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)

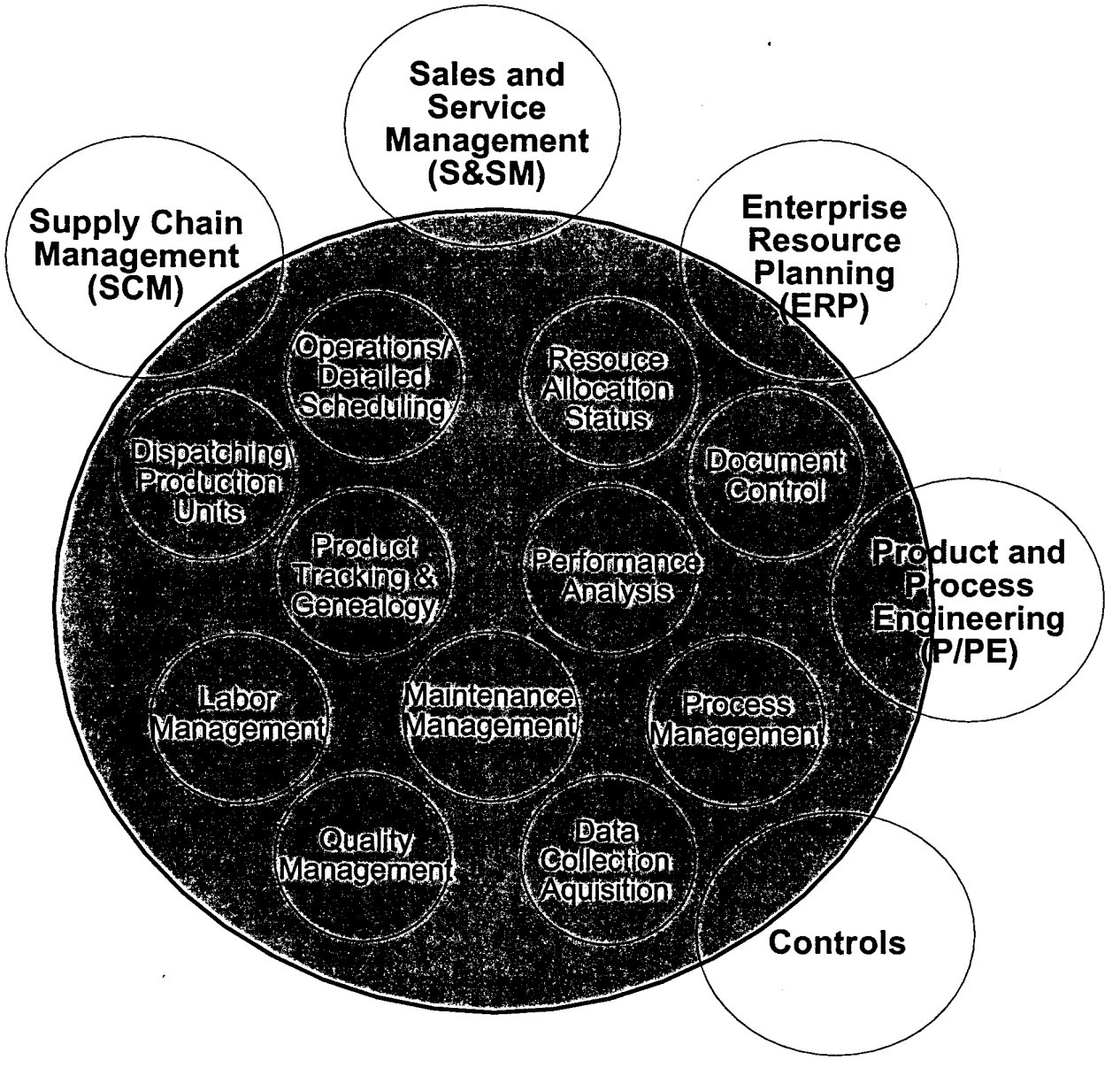


Table 7

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
MATERIAL/ 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/ PERSONEL	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	.
EQUIPMENT/ 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 INSTRUCTIONS/ SPECIFICATIONS/ 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 Switserland (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.

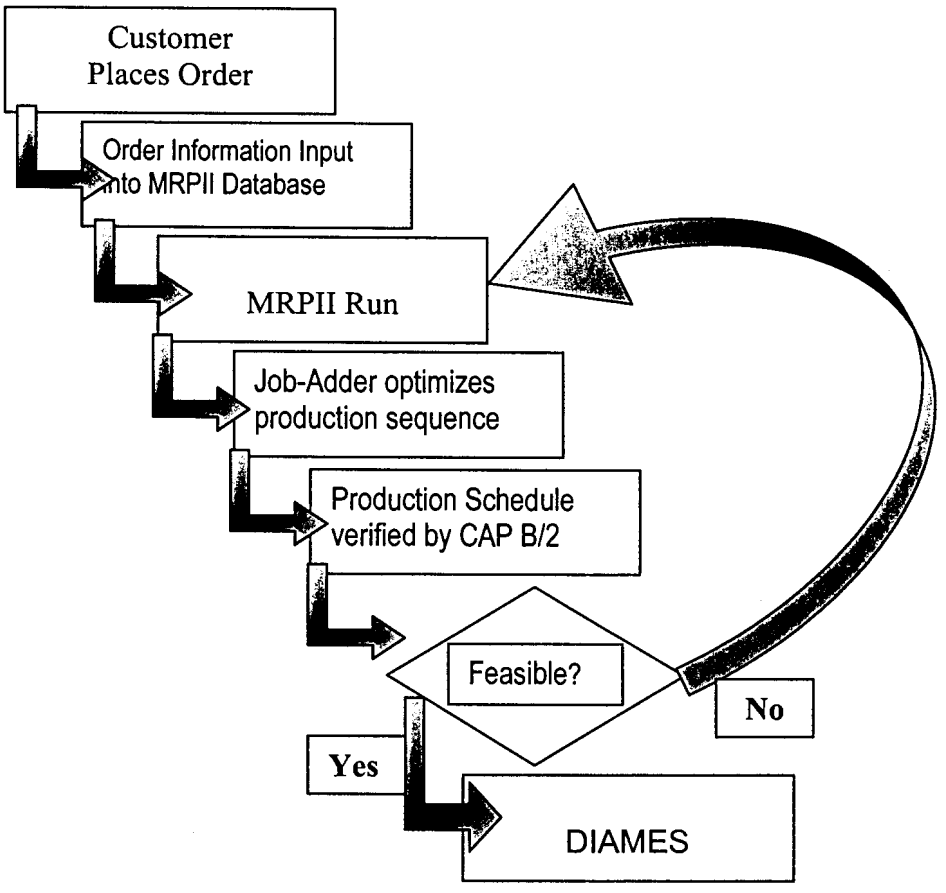
- This "second-iteration" production plan is then fed into the CAP B/2 finite capacity scheduler to check the feasibility of the plan against the current resource availability. If the plan is not feasible the planning sequence is repeated, otherwise the final production plan is passed onto the DIAMES 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	**Factory Suite 2000**	**Workstream Open**	**RtPM**
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.	Alarms draw the attention of planners to situations such as breakdowns and alternative routings are suggested. Changes to work order details are easily accomplished.	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.	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	**Factory Suite 2000**	**Workstream** Operator	**RtPM**
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.	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.	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.	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	Factory Suite 2000	Workstream Open	RtPM
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	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	Automatic data collection is controlled by the Script Controller and collected data belongs to the Station Controller which is responsible for data distribution.	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	Factory Suite 2000	Workstream Open	RtPM
Exception messages are relayed to DIAMES users and foremen via e-mail and (through Page-X) pagers.	Exceptions are flagged. In the case of machine breakdowns is automatic resolution via alternative routings possible by using recipes.	Exceptions are flagged. Automatic resolution via alternative routings is also possible by using scripts. Alternative routings can also be simulated before they are implemented	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	Factory Suite 2000	Workstream Open	RtPM
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.	Machine specific data may be used to plan maintenance. Dedicated maintenance management packages may interface directly with FS2000 for data gathering.	Machine specific data may be used to plan maintenance. Dedicated maintenance management packages may interface directly with Workstream Open for data gathering.	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 *initiating*/ 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 *reaction* 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