company. Keops-Isis is planning to employ even more Industrial Engineers, since Industrial Engineers have proved to interact excellent with their clients. (Theron,13 May 1999).
BKS Hatch	The vision of Hatch is to be the world's pre-eminent supplier of technical and strategic services including Consulting, Information Technology, Engineering, Project Management and Construction to the Mining and Metallurgical industries. Hatch's Advanced Systems group has extensive experience designing and installing MES and ERP systems. (www.hatch.co.za)	In 1998 the first (and only ever since) Industrial Engineer was employed at BKS Hatch, South Africa.

A sample size of two is small an insignificant to allow generalization. Conclusions on the involvement of Industrial Engineers in the MES arena, should not be derived directly.

6. 1.3. TRAINING OF THE INDUSTRIAL ENGINEER WITH REGARD TO MES

Röhrs (1996) developed a training model for Industrial Engineers as illustrated in *Figure 19* on the next page.

The vertical axis (systems axis) represents the continuum of types of systems. The top of this axis represents abstract systems (information), while concrete systems (equipment) are represented at the bottom. These systems can either be human driven (left) or technique driven (right) as indicated by the process (horizontal) axis. The Industrial Engineering areas of expertise are indicated in the relevant positions on this model.

The scope of Industrial Engineering (as derived from *Figure 19*) can be brought into context with MES through the MES Function Matrix (Chapter 4). This is done in *Table 37*, following *Figure 19*. Some of the Industrial Engineer's areas of expertise (such MRP, MRPII or automation) fell within the scope of planning or control systems and not execution. It is, however, indicated on this matrix, since expertise with regard to the other levels of systems is needed to establish optimal integration.

Figure 19

Training model for Industrial Engineers

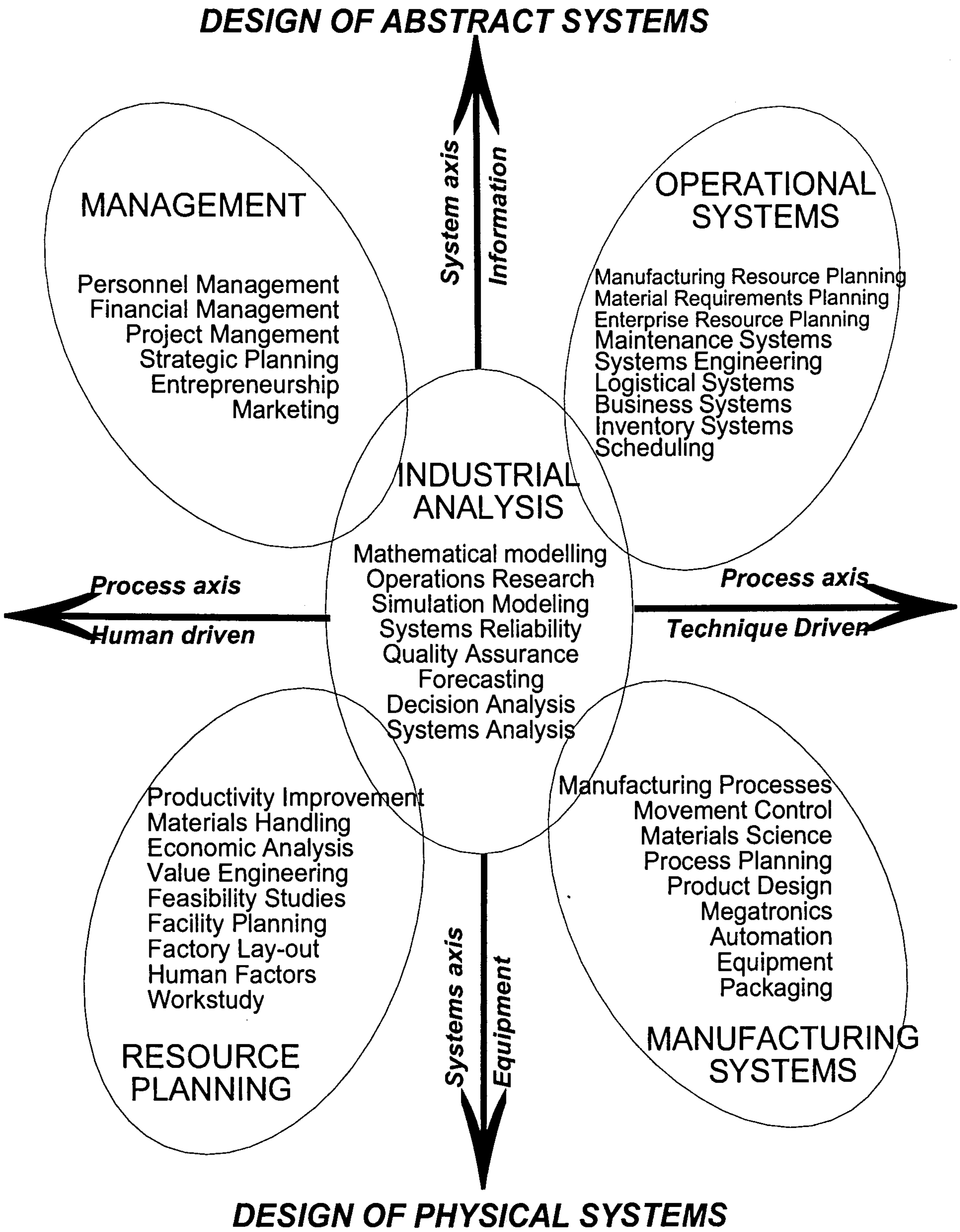


Table 37

The expertise of the Industrial Engineers within the scope of Manufacturing Execution Systems

	GUIDE/ COORDINATE	INITIATE/ READY	ANALYZE	REACT
MATERIAL/ PARTS/ PRODUCT	• MRP/ MRPII • Logistical Systems • Inventory Systems • Scheduling	• Logistical Systems • Materials Handling	• Mathematical Modeling • Operations Research • Quality Assurance • Materials Handling • Materials Science	• Scheduling • Quality Assurance • Decision Analysis • Materials Handling
LABOUR/ PERSONNEL	• Personnel Management • Scheduling	• Personnel Management • Human Factors	• Personnel Management • Mathematical Modeling • Human Factors	• Personnel Management
EQUIPMENT/ TOOLS/ FIXTURES	• Scheduling • Automation	• Maintenance Systems • Automation	• Maintenance Systems • Mathematical Modeling • Operations Research	• Maintenance Systems • Decision Analysis
WORK INSTRUCTIONS/ SPECIFICATIONS/ PROCEDURES	• Value Engineering • Manu-facturing Processes	• Value Engineering • Product Design • Manu-facturing Processes	• Operations Research • Economic Analysis	• Decision Analysis
WORK ORDERS	• Logistical Systems • Scheduling	• Logistical Systems • Scheduling	• Mathematical • Modeling • Forecasting • Economic Analysis	• Scheduling • Decision Analysis

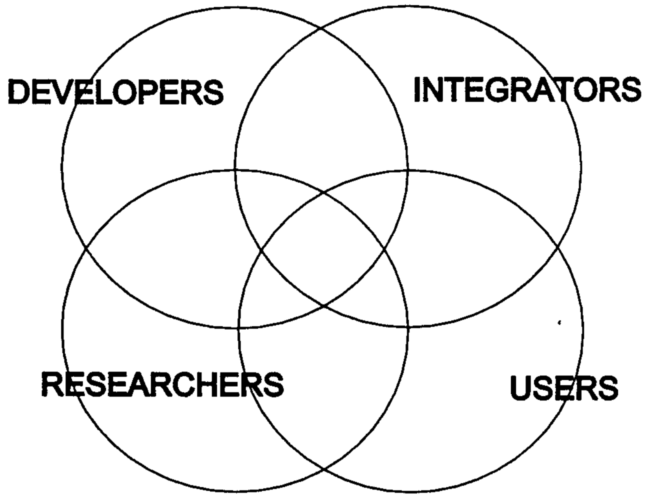
Areas of expertise, such as project management, marketing and systems engineering do not appear in *Table 37*, but it are related to the roles played within the MES arena. It is evident that the Industrial Engineer possesses important skills to assists in the development, implementation and use of MES.

6. 2. ROLES WITHIN THE MES ARENA

Within the MES arena 4 roles are identified as indicated in *Figure 20*.

Figure 20

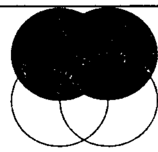
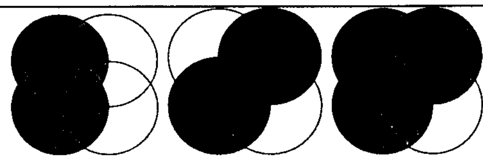
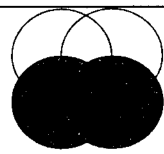
The roles played within the MES arena

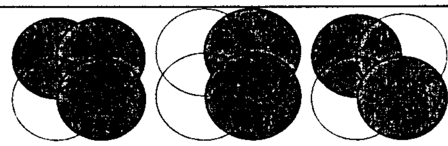
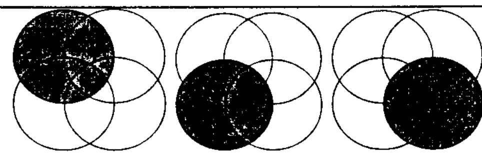


These roles may overlap in some way or another, as explained in *Table 38*.

Table 38

Overlapping of roles played with regard to MES

It often happens that one company is both developing and integrating certain MES products.	
Both developers and integrators may be involved in research on MES.	
Some manufacturers (users) – such as the semiconductor industry (Sematech, 1999, http://www.sematech.org) – often engaged in research on the application of MES within their industry or business.	

Users may also work together with developers and/or integrators to develop an Manufacturing Execution System solution for that business. Due to the duration and strategic nature of MES implementation, it is normal for a user organization to engage in a partnership with an integrator organization. (HATCH Africa,1998:1)	
In most instances users of MES are not involved in the development of MES and some institutes (such as MESA International) have the sole purpose of promoting MES through research. Some vendors may also only focus on the development of a product, but integrators never work in isolation.	

6. 2.1. ROLES FULFILLED BY THE INDUSTRIAL ENGINEER

According to the Handbook of Industrial Engineering (1991:4), "Industrial Engineering will be recognized as the leading profession whose practitioners

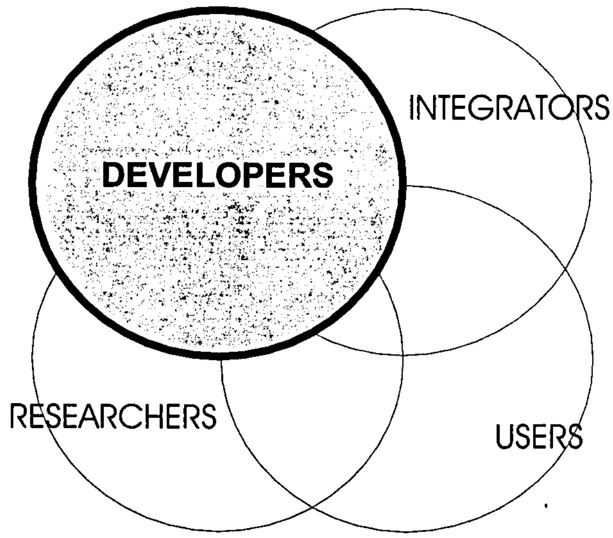
- plan, design,
- implement, and
- manage integrated production and service delivery systems that assure performance, reliability, maintainability, schedule adherence and cost control. These systems may be socio-technical in nature, and will integrate people, information, material, equipment, processes, and energy throughout the life cycle of the product, service, or program."

The roles of system

- development (plan, design),
- integration (design, implement) and
- use (manage)

can be identified from this definition. Each of these roles, together with the research role, is investigated in the remainder of this chapter.

6. 3. THE INDUSTRIAL ENGINEER AS MES DEVELOPER



"Information Engineering" is sometimes suggested as a substitute name for the Industrial Engineering profession. It refers to the combined hardware and software aspects of systems improvement. The profession will draw on artificial intelligence, expert systems technology, data base systems, and computer chip concepts to supplement its current set of techniques and tools to achieve the information engineering status. Computer-integrated manufacturing systems, software systems development, decision support systems, expert systems, enterprise wide information systems, project control systems, and economic analysis systems illustrate the prospective results of this thrust." (Handbook,1991:26)

From a comprehensive list of typical roles played by an Industrial Engineer (Handbook of Industrial Engineering,1991:18), the roles related to the development of software solutions are the following:

1. **Designer/ Planner**
   - Produces the solution specifications and serve as advocate of the solution through the implementation phase.
2. **Innovator/ Inventor**
   - Seeks to produce a creative/unique/advanced technology solution and advocate its use all the way through implementation.

These roles are related to the development of an Manufacturing Execution System.

6. 3.1. DESIGNER/ PLANNER

"An Industrial Engineer produces the solution specification and serve as advocate of the solution through the implementation phase." (Handbook, 1991:18).

According to Forstedt (1998:www.consilium.com/Publications/ics.htm) the trend is away from writing software internally in favour of sticking with core competencies, and looking for software vendors to provide the cost to develop, support and enhance. The Industrial Engineer is in an excellent position to identify the functions needed and translate the need to specifications, which would enable vendors to develop software to attend to this need.

6. 3.2. INNOVATOR/ INVENTOR

"An Industrial Engineer seeks to produce a creative/ unique / advanced technology solution and advocate its use all the way through implementation."
(Handbook, 1991:18).

Code development arrangements are not uncommon between manufacturers and software providers when there is no software product that meets the user requirements. With the emphasis today being on quality and reliability, more demands are being placed on software vendors to become ISO 9000 registered, to provide better product testing and documentation, and to participate in the enhancement process with their partners the manufacturers (Anonymous, 1998:4A). The average information technologist does not have sufficient knowledge regarding manufacturing management or concepts such as ISO9000. The Industrial Engineer should thus be involved in the development process.

6. 3.3. CONCLUSION

The Industrial Engineer can make a significant contribution towards the development of MES. Since Industrial Engineers is to a great extent concerned with integration, even greater contributions should be made regarding MES integration, as discussed in the next section.

6. 4. THE INDUSTRIAL ENGINEER AS MES INTEGRATOR

"MES encompasses multiple areas of expertise and the initial preparation, selection, and implementation of MES software are events in which most companies have no previous experience. Experienced integrators should be a part of the team. Manufacturing consultants can provide an outsider's experienced perspective in analyzing business process improvements.

(MESA International, 1996: www.MESA.org/html/main.cgi?sub=29)

From the same list used to define roles related to software development (Handbook, 1991:18) roles, related to the integration of products, are selected:

1. **Boundary/ Spanner**
   - Bridge the information/style/interests gap between the developer and user/client/adopter.
2. **Facilitator/ Coordinator**
   - Provide appropriate purposeful activity approach guidance and structure to a group.
3. **Analyst**
   - Separate a whole into parts and interactions and examine them to explore for insight and characteristics.
4. **Project Manager**
   - Operate, supervise, and continuously evaluate the usually large scale and complex project structure or system.
5. **Chairperson**
   - Be responsible for a project and manage and facilitate the team/group/task force.
6. **Decision Maker**
   - Select a preference from alternative possibilities for topic of concern.
7. **Trainer/ Educator**
   - Have people involved learning the skills and knowledge of Industrial Engineering and the various approaches to purposeful activities.

6. 4.1. BOUNDARY/ SPANNER

"An Industrial Engineer bridges the information/style/interest gap between the developer and user/client/adopter" (Handbook, 1991:18)

Swanton (1998:www.amrresearch.com/repac) explains that, with technical backgrounds, vendors and plant users tend to miss important business and political realities when advocating system projects. According to BKS Hatch Africa (1998:1) - one of the leading MES integrators in South Africa - the needs, which address the business vision, must be identified and met, through the implementation of an Manufacturing Execution System. The affected business processes must be characterized and evaluated, and sometimes changed. The readiness within the business to successfully implement the systems must be assessed and developed. Forstedt (1998:www.consilium.com/Publications/ics.htm) highlights the opportunity to reengineer manufacturing processes and documentation when implementing an Manufacturing Execution System.

Swanton (1998:www.amrresearch.com/repac) listed some questions, which need to be answered when an Manufacturing Execution System is implemented:

- What changes are driving my industry? Top executives have a clear picture of changes necessary to stay competitive, and the project must further these goals.
- Will it enhance ERP and supply chain projects? These same executives have already bet their careers on expensive enterprise-level projects. To get corporate backing a plant project must demonstrate enhancement or, even better, necessity for plant success.
- What are my fundamental business processes? Though much has been made of corporate business processes such as "order to cash," similar processes exist in the plant.
- How will I sustain a competitive advantage? Many plants judge themselves on a static bar such as production efficiency and cost.

The Industrial Engineer is in the position to answer these questions and present it in a way, which can be understood by vendors and plant users with a technical background.

6. 4.2. FACILITATER/ COORDINATOR / CHAIRPERSON

"An Industrial Engineer provides appropriate purposeful activity approach, guidance and structure to a group and is responsible for an Industrial Engineering project and the management and facilitation of the team/group/task force. (Handbook, 1991:18)

MESA International (1996:www.MESA.org/html/main.cgi?sub=29) explains that MES implementations affects the entire organization. Data from one area may be used to make decisions in another area. If that data is not timely or accurate, poor decisions may result in the related area. It is, therefor, mandatory that the whole organization be committed to understand the big picture of what is needed. Participation and/or proper representation in the evaluation and selection process helps assure successful implementation. MES integrator must assure that the entire organization's requirements and not just individual departmental needs drive the new system's requirements.

Heini Wellman (1998:www.foodexplorer.com), who holds a master's degree in mechanical and industrial engineering, heads a multi-functional team which studies the replacement of Nestle's current factory-based ERP systems and its integration with the MES systems for Nestle's manufacturing plants. Wellman explained his facilitation/ coordination role as MES integrator:

"For MES, we formed a special interdisciplinary working group, under an interdisciplinary steering committee. The steering committee includes people from manufacturing systems, information systems, engineering (plant automation), and quality management. The special working group has representatives from these same areas. The project is lead by people concerned with manufacturing systems: Manufacturing systems people are not information systems people, but people who think about our manufacturing systems and methods. That's what I'm responsible for. I serve on the steering committee, and I organize the special working group, which is headed by a manufacturing systems person. For balance, the head of engineering chairs the steering committee."

The Industrial Engineer is thus equipped to facilitate and coordinate the company-wide implementation of an Manufacturing Execution System.

6. 4.3. ANALYST

"An Industrial Engineer separates a whole into parts and interactions and examine them to explore for insight and characteristics." (Handbook, 1991:17)

Systems integrators can assist in evaluating integration requirements, responsiveness, flexibility, and delivery and retention of critical information (MESA International, 1996:www.MESA.org/html/main.cgi?sub=29). According to Swanton (1998:www.amrresearch.com/repac) the potential of MES, as an analyzing tool, is not exploited optimally by MES users. The Industrial Engineer has the ability to make sure that this business process is not neglected when an Manufacturing Execution System product is chosen and integrated.

6. 4.4. DECISION MAKER

"An Industrial Engineer selects a preference from among alternative possibilities for topic of concern." (Handbook, 1991:18)

The Automation Research Council (1998:www.arcweb.com/ARCsite/MktStudies/mktstudies.htm) highlights the fact that the installation of production management systems is a lengthy and costly process (often taking a year-and-a-half or longer in large plants). Because production management software projects involve extensive system integration services, manufacturers need to be careful in selecting a supplier. Supplier selection is particularly important because most production management software companies are small. Manufacturers selecting production management vendors would like assurance that their prospective partner will be capable of an ongoing relationship, available to solve problems and update the system.
The Industrial Engineer is trained in the making of decisions such as these.

6. 4.5. PROJECT MANAGER

"An Industrial Engineer operates, supervises, and continuously evaluates the usually large scale and complex project structure or system." (Handbook, 1991:18)

Each MES implementation project varies from one another. Project differences relates to:

- the type of industries,
- existing systems,
- budgets,
- scope of projects and
- available information technology.

Although no generic implementation strategy exists, the project manager (such as an Industrial Engineer) should consider the following:

According to Theron (1998), change management is especially important in converting existing legacy or manual systems to an integrated MES. Aspects that need to be taken into consideration are:

- Participation, representation and understanding from all areas affected by the MES
- Organizational preparation for change
- Senior management supporting/managing the project
- Budget commitment
- Existence of other complementing systems (SCM, ERP, Control)

Valstar (1998: www.valstar.co.uk/MES/MESprod.html) is using the following strategy to implement their MES:

1. Investigation of manufacturing environment by integrator
2. Testing of system by key users
3. Configuration of hardware and software on grounds of the suggestions by key users
4. Testing of system to determine key data collection points, events and external interfaces
5. Installation of production system and initialization of production database
6. Maintenance and long term support.

Due to the long duration and strategic nature of MES implementation, it is normal for an user organization to engage in a partnership with an integrator organization. (HATCH Africa,1998:1). The Industrial Engineer - not being a technical specialist - is ideally suited with appropriate experience to fulfill the role of project manager.

6. 4.6. TRAINER

Despite all of its functionality, MES still faces two notable barriers to success. One is the attitude of people in production and the other barrier is their comfort level working with real-time information systems. MES must be embraced by

- *managers, supervisors, and*
- *others on the shop floor to be effective.*

(Forger,1997:www.manufacturing.net/magazine/mmh)

(a) TRAINING/ EDUCATION OF "MANAGERS AND SUPERVISORS"

According to Leibert (1995:7) the vision to implement a factory floor-based workflow system is often derailed up front, during the evaluation stage. Top-level management frequently closes its eyes to situations they don't want to acknowledge. They also might not be aware of the barriers to effectively evaluating a workflow system. The reasons for ineffective evaluations have to do with the misunderstanding of system capabilities and the lack of understanding about how employees will be affected through a new way of working. Good system changes often require business changes that occasionally can be in conflict with the status quo found at middle and lower management levels.

(b) TRAINING/ EDUCATION OF "OTHERS ON THE SHOP FLOOR"

Charles Klee (Forger,1997:www.manufacturing.net/magazine/mmh) explains that the biggest challenges in implementing MES and in obtaining satisfactory results are related to people. In order to get all of the employees to think and act together after so many years of independent activities, a steering committee including top management was formed to break down the barriers between departments. By using live data and making it available to multiple departments, people must dispense with the informal information systems they have relied on in the past. In turn, that changes the way work gets done. Resistance to that shift will disappear, as people become more comfortable with the new method of operating.

It is also important to analyze the degree of control necessary, which will depend on, among other things, how well trained/educated the production personnel are and whether or not they are computer literate (Forstedt,1998:www.consilium.com/Publications/ics.htm).

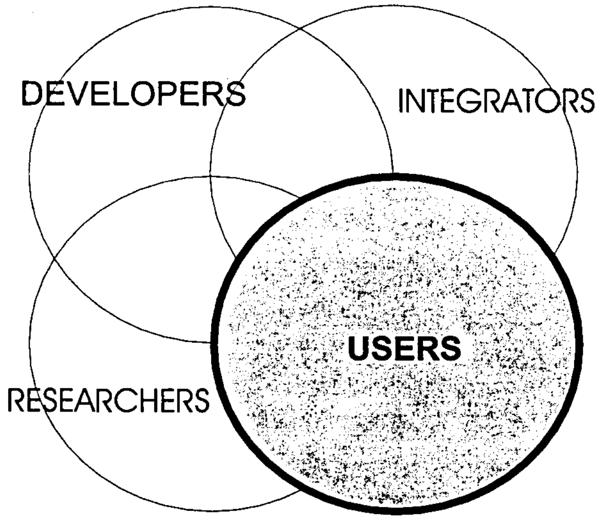
The Industrial Engineer has knowledge of both organizational behaviour and the contents of suggested training and can assist in the development of an MES training program.

6. 4.7. CONCLUSION

"Automation of manufacturing, professional, and office systems and activities will accelerate. Paradoxically, the importance of human beings in these systems increases as greater skills are needed to design and operate the systems while the number of people employed goes down. No office computer, robot, automated cell, or computerized manufacturing system will ever be able to contribute, as can the people who remain. Socio-technical systems are needed to accommodate the multiple perspectives of reality. The Industrial Engineering will be called on to provide the facilitating abilities, change processes, technology understanding, and human factors knowledge to produce the breakthroughs and continuing improvements in them"
(Handbook,1991:26)

The expertise of the Industrial Engineers described above is needed for optimal integration of MES. MES can furthermore be applied by the Industrial Engineer to obtain continuous improvement, as discussed in the following chapter on the users of MES.

7. USERS OF MES



The users of MES is categorized in this chapter on according to the following categories:

1. Industry sectors
2. Companies
3. Individual users within companies

CONTENTS OF THIS CHAPTER

7. 1. THE USE OF MES WITHIN INDUSTRY SECTORS

According to Consilium (1998:www.consilium.com/Publications/why.htm) the following industry sectors represent the vast majority of the total packaged integrated MES installed base:

- Semiconductor
- Electronics
- Aerospace and defense,
- Pharmaceutical and health care products, and
- Chemical industries.

The need for traceability, together with complex or unstable processing and heavy governmental regulations, within these industry sectors, is believed to be the common driver for the growth of MES products.

7. 1.1. INDUSTRY SECTOR UTILIZATION OF RELATED SYSTEMS

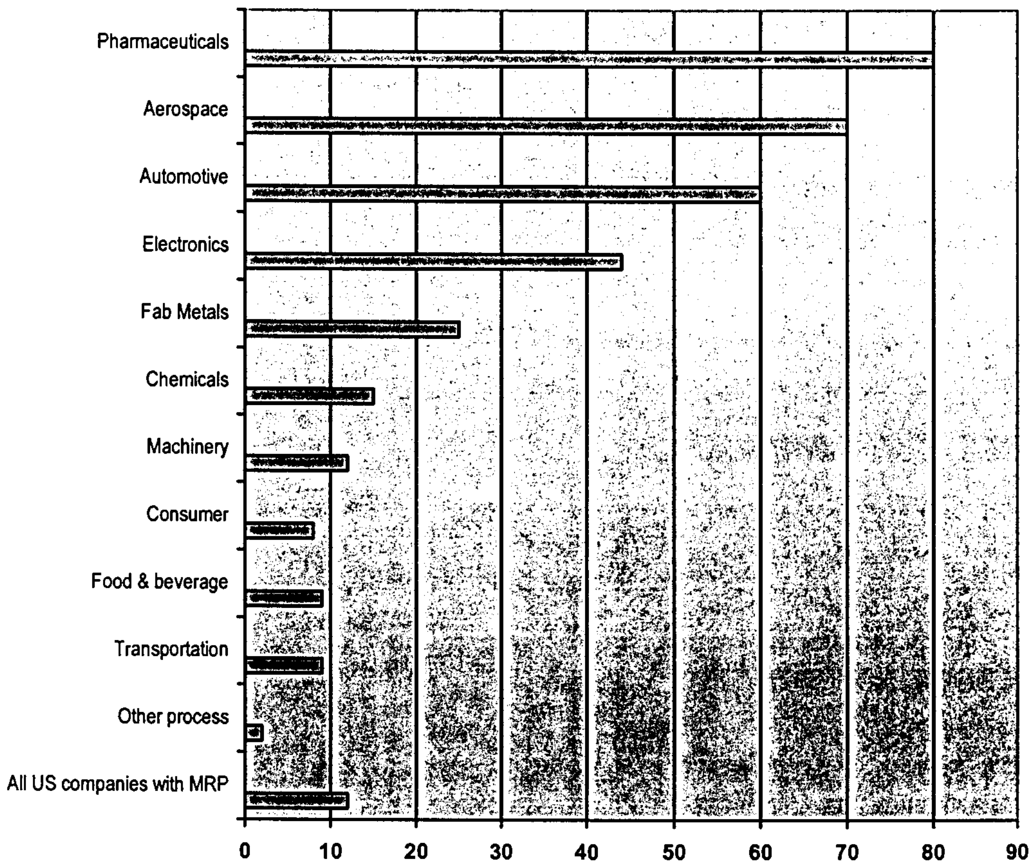
These industry sectors corresponds to a great extend with companies who have taken the lead on the field of MRP and MRPII. *Figure 21* shows the percentage of companies in the United States that have installed MRPII-type systems (Chase:1995:589).

7. 1.2. INDUSTRY SECTOR UTILIZATION OF MES WITHIN SOUTH AFRICA

The automotive and fabricated metals industries rank high on the MRPII list, but are not present on the list of industries with high implementation of MES. It is, however, interesting to note that the metals industry is the focus of the two of the most significant South African MES integrators (KEOPS-ISIS and BKS Hatch). These two companies also do some MES implementations in the automotive industries.

Figure 21

Percentage of Companies in 11 Industries (within the USA) with installed MRPII systems



In a resent survey by South African Instrumentation and Control Journal (1999:8-12) thirty software integrating companies in South Africa were given the choice of highlighting (in five words), their integration expertise. The industry sectors covered by these integrators were also added to this survey. Nine of these thirty companies have chosen MES as to describe their integration expertise. The feedback from these nine companies is summarized in *Table 39*, on the following page.

The scope of projects undertaken by these companies is unknown and MES integrators interviewed for purposes of this dissertation is not part of this list. An accurate ranking of the MES utilization within South Africa can therefor not be provided.

Table 39

South African MES integrators

INDUSTRY SECTOR	COMPANIES WITH MES EXPERTISE								
	Alstom Industrial Systems	DLRA Projects	Gemsys	ICIS	ISI (Industrial Systems Integrators)	Quad-SI	S&P Poroject Engineering	Tradex	Warthog Industries
Food & beverage	■	■	■	■	■	■	■	■	■
General manufacturing	■	■	■	■	■	■	■	■	■
Materials handling	■	■	■	■	■	■	■		■
Mining & Metals	■	■	■	■	■	■	■		
Power generation & distribution	■	■	■	■	■	■	■		
Water & wastewater	■	■	■	■	■	■	■		
Pulp&paper	■	■	■	■	■		■		
Transportation	■	■	■	■		■	■		
Automotive manufacturing	■		■	■			■		■
Petrochemical		■	■	■	■		■		
Sugar		■	■	■		■	■		
Environmental control & monitoring		■	■		■		■		
Warehousing & storage	■		■	■		■			
Pharmaceutical	■			■			■		
Rubber and plastic	■					■	■		
Marine	■		■						
Textiles							■		

7. 1.3. DRIVERS WITHIN INDUSTRY SECTORS

Manufacturing Execution Systems provide similar benefits regardless of the industry they are applied to. However, there are also unique drivers within industries that emphasize specific MES capabilities over others depending on the manufacturing environment. According to Marks (1997:http://www.industry.net/nmw97/MES1.htm), these business drivers have important ramifications on how MES systems are viewed, funded and implemented by companies in different manufacturing industries

Consilium (1998:http://www.consilium.com/Publications/why.htm) listed some of these industry drivers (*Table 40*).

Table 40

Drivers of change towards MES within industry sectors

Industry	Drivers of Change
Aerospace & Defense	Government Compliance Tractability Product Quality Work Track by Contract
Chemicals	Safety Environmental Requirements Service Responsiveness
Electronics	Vendor Quality Quality Trends Warranty Time-to-Market
Pharmaceuticals	Government Reporting Electronic Batch Records Electronic Data Collection Recipe Management
Semiconductor	Complex Materials Plans Lot Tracking Yield/ Quality Time-To-Market Finite Capacity Scheduling Resource Utilization
Food Processing	Yield Quality Lot Tracking Government Compliance

According to Forstedt (1998: http://www.consilium.com/Publications/ics.htm), MES packages are gaining wider acceptance as more and more industries are faced with customers demanding better delivery performance and higher levels of quality at lower cost.

7. 1.4. MES FOR DISCRETE MANUFACTURING AND PROCESS MANUFACTURING

McClellan (1997:22) explains that the idea of MES is being applied to all manufacturing environments, from discrete-part manufacturing to process manufacturing such as a chemical plant, a pharmaceutical plant or brewery. He suggests the following industry classification regarding the use of MES within industry sectors:

- Discrete part
- Repetitive discrete part
- Batch process
- Continuous Process

In Chapter 4 the suggestion is made the MES Function Matrix is used as framework to develop an MES checklist for a specific industry. The statement is made that the elements of manufacturing and the elements of execution (as defined for purposes of the MES function matrix in Chapter 4) are related to the type of industry. To support this statement, the differences between process manufacturing and discrete manufacturing is discussed according to some elements of manufacturing (*Table 41*) and some elements of execution (*Table 42*). Both of these tables appear on the next page.

Table 41

The differences between discrete manufacturing and process manufacturing on grounds of elements of manufacturing used to develop the MES Function Matrix.

Discrete Manufacturing	**Process Manufacturing**	**ELEMENTS OF MANUFACTURING**
Stored in containers	Stored in tanks, silos, bulk	• ***Material***
"Discrete manufacturers add value by machining, fabricating, and assembling parts. All material is usually input at the beginning of the manufacturing process. This process produces one output unit (i.e., a completed subassembly or finished product). This type of manufacturing process can be modeled using the bill of materials and routing files in a discrete MRPII software package."(Luber,1991:319)	Process manufacturers add value by using energy, equipment, and other resources to blend or separate ingredients and cause chemical reactions. The manufacturing process consists of multiple steps or stages. Each stage may require ingredients and resources to be input, and each stage may yields multiple outputs such as co-products, by-products, waste, energy, and recyclable materials. (Luber,1991:319)	• ***Material*** • ***Work Order*** • ***Speci-fications***
Tight specifications Bill of Materials	Wider specifications Formula	• ***Speci-fications***
Categorized by item number	Categorized by product number	• ***Work order***
Discrete manufacturers can often increase capacity by hiring additional workers, buying or leasing more machines, or subcontracting work to external suppliers.	Process manufacturers generally must work within the constraints of fixed capacity. Short of building and additional plant. There is often little that a process manufacturer can do to increase capacity.	• ***Equipment***

Table 42

The differences between discrete manufacturing process manufacturing on grounds of elements of execution used to develop the MES Function Matrix.

Discrete Manufacturing	**Process Manufacturing**	**ELEMENTS OF EXECUTION**
Easy and accurate to measure (count)	Difficult to measure (volume etc)	• ***Analyze***
Consistent and predictable quality	Quality is unpredictable and time variant	• ***Analyze***
Predictable yields	Inconsistent Yields	• ***React***
Initial MRP concepts (which still dominate many application designs, focussed on the needs of discrete manufacturers	Despite the rapid growth in the ERP market over the pas few years, the process segment remained relatively untapped from 1995 to 1996. According to the AMR, ERP in process industries are expected to increase.	• ***Coordinate***

7. 1.5. INDUSTRIES OTHER THAN MANUFACTURING

The term *Manufacturing* Execution Systems implies that it is a concept focussed on manufacturing industries. MES principles and products can presumably be applied to service industries too. Further discussion does not fall within the scope of this dissertation.

7. 2. COMPANIES AS USERS OF MES

According to McDonough (1995:http://mfginfo.com/htm/MESi-artical.htm) the cost of an MES is not strongly linked to the size of a plant or the volume of a foundries production. MES systems that run on large mainframe / mini-frame types of hardware have significant costs and support issues that have a life all their own, independent of the MES software running on them.

Only a small fraction of manufacturing businesses can afford the cost of installing and maintaining an integrated MES solution. When a Manufacturing Execution System is integrated into an existing business system, maintenance and integration costs incur. According to NIST (1998:http://www.atp.nist.gov/atp/focus/tima.htm) these costs contribute to the fact that total integrated MES are not feasible for small and medium enterprises.

Examples of South African plants at which Manufacturing Execution Systems are implemented, are listed below:

- Alusaf Hillside Smelter (KEOPS-ISIS)
- Royal Swazi Sugar Corporation (KEOPS-ISIS)
- Delta corporation (KEOPS-ISIS)
- Scaw Metals (KEOPS-ISIS)
- Saldanha Steel (KEOPS-ISIS)

These manufacturing plants are considered to be large. The main reason for the lack of smaller manufacturers, making use of MES, is not necessarily the cost of the systems. It does, however, support the statement that current MES are only affordable to larger manufacturers. In South Africa the growth of the manufacturing industry sector is to a great extent in the hands of small and medium sized manufacturers. Thus, it would be to the benefit of the country if MES could be made affordable to these manufacturers. Together with the physical software, the training regarding the use of this product, as well as underlying concepts, need to be provided to these manufacturers. One of the suggestions by Willemse (1999) - regarding market positioning of the product DIAMES - is to develop this product into a product accessible to medium and small manufacturers.

7. 3. THE USE OF MES WITHIN COMPANIES

"By moving execution capabilities out to the operators, manufacturers can create a pull environment on the shop floor, creating a process that contains nothing but value-added activities. Support activities would be done in parallel to manufacturing activities so they do not constrain the creation of value. Activities that do not create value for the manufacturer or its customers are eliminated." These key players are subsequently described (MESA International, 1996:www.MESA.org/html/main.cgi?sub=32)

7. 3.1. SHOP FLOOR OPERATORS

Execution-driven applications provide operators with real-time dispatch lists that show work orders in priority sequence. This job sequence information is continuously adjusted as actual manufacturing operations take place – or as priorities change. As information of the work order completion is provided by the operator, availability for the next operation is shown.

Shop floor operators have access to detailed work order status screens that provide them with support requirements for each job, including engineering drawings, programs, tooling, materials and special instructions. Actual work order status is communicated in real-time to production control personnel and to the scheduling system. Information on jobs in queue, set-up, run and problem states can be entered and communicated continuously. Real-time communication of problems to production scheduling and support functions expedites problem resolution.

7. 3.2. PRODUCTION SCHEDULERS

Scheduling personnel are able to easily change order priority, routings and schedules (due to alternate routings, engineering changes, quantity changes, rework and cancellations) and communicate these changes to the shop floor instantaneously. Schedulers have the capabilities to override the schedule and change an order's place in the job sequence, or group similar jobs to save set-up time. Work orders and routings can be downloaded from MRP systems or entered manually. Support function resource requirements, such as tools, documents and fixtures, can be easily imported into the system for communication directly to work center operators. Job status information facilitates their working with customer service; managers and supervisors to prioritize schedule changes. "What if" simulation capability allows them to test alternative scenarios prior to finalization of changes.

7. 3.3. SUPPORT GROUPS : STOCK ROOM, TOOL ROOM, MAINTENANCE ENGINEERING

The manufacturing management system provides work order priority, location and requirements on a real-time basis to all support functions in order to maximize manufacturing throughput. The system supplies each support function with detailed plans of what to do and when to do it, on a minute-by-minute basis. Real-time alarms identify problem situations occurring on the shop floor, allowing support personnel to respond quickly. Support groups can input in advance when they are unable to meet scheduled requirements, providing information that automatically revises schedules.

7. 3.4. CUSTOMER SERVICE AND SUPERVISORS

The execution system provides customer service, supervisory and other personnel the work order status for any functional area within the plant. The system offers them multiple views of production status information including historic, current and projected data. Customer service personnel can use production information to make sure new customer commitments can be met without impacting previous promise dates.

Supervisors can use the information to make decisions on whether to employ alternate machines or work centers to relieve shop floor bottlenecks, and to identify problem order and material shortages.

7. 3.5. MANAGERS & MANUFACTURING ENGINEERING

The system provides detailed data on individual work centers and tools for identification of performance improvement areas. Complete backlog analysis and trending, input/output control and throughput calculations provide the information needed to identify production bottlenecks. It also enables detailed analysis of queue, set-up, run and problem times so that the best opportunities for cycle time reductions can be pinpointed.

7. 4. MES AS TOOL FOR THE INDUSTRIAL ENGINEER

"Compared with MRPII/ERP and SCADA products, MES still are not well understood primarily because manufacturing was long viewed as a necessary evil rather than the core of the business. However, the current business climate is forcing corporations to focus on manufacturing practices in order to continuously improve and achieve new so-called stretch goals." (Forstedt:1998:www.consilium.com/Publications/ics.htm)

The Industrial Engineer coordinates continuous improvement. According to the Handbook for Industrial Engineering (1991:18), the manager of a continuous improvement program is someone who operates and supervise the program for continuing search for change and improvement in the organization. The use of MES in the continuous improvement process as well as the implementation of quality standards are discussed accordingly.

7. 4.1. CONTINUOUS IMPROVEMENT

"Continuous improvement seeks continual improvement of machinery, materials, labor utilization and production methods." (Chase, 1995:180)

(a) CONTINUOUS IMPROVEMENT THROUGH THE ELIMINATION OF WASTE

The so-called "Seven Wastes of Manufacturing" are often used to identify areas for continuous improvement. Schroer (1998:87) identified ways of overcoming each of these wastes through continuous improvement. These wastes - as well as possible causes identified by Schroer (1998:88) – are listed below:

(1) Overproduction
- Policy; Management decisions; Batch scheduling systems

(2) Waiting and searching
- Waiting for materials; Poor layout; Wrong tool; Unexpected problems

(3) Transportation
- Poor layout; Available storage area; Large lots

(4) Processing
- Improper fixtures/ tools; Insufficient standards;

(5) Motion
- Poor layout; Lost items; Poor work arrangement Misunderstanding Poor standards

(6) Defects
- Poor manufacturing methods; Damaged/ Lost goods; Poor training

MacDonald, (1998:www.consilium.com/Publications/roi.htm) explains how MES can contribute to the reduction in cost related to the elements of manufacturing. The information provided by Schroer (1998:86) and MacDonald is combined to illustrate the potential of continuous improvement through MES. (*Table 43* on the following page).

Table 43

The use of MES to reduce wastes and contributes to Continuous Improvement

Engineering data collection	Company wide planning	Intelligent dispatch	WIP tracking	Wastes of Manufacturing
Greatly improved control of production process through tight control of vital engineering and production data.	Greatly improved production planning through visibility into history and current backlog.		Ability to implement JIT procedures Reduce WIP buildup due to greatly enhanced control. Reduce the level of finished goods due to reduced need to build excess stock to cover or hide problems in manufacturing execution.	**(Over) production and Inventory**
Reduced machine downtime by invoking automatic preventive maintenance.		Improved equipment utilization and on-time delivery and increased overall plant throughput by real-time balancing of the production lines.	Reduction of WIP cycle time.	**Waiting and searching**
			Reduce WIP buildup due to greatly enhanced control.	**Trans-portation**
Reduce problems in engineering plans by assisting in analysis and troubleshooting. Statistical quality control. Improved performance to specification.	Better decision making on products, equipment, facilities, labour loading, shutdowns and use of subcontractors.	Achieving better control of product release to the shop, minimizing excessive setups and reducing operation cycle times and their variability.		**(Over) Processing**
				Motion
Reduced scrap and rework through early identification of negative trends. Quicker resolution of quality control problems.			Reduce scrap and rework due to yield improvement and fewer operator errors Improved worker productivity through tight control of work instructions, materials and processes.	**Defects**

Table 43 (Continued)

The use of MES to reduce wastes and contributes to Continuous Improvement

	Wastes of Manufacturing					
	(Over) production and Inventory	**Waiting and searching**	**Trans-portation**	**(Over) Processing**	**Motion**	**Defects**
Resource tracking		Reduced equipment/labour downtime.	Improved equipment utilization and control through ability to analyze equipment performance.	Improved labour productivity.		
Cost accounting				Faster and more effective decision making through greater visibility.		Reduced waste through assistance in identifying and removing.

(b) MES FUNCTION MATRIX RELATED TO THE DEMING CYCLE

From *Table 43* it is clear that except for the waste of motion, MES can definitely contribute towards the continual elimination of these wastes - thus accomplishing improvement. To support the use of MES as continuous improvement tool, the Deming cycle for continuous improvement is related to the MES Function Matrix (developed in Chapter 4).

The Deming cycle is a method that can aid management in stabilizing a process and pursuing continuous, never-ending process improvements and conveys the sequential and continuous nature of the continuous improvement process (Gitlow, 1995:107). The MES Function Matrix (developed in Chapter 4) is brought into relation with this cycle in *Table 44* on the next page.

Table 44

The Deming cycle for continuous improvement related to the MES Function Matrix

Deming Cycle (Gitlow, 1995,107-109)	MES Function Matrix (Chapter 4)
STEP 1 : PLAN	**ELEMENT OF EXECUTION : Coordinate/ Guide**
The collection of data about process variables is critical when determining a plan of action for what must be accomplished to decrease the difference between customer needs and process performance. A plan must be developed to determine the effects(s) of manipulation process variables upon the difference between process performance and customer needs.	Based on data received from controls. This is used to update the schedules and other attributes in such a way that the difference between what is planned and process performance can be decreased. The effects of these alternation also need to be evaluated
STEP 2 : DO	**ELEMENT OF EXECUTION : Initiate/ Ready**
The organization must educate everyone involved with the planned experiment so that they understand the relationship between the manipulated variables and the proposed decrease in difference. Secondly everyone must be trained so that they understand how their jobs will be influenced.	People and equipment are informed on the changes in plans and how it effects them.
STEP 3 : STUDY	**ELEMENT OF EXECUTION : Analyze**
The result of the "DO" phase is answered to determine if the manipulated process variables behave according to plan and if the downstream effect creates any problems or improvements.	"The traditional data analysis tasks focus on determining the root cause of production problems. Most MES reporting is geared to these needs, but often at too low a level of detail. AMR This analysis function represents a key method for plants to continue improvement. All of these functions are handled today informally or with personal spreadsheets, but we believe they need to be incorporated into the formal plant architecture. However, a clear distinction between generating the information and using it to make decisions is required" *(Swanton, 1998:www.amrresearch.com/repac/)*
STEP 4 : ACT	**ELEMENT OF EXECUTION : REACT**

(c) TOTAL QUALITY MANAGEMENT (ISO9000)

Continuous improvement is part of the Total Quality Management philosophy. To elaborate on the use of MES as tool to accomplish continuous improvement and total quality management, the way in which MES can be used to establish quality standards, is discussed.

ISO9000 is a series of standards that outlines the requirements for a quality management system. The need to comply with ISO9000 (and other) standards is regarded as an important reason why companies choose to implement a Manufacturing Execution System. Unlike most standards, ISO9000 does not provide product certification, but it specifies the minimum system requirements to ensure that good manufacturing practices are followed. "After implementation a Manufacturing Execution Systems can be used to ensure that manufacturing is performed in conjunction with the policies and procedures set out by ISO900O, recording where exceptions occur and acting as a key source of data for demonstrating conformance during audits."

Golovin (1998:www.consilium.com/Publications/iso.htm) evaluated the abilities of MES against the 20 points of the ISO 9000 standards. The MES Function Matrix is used as structure to discuss this analysis (*Table 45* on the next page).

7. 5. CONCLUSION

MES has the potential to enhance manufacturing efficiency and effectiveness in any manufacturing industry sector. The approaches towards the implementation and use of MES may vary, however. The Industrial Engineer can contribute to the use of MES in any industry sector and MES can be used as tool to accomplish continuous improvement.

Table 45

The establishment of ISO9000 standards through MES

	GUIDE/ COORDINATE	INITIATE/ READY	ANALYZE	REACT
MATERIAL/ PARTS/ PRODUCT	ISO 9000 requires that data captured according to the procedures defined in the Inspection and Testing clause be associated with the product parts and be accessible.	In requiring product identification and tractability, ISO 9000 expects an auditor to be able to identify the current status and past history of a product part within the manufacturing process.	ISO 9000 requires that some form of statistical charting be used during the manufacturing process, in accordance with defined procedures.	ISO 9000 requires that nonconforming product - product that does not meet the specification - is handled according to predefined procedures.
LABOUR/ PERSONNEL	ISO 9000 specifies those training materials and classes are developed that all personnel are trained using these, and that these personnel should then be certified to perform tasks that require that level of training.			
EQUIPMENT/ TOOLS/ FIXTURE	ISO 9000 demands that the equipment used for performing inspections and testing are fully calibrated in accordance with defined procedures.			
WORK INSTRUCTIONS/ SPECIFICATIONS/ PROCEDURES	ISO 9000 requires control not over the creation of documentation, but over its approval, release, and use on the shop floor. ISO 9000 demands that within a processing operation, procedures be defined and followed for controlling the manufacturing process.	ISO 9000 specifies that training materials and classes be developed, that all personnel be trained using these, and that these personnel should then be certified to perform tasks that require that level of training.	ISO 9000 requires that internal quality audits be supported within the quality system.	ISO 9000 demands that when errors during manufacturing, procedures be defined and followed to correct those errors.
WORK ORDERS	According to ISO 9000, when material is received from a customer for inclusion in final product, the product must be separately identifiable and procedures for receiving and manufacturing this material must be followed.			

8. MES RESEARCHERS

"Now that the MES model and functions has been redefined, the next step is to continue educating manufacturers and vendors. Educating needs to be done so
(1) people recognize what these systems are,
(2) what capabilities they have and
(3) what benefits users can achieve." (Fulcher,1997:26)

The role of the Industrial Engineer with regard to the development, integration and use of MES was explained in the previous chapters. The role of the Department of Industrial and Systems Engineering (University of Pretoria) with regard to MES research and education is investigated in this chapter. Information on existing MES research initiatives is evaluated and suggestions is made concerning a local research initiative.

CONTENTS OF THIS CHAPTER

8. 1. CURRENT MES RESEARCH INITIATIVES

A number of research initiatives, which participates in some way or another in MES research, was identified. With the exception of the South African Production and Inventory Control Society (SAPICS) all of these initiatives are international or from foreign countries.

The names of these initiatives are listed below:

- Advanced Manufacturing Research (AMR Research)
- Manufacturing Execution Systems Association (MESA)
- National Institute of Standards and Technology (NIST)
- American Production and Inventory Control Society (APIÇS)
- Automation Research Corporation (ARC)
- National Center for Manufacturing Sciences (NCMS)
- South African Production and Inventory Control Society (SAPICS)
- Object Management Group (OMG)
- Semiconductor Manufacturing Technology (SEMATECH)

The activities and nature of these research initiatives are discussed within the following pages. A discussion, regarding a proposed MES research initiative, is done thereafter.

8. 1.1. ADVANCED MANUFACTURING RESEARCH (AMR Research)

Main Business and Research Fields	AMR Research is an industry and market analysis firm specializing in enterprise applications and related trends and technologies. Tracking more than 400 leading software and service providers, AMR Research helps Global 1000 companies evaluate, select, and manage new systems for every part of the enterprise, including logistics and supply-chain management, Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES), and electronic/Internet commerce. Through a working partnership, AMR Research helps companies navigate through each phase of the IT life cycle: Research fields includes : **MANUFACTURING STRATEGIES** Analyst from Manufacturing Strategies specialize in specific vertical industries and have a thorough knowledge of all elements of the plant architecture, including controls and automation, Manufacturing Executives Systems (MES), and plant level ERP. This

	service approach also balances the needs of the plants with their role in the broader enterprise and supply chain. **SUPPLY CHAIN STRATEGIES** This service provides research on Supply Chain management, including demand/development planning systems, warehouse automation, customer asset management, electronic commerce, related technology, and industry trends. **SAP ADVISORY PROGRAM** This product serves the user who has already selected SAP as its ERP vendor. - *Market Analysis and Review Service* Software companies use this service to drive business planning, and aid in developing specific sales and product plans. Industrial companies use this information to provide a detailed overview of vendor performance. Investors and the financial community use this service to provide a concise and authoritative overview of dynamic growth markets. - *Enabling Technology Strategies* Provides research and analysis on the key enabling technologies for manufacturing and supply chain applications.
MES Specific Research	The term MES was coined and the Three-Layer-Model is developed by AMR Research. The latest MES related output from this institute is the development of the REPAC model.
Physical Location	Boston (USA)
Non-Profit ?	Although not explicitly mentioned, the assumption can be made that AMR Research is a profit-driven company.
Date founded	1986
Research Studies and publications	AMR Research's Reports and Alerts are available to clients via hard copy, electronic delivery, and AMR Research's web site. Through a key word or topic search, clients can quickly find the research they require in real-time. Non-clients can get access to executive summaries of these reports. The Executive View is a monthly letter that analyzes the business impact of enterprise applications for senior executives.
Web site	The address of the web site is http://www.amrresearch.com. Non-clients have limited access.
Analysts designated to company	Each client is assigned one client research manager who serves as a central point for all of our services. This approach streamlines the inquiry process for the clients and speeds response time to research needs.
Conferences Trade Shows, Meetings and Roundtables	AMR Research's semi-annual Executive Conferences are where hundreds of IT executives and solution providers gather to hear real-world case studies from leading industry users and market insight from AMR Research analysts. These conferences are the premier gathering of top-level decision-makers. Meetings are organized for clients

8. 1.2. MANUFACTURING EXECUTION SYSTEMS ASSOCIATION (MESA)

Main Business and Research Fields	The leading manufacturing execution system (MES) software vendors formed MESA. MESA is a not-for-profit trade association providing a legal forum for competitors to work together to expand awareness and use of manufacturing technology, particularly MES and all the related products and services required by the modern manufacturing enterprise. MESA membership is corporate. Each member company is represented by one "delegate," and can have any number of "alternate" representatives as it wishes.
Physical Location	USA
Non-Profit ?	Non-Profit
Date founded	1992
Research Studies and publications	**Educational Materials & White Papers** MESA International publishes educational materials and offers them free of charge to manufacturing executives around the world. Included in the package are a member directory, which lists all members, the markets they serve, and complete write-ups on the products and services members offer. Complete information on all individuals who request MES information are forwarded to all members every month. **MESA International's MES Magazine Supplements** The Performance, Manufacturing Systems, Managing Automation and Industry Week are some of the major publications in which MES Supplements have appeared. Featuring articles on the benefits of MES, successful installations, and vendor listings.
Web site	http://www.MESA.org
Conferences Trade Shows, Meetings and Roundtables	**MES Roundtables - organized and sponsored by MESA International.** These Roundtables include a conference program which features users as well as vendors and vendor product demonstrations. **Trade Show Participation - MES Pavilions.** To gain greater attention for MES, MESA International members exhibit together in trade show pavilions at the leading manufacturing shows. Organizers of these shows typically offer extra promotion for MES Pavilions. Members participate in the pavilions and gain special promotion as exhibitors.

8. 1.3. NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST)

Main Business and Research Fields	The National Institute of Standards and Technology was established "to assist industry in the development of technology needed to improve product quality, to modernize manufacturing processes, to ensure product reliability and to facilitate rapid commercialization of products based on new scientific discoveries." Main Research Areas in NIST Labouratories • Building and fire research • Chemical science and technology • Electronics and electrical engineering • Information technology • Manufacturing engineering • Materials science and engineering • Physics
MES Specific Research	The program on Technologies for the Integration of Manufacturing Applications (TIMA) particularly focuses on the integration of and Interoperability among MES. The TIMA program focuses on developing and validating technologies, methods and infrastructures that reduce dramatically the cost and time needed to integrate manufacturing execution systems into a manufacturing enterprise. The Framework Project will provide industry with tests and methods for analyzing and validating emerging manufacturing information standards and technologies. Work will be focused on information models for manufacturing, software application interface definitions, object-oriented class hierarchies, data access protocols, scheduling and control strategies, integration mechanisms, and communication architectures.
Physical Location	Throughout the United States of America
Non-Profit ?	Not-for-profit
Research Studies and publications	Information on projects described above is distributed through: • NIST Technical Publications Database, NIST Virtual Library , NIST Journal of Research, General Publications • Fact Sheets; Press Releases and Newsletters; Guide to NIST; Selected General Publications; Strategic Planning and Economic Analyzes Program Specific Links • Publications Pages from NIST Programs; FIPS - Federal Information; Processing Standards; Fire Research Information; Service Standards Publications
Web site	http://www.nist.gov
Conferences, Trade Shows, Meetings and Roundtables	NIST Conferences and Workshops is held regularly.

8. 1.4. AMERICAN PRODUCTION AND INVENTORY CONTROL SOCIETY (APICS)

Main Business and Research Fields	APICS is recognized globally as • The source of knowledge and expertise for manufacturing and service industries across the entire supply chain in such areas as materials management, information services, purchasing and quality. • The leading provider of high-quality, cutting-edge educational programs that advance organizational success in a changing, competitive marketplace a successful developer of two internationally recognized certification programs, Certified in Production and Inventory Management (CPIM) and Certified in Integrated Resource Management (CIRM) a distribution center for hundreds of business management publications and Educational materials a source of solutions, support, and networking local chapters, workshops, symposia, and the annual APICS International Conference and Exposition.
MES Specific	No specific MES research/education project exists. MES are, however one of the concerns of APICS. The only published book on MES thus far was an initiative of APICS. (McClellan:1997)
Physical Location	United States of America
Non-Profit	Not-for-profit
Date founded	1957
Research Studies and publications	APICS membership means valuable direct benefits. Each year, APICS members receive free publications valued at several times the cost of Society and chapter dues. • APICS--The Performance Advantage • Production & Inventory Management Journal • APICS Buyer's Guide • APICS Dictionary • APICS Bibliography • International Conference Proceedings APICS Business Outlook Index
Web site	http://www.apics.org
Conferences and Trade Shows, Meetings and Roundtables.	Annual conferences are held by APICS. Various APICS chapters exist worldwide. Chapter seminars is frequently held.
Educational ProgramMES	APICS is marketing itself as the educational society for resource management Education is established through: • In-House Training and • Applied Manufacturing Education (AMES) • Chapter Certification Review Course Schedule

8. 1.5. AUTOMATION RESEARCH CORPORATION (ARC)

Main Business and Research Fields	Providing advice and market intelligence to manufacturing companies and their automation suppliers
MES Specific	Although no specific MES program or project is launched, the ARC is concerned with MES.
Physical Location	International
Non-Profit	Although not explicitly mentioned, the assumption can be made that AMR Research is a profit-driven company.
Date founded	1986
Research Studies and publications	ARC is the premier provider of market data, forecasts, and reports for a wide range of enterprise application solutions and automation products and systems. ARC's studies and reports are recognized worldwide for their accuracy and detailed analysis. This accuracy and analysis is a direct result of our experienced staff, who on average each bring over fifteen years of direct industry experience to ARC. In addition to our experienced staff, ARC maintains an in-depth database on the enterprise and automation marketplace. It contains the latest information on technologies, standards, and the products and capabilities of hundreds of companies. With offices worldwide, we provide the best perspective on the global market with detailed analysis of regional markets as well. Our extensive global network of contacts is the reason ARC Market Studies are considered the most reliable source of market intelligence available.
Web site	http://www.arc.com
Analysts designated to company	Upon purchasing a report from ARC, analyst directly responsible for this report may be contacted to discuss our research findings, analysis, and conclusions. ARC's Advisory Services deliver a comprehensive portfolio of knowledge-based products and services that will keep you ahead of the latest developments in enterprise applications and industrial automation.
News Letter	Only for Clients

8. 1.6. NATIONAL CENTER FOR MANUFACTURING SCIENCES (NCMS)

Main Business and Research Fields	The National Center for Manufacturing Sciences provides the legal and logistical framework under which member companies and other partners can participate in pre-competitive manufacturing R&D. Through the NCMS collabourative process — tested on hundreds of programs over a decade — companies can team on research projects that would be too large, costly or time-consuming for them to accomplish on their own. They can also tap into a wide array of services and support to help them meet their individual Program objectives. There are currently no major research collections outside NCMS devoted to all aspects of manufacturing. The Manufacturing Information Resource Center (MIRC) has developed a library comprehensive in all areas of manufacturing research. Particular strengths of the collection include resources on quality, manufacturing processes, and environmental issues. Among the major research topics covered are: • Business and marketing – information on markets, products, companies, and technologies, economic data and financial news. • Computers - user interfaces, connectivity issues and software information. • Defense - contracts and awards, research in progress, and aerospace markets and tchnologies. • Law and government - Commerce Business Daily, the Federal Register, legislation and Congressional reports, and Capitol Hill news. • Materials science - engineered materials, both conventional and unconventional, and the technologies and processes involved. • Patents, trademarks, and standards - for both the United States and abroad. • Science and technology - manufacturing engineering, electronics packaging, and telecommunications.
Physical Location	North America
Non-Profit	Non-profit
Web site	http://www.ncms.org/
Conferences and Trade Shows, Meetings and Roundtables	NCMS Technical Conferences provide opportunities for companies to partner on pre-competitive manufacturing research projects, network with firms representing a diverse array of industries, see the highly successful NCMS collabourative process model at work, and learn about current and emerging trends in usiness and industry. The NCMS Annual Technical Conference, held each spring, is the consortium's major public forum for highlighting past, current and anticipated collabourative programs. As an adjunct to this event, NCMS hosts a Fall Workshop Series where companies can hear about, and take advantage of, emerging project offerings.

8. 1.7. SAPICS (EDUCATIONAL SOCIETY FOR SUPPLY CHAIN MANAGEMENT)

Main Business and Research Fields	The mission of SAPICS is to be the leading provider of knowledge and continuous improvement in production, Operations and supply chain management in Southern Africa.
MES Specific	The MES Special Interest Group of SAPICS has the following mission: To improve global competitiveness in the Southern African manufacturing industry through MES.
Physical Location	South Africa (Kempton Park)
Non-Profit ?	Not-for-profit
Date founded	1996
Web site	http://www.cy.co.za/sta/sapics
Conferences and Trade Shows	The following services is provided by SAPICS • Workshops and Two Day Seminars • Annual Conferences • SAPICS Newsletter
Roundtables and meeting	Open
News Letter	The newsletter send out to members, is also published on the World Wide Web.
Educational Program	MANUFACTURING - PRODUCTION AND INVENTORY MANAGEMENT • Basic Principles of Production and Inventory Management Course • Principles of Production and Inventory Management Course CERTIFICATION in PRODUCTION and INVENTORY MANAGEMENT (CPIM) • CPIM Basics of Supply Chain Management • Inventory Management • Just-in-Time • Material and Capacity Requirements Planning • Production Activity Control • Master Planning • Systems & Technologies CERTIFICATION in INTEGRATED RESOURCE MANAGEMENT (CIRM) REVIEW COURSES - CIRM • Enterprise Concepts and Fundamentals • Identifying and Creating Demand • Designing Products and Processes • Delivering Products and Services • Integrated Enterprise Management MATERIALS MANAGEMENT • Stores & Stock Control Course • Effective Supply, Warehousing & Distribution Course • Fundamentals of Materials Management Course • Executive Education SUPPLY CHAIN MANAGEMENT - EXECUTIVE OVERVIEW WORKSHOP

8. 1.8. OBJECT MANAGEMENT GROUP (OMG)

Main Business and Research Fields	The OMG was formed to create a component-based software marketplace by hastening the introduction of standardized object software. The organization's charter includes the establishment of industry guidelines and detailed object management specifications to provide a common framework for application development.
MES Specific Research	The MES/MC workgroup is part of the manufacturing special interest group. This working group is concerned with the definition of interfaces to enable flexible integration and interoperation of computerized systems which support manufacturing production (as contrasted with the focus of other MfgDTF working groups on design, engineering and planning). We expect these interfaces to be applicable to a wide range of industries, which perform discrete, batch and/or continuous processing.
Physical Location	The OMG is headquartered in Framingham, MA, USA and has international marketing offices in Australia, Bahrain, Brazil, Germany, India, Italy, Japan and the UK, along with a government representative in Washington, D.C.
Non-Profit ?	Not-for-profit
Date founded	April 1989
Research Studies and publications	The Working Group issued a Request for Information (RFI) December, 1997 which invited input from individuals and organizations with insight or information in the any of the following areas: • Validating the group's definition of MES • How to functionally partition MES solutions for standardization • Examples, case studies and problems of interactions between MES solutions • Examples, case studies and problems of interactions between MES and other contexts in manufacturing (e.g.: ERP, PDM, MC) • Validating selection of SIMA reference model for scoping RFPs • Appropriate standards for MES Based upon the assessment of these responses, the following MES roadmap items have been identified: Request for proposals 1: • Manage Resource and Track Product Resource Allocation and Status; Labour Mgmt; Maintenance Mgmt; Product Tracking and Genealogy (tracking perspective); Material Storage and Transport (material perspective) Request for proposals 2: • Manage Resource and Track Product (continued) Resource Allocation and Status; Operations / Detail Scheduling; Dispatching Production Units; Product Tracking and Genealogy; Material Storage and Transport Request for proposals 3: • MES follow-on Process Mgmt; Quality Mgmt; Performance Analysis; Health, Safety and Environment Management
Web site	Information can be accessed at http://www.omg.org by clients and non-clients
Conferences, Trade Shows, Meetings and Roundtables	OMG Technical Meetings are held every six to eight weeks at various locations worldwide. These conferences include the Object World at COMDEX/ Enterprise series of events worldwide, Software Development East & West, and a variety of industry specific events.

8. 1.9. SEMICONDUCTOR MANUFACTURING TECHNOLOGY (SEMATECH)

Main Business and Research Fields	SEMATECH is a technology development consortium of U.S. semiconductor manufacturers. Its development programs include: • Interconnect • Front end processes • Assembly and packaging • Design systems Manufacturing methods
MES Specific	The first MES's was developed for the semi-conductor industry. This industry still takes in many ways the lead with regard to MES technology and concepts. No specific MES program or project exists, but due to relationship between developments in the semi-conductor industry and MES, this institiute is significant.
Physical Location	Austin, Texas
Non-Profit ?	Not-for-profit
Date founded	1987; International SEMATECH is a wholly-owned subsidiary of SEMATECH that began operations in April 1998.
Web site	http://www.sematech.org
Conferences and Trade Shows	An annual Advanced Equipment Control / Advanced Process Control (AEC/APC) conference is held by SEMATECH.

8. 2. PROPOSED ENVIRONMENT FOR RESEARCH INITIATIVE

The acceptance of the term MES to describe a system, which enables manufacturing execution, is growing throughout manufacturing industries. Since one company (AMR Research) started to use and promote this term, thousands of companies started to use it. The majority of information on MES provided on the World Wide Web is presented by companies as part of their effort to promote MES products and services.

The situation often occurs in this promotion material - as well as academic documents - that the meaning of MES (Manufacturing Execution Systems) is written in brackets next to the accronymn, while in the same paragraph a term such as ERP (Enterprise Resource Planning) or JIT (Just-in-Time) occurs, without any explaination. The conclusion can be drawn that the term MES is commonly accepted, but to commonly understood by all users and potential users.

In the remainder of this chapter the feasibility of a new research initiative is discussed. It is proposed that this MES research initiative is hosted by *the Department of Industrial and Systems Engineering* at the *University of Pretoria* in *South Africa*. Each of these three (underlined) environment aspects will subsequently be discussed.

8. 2.1. MES RESEARCH INITIATIVES *IN SOUTH AFRICA*

Since many research institutes which focuses on MES already exist, the question may arise if a research center within South Africa is needed. The following arguments are offered in favor of a South African based research center:

- Due to South Africa's geographical isolation, it is not feasible for smaller manufacturing companies to attend international conferences, meetings and presentations on a regular basis.
- Access to business analysts and research by institutes such as AMR Research is not within reach of most South African manufacturers due to the unfavorable exchange rate. Only one company within South Africa is currently a full client of AMR Research.

- Unique circumstances exist within South Africa, regarding technological infrastructure, as well as resource and labour utilization.
- All of these institutes were founded within the past 15 years. The youth of all of these research institutes underlines the growing need for research in this field. The risk of duplication of research by more than one institute is low.

8. 2.2. RESEARCH INITIATIVES AT THE *UNIVERSITY OF PRETORIA*

The mission of the University of Pretoria is to:

- create knowledge through research
- distribute knowledge through education and to
- apply the knowledge through service to the community and industries

Through the hosting of a research initiative all of these objectives are met:

- Various RESEARCH projects could be undertaken. Within one research initiative these projects could complement each other.
- Users, developers, integrators and potential users, developers and integrators are EDUCATED regarding the benefits, abilities, disabilities and trends of Manufacturing Execution Systems and related topics.
- By providing information regarding MES and by focussing projects on the solving of specific problems, the industry (COMMUNITY) is SERVED.

8. 2.3. RESEARCH INITIATIVE HOSTED BY THE *DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING*

"The Department of Industrial and Systems Engineering is at present the largest Industrial Engineering department in South Africa and plays a leading role in the education, development and promotion of the profession. The educational philosophy is aimed at emphasizing understanding and insight and to develop a scientific thought process rather than the rote learning of facts. In this way our Industrial Engineers are able to handle future changes in the technology and economy well into the next century. The emphasis is on a system approach to problem identification and solution while an

entrepreneurial and client orientation is stressed. An effort is made to provide graduates with a balanced education, thus maximizing their market value to as many companies in South Africa as possible." (Department of Industrial and Systems Engineering: http://ie.up.ac.za)

The infrastructure for teaching and research on field related to Industrial Engineering already exists at the department. A MES research initiative will contribute towards the mission of the department, namely the training of world class Industrial Engineers.

8. 3. SCOPE OF THE PROPOSED RESEARCH INITIATIVE

8. 3.1. RESEARCH FIELDS

Of all of the institutes discussed in section 8.1, MESA International is the only one of these institutes, which focusses exclusively on MES. Although the proposed initiative will be known as an MES research initiative, related research such as supply chain management (SCM), statistical process control (SPC) and labouratory information systems (LIMS) should not be excluded, as long as it is complementary to the research field of MES. The focus should, however, remain on MES.

8. 3.2. FUNDING

The majority of initiatives are marketed as non-profit organizations. Funds need, however, to be generated from some source or another to support activities. Three types of funding are identified from existing initiatives:

- Industry Sponsorships
- Fees for services
- Government

Funding possibilities for the proposed research institute are explored accordingly in *Table 45*. Two or even all three of these types may be the source of funds of some of the institutes (which were discussed in the first part of this chapter). Only the most prominent examples are given.

Table 45

Types of funding available for research initiative

Type of funding	Examples from current industries	Possibilities with regard to the proposed research initiatives
INDUSTRY SPONSOR-SHIPS	The Manufacturing Execution Systems Association (MESA International) and Semiconductor Manufacturing Technology (SEMATECH) is supported to a great extent by companies benefiting by the research.	This type of funding will be easier to exploit once the research initiative is established and some credibility is obtained.
SERVICES	Funds is generated through services rendered by AMR Research, Automation Research Council (AMR), APICS and the National Center for Manufacturing Sciences (NCMS).	• Broader research results can by made available at a certain fee. • Through contract research companies can fund a specific project. • Business analysis and consultation can be provided at specific fees.
GOVERN-MENT	Government funding is provided to the National Institute of Standards and Technologies (NIST) as well as the Object Management Group.	• In South Africa government subsidies is allocated with respect to research outputs, in the form of articles within accredited journals. • Research councils distribute government funds indirectly through awards. South African funding oppertunities through the National Research Foundation (NRF) is subsequently discussed in more detail.

(a) GOVERNMENT FUNDING THROUGH THE NRF

The objective of the National Research Foundation (NRF,1999: www.nrf.ac.za) is to support and promote research through funding, human resource development and the provision of the necessary research facilities, in order to facilitate the creation of knowledge, innovation and development in all field of science and technology.

(b) JOINT FUNDING BY GOVERNMENT AND INDUSTRY THROUGH THRIP

The Technology and Human Resources for Industry Programme (THRIP) is a joint venture between industry, research and educational institutions and government, that was established in 1991. The programme supports the development of technology and appropriately skilled people for industry to improve South Africa's global competitiveness. THRIP performs this task by providing resources and mechanisms in support of collabourative research in the areas of science, engineering and technology. (NRF,1999: http://www.nrf.ac.za/programmeareas/thrip).

THRIP will consider contributing R1 for every R2 invested by the private sector in SET research projects of which the project leader and project are based at a higher educational institution, according to the following criteria:

- The research must be of a high standard.
- A project must have clearly defined technology outputs.
- At least one higher education institution and one industrial partner should be involved.
- At least one student must be involved in and trained through the research.
- Only financial contributions are considered for THRIP matching support and commitment from the industrial partner/s must be clearly communicated.
- Only contributions from South African or South African-based industry partner/s are considered for matching support.
- The industrial partner/s must give a clear indication that the project will directly benefit the specific companies.

- Arrangement for the ownership and exploitation of intellectual property arising from a project must be agreed upon between the academic and industrial partners, prior to commencement of the project.

The project, which is used for purposes of the case study in Chapter 5, is funded through this scheme.

8. 3.3. COORPORATION WITH INTERNATIONAL INSTITUTES

The Manufacturing Execution Systems Association (MESA International), has announced in 1996 a partnership with its counterpart MESA of Europe, headquartered in Cheshire, England, to expand the awareness and implementation of manufacturing execution systems (MES) and related products and services.
(Hakason,1996:www.MESA.org/html/main.cgi?sub=15).
Similar partnerships can be pursued to explore possibilities in Southern Africa.

Contact was established with the AMR Research. Since negotiations are still in progress, this is not discussed in this dissertation.

8. 3.4. SERVICES PROVIDED

Based on services provided by current research institutes, the following services are identified as services that can be provided by the research initiative:

(a) RESEARCH STUDIES

Since the proposed research center is initiated from the University of Pretoria, it would be ideal to use the formal research structures of the university.
Depending of the scope of the project, research can be conducted through:

- an Honors degree project (approximately 125 man hours),
- a masters degree project (approximately 250 man hours),

- a masters degree dissertation (approximately 1000 man hours) or a
- PhD doctorate.

Research teams consisting of a combination of people enrolled for various degrees can attempt larger projects. Personnel from the University responsible for mentoring and research could act as project leaders.

Research studies on market or technology issues are conducted and presented through research documents, by almost all of the institutes. Depending on the specific research institute and type of study, these studies are either

- made (partially) available to anyone without any fee;
- made (partially) available to anyone against a specific fee or
- made available to members/clients only.

The guideline of the University of Pretoria with regard to intellectual property rights will have an influence on the mode by which the research outputs is sold. By distributing outputs from these projects through articles, the mission of the University of Pretoria is accomplished and the initiative is promoted.

(b) EDUCATION

The aim of MESA (Manufacturing Execution Systems Association) International is to educate the manufacturing society. This is done through the distribution of white papers as well as roundtable meetings. APICS - which calls itself the educational society of Resource Management - is providing international courses in Production and Inventory Management (CPIM) and Integrated Resource Management (CIRM). APICS, MES SIG and AMR hold conferences on a regular basis.

Educational courses on MES can be made available through the structures of the University of Pretoria on the following levels:

- Post graduate courses
- Short certificate courses

- A subject as part of a structured program

These courses will be directed either at

- Industrial Engineers in need of knowledge and skills regarding enterprise integration through MES, or at
- Information managers and technologists, requiring insight on manufacturing management.

(c) CONFERENCES AND MEETINGS

Representatives from this research initiative will take part in South African conferences related to MES. The most significant of these would be the

- annual conference held by SAPICS and
- the conference of the Southern African Institute for Industrial Engineering.

Until a specific need for a conference is identified, this research initiative will not embark on the organizing of conferences. Meetings should, however, be organized between users, developers and integrators of MES. The purpose of these meetings should be to

- expand the MES network,
- share information on the latest technologies and concept and
- identify research projects.

(d) ACCESS TO INFORMATION THROUGH THE WORLD WIDE WEB

Each of the institutes investigated are making use of the internet through the hosting a web site. MES related information (which is not necessarily the product of a formal research study) is accessible through the World Wide Web. Keeping in mind the high degree of information technology related to MES research, the assumption can be made that very few - if any - institute, will not utilize internet information technology. The establishment of a web site as service by this research initiative is taken further for purposes of this dissertation.

8. 4. THE ESTABLISHMENT OF A VIRTUAL RESEARCH FRAMEWORK

This virtual research framework consists of a

- web site (distributing information from one source) and a
- list server (a multi-source information forum).

8. 4.1. POTENTIAL USERS OF THIS SERVICE

Although it is not possible to derive specific numbers regarding users and publishers, it is clear that the World Wide Web is a popular communication forum for manufacturers and industrialists. It is also common knowledge that the use of the WWW is growing exponentially

The South African Internet search engines, Ananzi (www.ananzi.co.za) and Aardvark (www.aardvark.co.za) have both directories for manufacturing and engineering. Ananzi-TecNet (www.tecnet.co.za) is promoted as the exclusive engineering, industry, mining and manufacturing directory.

The focus of this initiative is om

- South African Industries and
- foreign companies with an interest in MES are also potential users of this web site.

This web site can also be used as communication forum between project partners.

8. 4.2. SPECIFICATIONS

The aim of the web site is to provide a forum from which the following MES information can be shared:

- History of MES and future trends.
- Theory on business models and functions.
- New developments and products.
- Links to MES related web sites.
- South African specific
  - Implementation projects
  - integrators and service providers (integrators, consultants etc.)
  - events.
- Past, current and proposed research projects of this research initiative.

The suggestions of Mara (1995:199,200) on how to establish a web presence is followed as explained in *Table 46* on the next page.
Space is available on the Internet server of the Department of Industrial and Systems Engineering. A unique account is dedicated to the MES web site at the following address:
http://maui.ee.up.ac.za/~mes

Table 46
The establishment of a web presence (Mara:1991:200)

Register at search engines	This web site is registered at the following search engines: South African • Aardvark (science:engineering / business:manufacturing and packaging) • Web-chart (science and engineering : industrial engineering) • Zebra • Webcrawler (businees and commerce:manufacturing) International • Google • Excite • Euroseek • Infoseek
Trade URL-postings with related servers	It was decided not to use this option, while the web site is still under construction.
Advertise through the appropriate newsgroup	Messages are send periodically to the following newsgroups to advertise the web site: • alt.manufacturing.misc • clari.biz.industry.manufacturing.releases • git.manufacturing.prc • sci.engt.manufacturing • za.misc • za.edu.comp
Advertise through non-internet media	The address of this web site is added to all documentation on projects of this initiative.

8. 4.3. LIST SERVER

Mailing lists enable users to broadcast e-mail to groups of other e-mail users who share a common interest. These lists serve as forums for questions and answers, announcements, discussions and often spirited arguments (Rosenfeld,1995:24). A List server is an e-mail distribution list. When an e-mail message is sent to a list server, the message is distributed to all the e-mail addresses of people subscribed to the specific list server.

Users may subscribe to individual list servers via electronic mail, in which case the articles will be forwarded to the recipient via electronic mail. Users subscribing to individual list servers, may request the information in various formats, e.g. each article as a separate electronic mail message or all articles for a specific day concatenated into a single message. A specific list server covers only one topic of interest, albeit different categories of the specific topic (University of Pretoria, 1998, http://www.up.ac.za).

An MES list server is created (to serve as virtual communication forum) for developers, integrators, users and researchers with the focus on South African industries. This server is marketed through the MES web site. Users can subscribe to this list server by sending an e-mail - without a subject - to mes@kendy.up.ac.za. The following should be written in the body of the e-mail:
Subscribe mes

8. 5. CONCLUSION

Based on the evaluation of a number of institutes, currently facilitation MES research, the following mission statement is compiled for a proposed MES research initiative at the University of Pretoria:

The VISION of the Research Initiative for MES is to enable and enhance the creation and transfer of knowledge regarding MES.

The following **GOALS** and **OBJECTIVES** are set to accomplish this vision:

Provide the infrastructure to initiate and coordinate research projects for the benefit of integrators, developers and users of MES.

- Identify research projects for the benefit of MES integrators, users and developers and facilitate the accomplishment of these projects.
- Select and supervise postgraduate and final year undergraduate students to undertake research projects for the benefit of MES integrators, developers and users.
- Generate funds to enable the accomplishment of research projects through industry sponsorship, government funding and official scholarships and bursaries.

Obtain industry credibility and maintain a network of parties concerned with Manufacturing Execution Systems

- Establish and maintain a web site serve as information archive and communication forum.
- Publish articles on projects completed by the initiative in national and international accredited journals.
- Present papers on projects and other MES related topics at national and international conferences.
- Facilitate conferences and business meetings.
- Establish links with similar international initiatives, such as AMR Research and Manufacturing Execution Systems Association (MESA) International.

9. CONCLUDING CHAPTER

The purpose of this dissertation is to determine and establish the role of Industrial Engineering in the development, implementation and use of MES.

On grounds of this purpose and within the scope of the study, the following propositions (and objectives) were set:

Objectives	Questions
PROPOSITION 1: The concept of MES is valid (The concept of MES is used by and useful to manufacturing industry).	
Objectives	**Questions**
Integrate literature regarding MES business models and applications.	• What are Manufacturing Execution Systems? • Where does the concept of MES originate and in which direction is it evolving? • In which industry sectors (and to which extent and with how much success) are MES implemented?
Integrate opinions of South African role players throughout the literature study	• To which extent is the concept of MES accepted by South African manufacturing industry? • What is the view of South African developers, integrators and users.
Develop a new or combined model to be used as MES evaluation tool (if current models prove to be insufficient).	• Can current MES function models be used as tool to evaluate MES products and environments? • How should an appropriate evaluation model look?
Demonstrate the validity of the newly developed MES model - as well as the validity of MES as concept - through a case study (DIAMES).	• How does DIAMES perform as a Manufacturing Execution System and what developments are required? • Does an evaluation exercise - using the newly development MES model - prove that the product DIAMES can indeed be marketed as a manufacturing execution system? • In which other ways can the newly developed MES model be used to analyze MES products and environments?
PROPOSITION 2: The Industrial Engineer has a contribution to make, regarding MES	
Objectives	**Questions**
Relate MES to Industrial Engineering by integrating literature on Industrial Engineering.	• How are Industrial Engineers trained? • How are Industrial Engineers practically involved in industry? • Which roles are to be played in the MES arena and to which extent can the Industrial Engineer fulfill these roles?
Initiate a research program for MES at the Department of Industrial and Systems Engineering (University of Pretoria).	• What other MES research initiatives exists? • What should the focus and scope be of such an initiative?

9. 1. CONCLUSIONS ON GROUNDS ON OBJECTIVES

The purpose of this chapter is to conclude this research effort and to evaluate the extent to which these propositions are supported. This is done according to each of the 6 objectives:

9. 1.1. INTEGRATE LITERATURE REGARDING MES BUSINESS MODELS AND APPLICATIONS

The term Manufacturing Execution Systems (MES) was created by Advanced Manufacturing Research (AMR) in 1990. The term is used to describe the suite of software products, which enables the execution of manufacturing through the integration of the planning and control systems of an enterprise.

As manufacturing strategies evolves, so is the way by which manufacturing is planned and controlled. Manufacturers adopt integrated MES software packages for the same reason they turned to MRP II in the 1970s, namely to gain competitive advantage in world markets. MES products were first adopted in industries with high value products, complex or unstable processing, or heavy governmental regulations. Included in this group are semiconductor manufacturers, prime contracts in the aerospace and defense industries and makers of pharmaceuticals. MES packages are gaining wider acceptance as more and more industries are faced with customers demanding better delivery performance and higher levels of quality at lower cost.

The concept of MES is well established and is integrated inextricably within planning and control systems. However, developers of planning systems are continuously adding MES functions to their products, as are developers of control systems. It can thus be anticipated that the market served by vendors and integrators exclusively focussing on MES are narrowing.

9. 1.2. INTEGRATE OPINIONS OF SOUTH AFRICAN ROLE PLAYERS THROUGHOUT THE LITERATURE STUDY

A survey from the South African Instrumentation and Control Journal proves that MES is a concept used and accepted by South African systems integrators. Views of South African MES developers, integrators and users were integrated throughout this dissertation. The sample size of South African MES developers, integrators and users is, however, small. Research, regarding the status quo of MES in South Africa, is thus not representative and should not be used as baseline. The conclusion from this objective can, however, be used as hypothesis for further research.

9. 1.3. DEVELOP A NEW OR COMBINED MODEL TO BE USED AS MES EVALUATION TOOL

As contribution towards the evolution of MES business models, the MES Function Matrix was developed. This MES Function Matrix is not a checklist or an MES module breakdown, nor is it meant to replace existing models. It is rather a framework to contextualize and assess MES products and environments. This matrix can (amongst others) be used to:

- Identify the strengths, weaknesses, opportunities and threats regarding a specific MES product.
- Identify the areas in a business not benefiting optimally from MES and relate the benefits of MES in terms of return on investment (ROI).
- Identify common MES attributes related to certain industries and environments.
- Explain the relationship between MES and other business applications and functions.
- Evaluate MES products and relate it to a specific environment.
- Indicate interfacing or integration within an MES environment.

The MES Function Matrix was also used in this dissertation to relate MES to the Industrial Engineering training model, as well as continuous improvement.The validity of this model was supported through the comparison with existing models, as well as a case study application.

9. 1.4. DEMONSTRATE THE VALIDITY OF THE NEWLY DEVELOPED MES MODEL - AS WELL AS THE VALIDITY OF MES AS CONCEPT - THROUGH A CASE STUDY

DIAMES was used as case study to demonstrate how the MES Function Matrix can be used as MES assessment tool. DIAMES was not evaluated in isolation. The MES environment of Abedare Cables (where DIAMES is used) was also investigated. Through this, the validity of MES as concept was supported.

9. 1.5. RELATE MES TO INDUSTRIAL ENGINEERING BY INTEGRATING LITERATURE ON INDUSTRIAL ENGINEERING

Four types of role players are active in the MES arena:

- Developer
- Integrator
- User
- Researcher

The role of the Industrial Engineer, regarding all for of these roles is increasing. The greatest contribution can be made regarding integration, although the contribution towards MES development can not be ignored. MES provide vertical communication between planning and control systems. The expertise of the Industrial Engineer is needed to facilitate this vertical integration, but especially the horizontal integration between shop floor stations and planning functions.

MES have the potential to enhance manufacturing efficiency and effectiveness in any manufacturing industry sector. The approaches towards the implementation and use of MES may, however, vary. The Industrial Engineer can contribute towards the use of MES in any industry sector and MES can be used as tool to accomplish continuous improvement.

9. 1.6. INITIATE A RESEARCH PROGRAM FOR MES AT THE DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING (UNIVERSITY OF PRETORIA).

The term MES was created to describe the systems, which enables the execution of manufacturing. MES may be just another acronym in the vocabulary of the Industrial Engineer. The relationship between the roles to be played within the MES arena and the Industrial Engineer can, however, not be ignored. The discrepancy between the relationship and the current involvement on South African Industrial Engineers in the MES arena, is the drive behind the MES research initiative at the Department of Industrial and Systems Engineering of the University of Pretoria. A web site is created for this purpose.

9. 2. CONTRIBUTION OF THIS DISSERTATION

Through this dissertation the MES concept was evaluated and explained within the scope of Industrial Engineering.

According to MacDonald (1998:*www.consilium.com/Publications/roi.htm*) the evolution of MES started long before the term was coined in 1990, and it is still evolving:
"An Manufacturing Execution System is not something new or something only large, complex manufacturers need. If you have a manufacturing plant, you already have a Manufacturing Execution System"

However, by defining and modeling these systems - and by relating it to a certain area of expertise - a better understanding is nurtured, regarding the way in which these systems can enhance effectiveness and efficiency in a business or industry.

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