MES to ERP Integration: Rapid Deployment Toolset

A. Telukdarie

Post Graduate School of Engineering Management, University of Johannesburg, Johannesburg, South Africa
(arnesht@uj.ac.za)

Abstract – **Production facilities deliver value as subsets of larger corporate entities with a key enabler being systems, inclusive of Enterprise Resource Planning (ERP) and Manufacturing Systems. This research focuses on the development of an evaluation toolset for Manufacturing Execution Systems maturity, specifically determining a 'Business Units' maturity relative to a fully automated corporate process enablement. The methodology includes hierarchical segregation of the business together with focused, internationally referenced, questions, facilitating system maturity evaluation. The Likert association methodology facilitates data gathering. This research delivers a method and case study on an internationally benchmarked, express evaluation toolset, with capacity to conduct a Business Unit (BU) evaluation in minimum time. Key value adds of the toolset includes system prioritization on a business benefit and cost basis.**

Keywords – **Manufacturing Execution Systems (MES), Systems, Evaluation tools**

I. INTRODUCTION

Contemporary corporates operate multiple sites with the ability to produce a variety of products. Supply chain, order management, planning, optimization together with other shared functions may be centralized. Site/ BU specific data must be timeously [24] sent to head office for these and other functions such as reporting (Health Safety and Environment, Production, Maintenance, KPI's, Balance Scorecards, Planning etc.). The Corporate head office, usually employs an ERP while the plant may be dependent on a concoction of systems, specific to the manufacturing layer.

Production is usually collated via a plant control layer leaning into an Industrial IT domain. A production/business layer is built above this as a manufacturing system layer. These include Quality management, maintenance management, logistics management, simulation and optimization, safety systems and security systems. There are several International standards for manufacturing enterprises; CIM Pyramid, AMR 3-Layer Model, MESA Model, SCOR Model, REPAC Model, New Manufacturing Model, ISA-88, ISA-95 and Manufacturing Performance Model. Pattanayak, 2015 reinforces the

need to integrate the entire business including all ICT layers so as to maximize business process enablement.

Details on the need to mature the ICT environment from an integration perspective is also highlighted. The adoption of advanced business optimization is also highly dependent on business/ manufacturing integration as highlighted by Hakki, 2013. Exhibit 1 illustrates a high level view of an enterprise landscape from equipment to ERP.
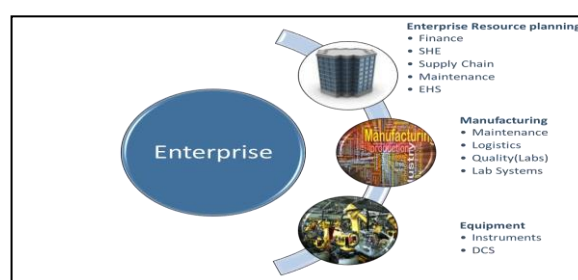

Fig 1. IT layout, instrument to enterprise

Research has clearly indicated differences in output capability of multinationals at different physical locations [13]. Research has shown that various dependencies that influence a facility having a difference in capability from a similarly managed counterpart within a multinational. Technology application and its impact on multinationals is investigated [8] with results indicating that technology delivered a significantly higher business output than nontechnology aligned business. Research results on technology impact on multinational capacity is reinforced by other researchers [11], confirming the impact of technology transfer from a multinational to a local business.

The number of companies rolling out new technologies across the globe is increasing [17] indicating that geographical location is a key consideration for multinationals. The impact of region on the ability of a multinational to successfully deploy technology has been the subject of various studies. It has been established that region or physical location has a significant impact on technology deployment [17].

The key challenge of manufacturing system maturity evaluation and its impact upon a diverse business, specific to the delivery of a comprehensive, automated, global (multi-site) shop floor to top floor enablement system was the subject of this research. A key challenge was the actual assessment process to determine the exact current business maturity together

with the existing manufacturing/ business system priorities. A fundamental component of the work conducted in this research was the quantification of the status of maturity of the business unit relative to the corporate requirements but more significantly relative to global best practice [1,2,3]. Typical reviews of MES maturities are usually vendor specific, diverse and require extended timelines. This research sought to circumvent the challenge by propositioning an accelerated alternate approach.

II. BACKGROUND

Mergers and acquisitions have resulted in the development of national companies into large international corporates [14]. Most multinationals operate of a global head office with subsidiaries located anywhere in the world. The key understanding is autonomy of operations with federated executive management [11]. Head office is responsible for overall business strategy, finance, governance and standards, reporting and business efficiencies. A key operating model adopted by multinationals includes core services which are centralized [14]. A site is considered to be a geographical or logical grouping determined by head office. It contains plants/ areas and processing units clustered together at a specific location. A site is involved in local site management and optimization.

Enterprise Resources Planning solutions have been adopted by large corporate as a means to manage businesses on the enterprise level. These solutions, although operating on the business level, are implemented in areas of specialization [16]. Areas of specialization include production, finance and human resources. ERP do not typically create data links into the operations sphere [17] but focus on ERP value chain integration.

Corporates are seeking a competitive edge by the adoption of ICT, specifically data and integration [27]. This includes the alignment to MES. Vidoni specifically proves that ERP systems align to MES via specific data models. With these types of advanced integration the key functionality synchronization is optimized.

A. Manufacturing Execution Systems

Production facilities have traditionally operated using localized control systems such as Programmable Logic Controllers (PLC), SCADA and DCS system. In the past 10-15 years Enterprise Resource Planning (ERP) systems have been used by various organizations as a means of high level operations planning together with other corporate functions. These two systems operate as two independent systems at different levels of enterprise control. The increased development in both these systems has not closed the information gap between them, resulting in manufacturing and business failures, bottlenecks and inefficiencies.

This bi-directional, Enterprise-Control System gap has been addressed with Manufacturing Execution Systems. MES solutions and models are limited to these individual approaches. Key gaps include the appropriate delivery within a complex multinational. The key objectives of corporates are to deliver a profit, with optimization and efficiency improvements being a significant toolset. Dorota, 2015 explored the possibility of optimization via continuous improvements, specifically focused on operational improvements via integration. The disconnect between ERP and MES is elaborated by Hakki as a potential challenge in delivering a totally enabled business. The integration challenges result in lack of various tiers of capability including operations, KPI's, optimization, business reporting and optimization. The benefits of integration and advanced data handling is reinforced by Chakraborty with the adoption and application of integrated data for optimization. Further publication in support of integration include;

Pattanayak, 2015 explored the need for business process integration. The research focused on the need to integrate all layers with ERP in order to maximize business process enablement.

Almada, 2015 defined the importance of integrating the production facilities with ERP to maximize/ optimize business outputs, with the need for comprehensive integration between MES and ERP for various components from HR, maintenance, planning etc.

- Tsai, 2013 identified the importance of ICT integration for supply chain optimizations in corporates.
- A fully integrated supply chain delivering optimization for business is reinforced by Denolf, 2015, elaborating on data integration across ERP and the various ICT components of the business.
- Vidoni identified the planning integration model with ERP as an essential competitive differentiator.

Access and Security, as Identified by Bradford, 2014 end to end identity and access management includes ERP and Manufacturing integration in a structured manner.

Benefits analysis includes, Integration, visibility of enterprise shop floor to top floor data.

- Integration, automated (accurate), data flows resulting in enabled workflows.
- Reproducible(shared/ similar), KPI's, reports
- Application rationalization, reduce the number of applications/ versions within the landscape.

- Replication, ability to plug in previous configurations with minor changes for similar facilities
- Shared/ replicated infrastructure, reduction in service contracts

B. Functional Model

The identification and review of international best practice on the position of MES within a corporate hierarchy is best described by the Purdue Reference Model and the MESA model. The functional model broadly details the operations of the organization in terms of business operations. The Functional Model is developed with considerations to the following reference models:

- The Purdue Reference Model for Computer Integrated Manufacturing [1,2,3]
- The MESA International Functional Model [1,2,3]
- The equipment hierarchy model from ANSI/ISA-95.00.03-2004 standard [1,2,3]

TABLE 1
FUNCTIONAL MODEL [1,2,3]

LEVEL 5	Business Intelligence
LEVEL 4	ERP : Business Planning
LEVEL 3	MES : Manufacturing Execution Systems
LEVEL 2	SCADA/APC : Execution Control & Optimization
LEVEL 1	DCS/PLC : Execution/Regulatory Control
LEVEL 0	Instrumentation : Sense and Monitor

The MES layer is a critical sandwich layer between business and operations. Significant business value could be delivered via automation of process actions and data exchange. The ability to quantify maturity of the MES systems functionality was the key focus of this research.

III RESEARCH DISCUSSION

The methodology for this study commenced with an international best practice search specific, to the MES domain. This includes but limited to, Manufacturing Execution Systems Association [MESA], Instrument Society of America [ISA] together with other standards.

C. Standards Review

A critical analysis of the existing MES standards is conducted. The analysis considered the strengths and limitations of the standards within the context of the BU manufacturing domain. Manufacturing execution systems originated with the onset of computer-integrated manufacturing in the 1980's. There has been a variety of models that has since lead to the modernization of MES. MES models were first developed in 1992 by AMR Research, Cambridge. The model reduced the manufacturing system problem set to three functional areas of planning, execution, and control. There has since been many revised MES models developed. The most popular MES models have been the:

- Supply Chain Operations Reference by the Supply Chain Council (SCOR model) [19]
- Ready, Execute, Process, Analyze, and Coordinate by AMR [REPAC model]
- Manufacturing Execution Systems Association (MESA model) [1]
- Instrument Society of America [1, 8]

These MES models are very extensive and cannot be fully detailed. An overview detailing their basic functioning together with the strengths and limitations of each model is summarized.

Based on the research of best practice MES systems the proposed MES evaluation toolset is divided into five key areas. These areas (as expanded from MESA/ISA/SCORE] are:

- Production Operations Management
- Maintenance Operations Management
- Inventory Operations Management
- Quality Operations Management
- Operations Performance Management

For the purpose of this research the five categories would be referred to a "Tier 1".

D. Evaluation Toolset Development

The five key areas above are further subdivided into MESA aligned categories, Tier 2. These categories are the key focus areas for evaluating the business units maturity in the MES space. The MESA[4] model is adopted as the key categorization framework for the development of the sub categories these include;

- Scheduling
- Planning
- Resource Management
- Tracking
- Performance management
- Data Management
- Document Management

For the purpose of this research these categories are defined as "Tier 2". The evaluation toolset is exploded into a third Tier, which are detailed questions related to individual functionality required by the business, refer to Exhibit 3. Detailed questions are detailed and appended.
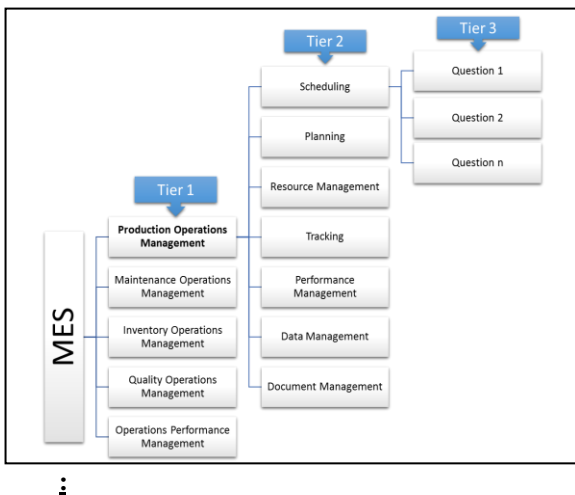
Fig. 2. Details of tiers *(sample of production)*

The questions, Tier 3, responses are constituted so as to complete the evaluation in the most effective and efficient manner. The research focused on gathering information on the current state of systems, the required and the priority of the system. The three feedback categories;
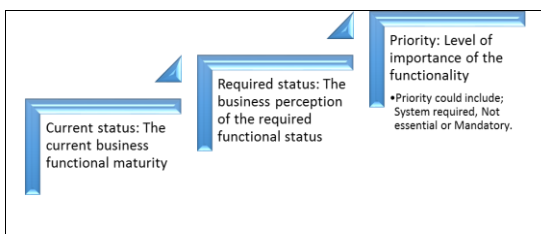

Fig. 3. Feedback categories

Each response is rated on a Likert scale. The team, conducting the evaluation, provides a current rating (1-5) and a required rating (1-5). The team is also required to confirm as to the system priority/ required.

The evaluation toolset focuses on probing the current status of a business unit for each MES system. The questionnaire also obtains inputs with regards the cost and weighted benefit (on a scale of 1-5) of the potential MES system. Mandatory MES systems (e.g. Safety) are pre-selected and BU's do not have authority to change this. All of these rating together with the "current" and "required" status is used to rate the maturity of the BU with regards that particular module. The BU representatives have to also indicate the need for the system at the BU. Here the company responds either yes or no.

It must be noted that the evaluation questionnaire is by no means comprehensive but covers the key MES functionality that needs to be considered by the BU. Further it must be noted that maturity are rated on a scale of 1-5 with the options listed below. Degree of association ranges for the business includes, no system to a fully integrated system.

The response index seeks to gather three information types, the current state, the cost benefit of the system, other benefits (not cost related) such as safety, productivity. The required response options for the current state is illustrated as a sample in the Appendix, below.

IV TEST AND DEPLOY

The toolset requires minimum data but a key consideration relates to accuracy, representation and balance. With this consideration, a minimum of a management and an operational representative must be present to prove data in the 5 key areas.

The questions are deployed at a BU, in the petrochemical sector. The business must be represented by the five areas i.e. Production, Maintenance, Logistics, Quality and Operational performance (including safety and security). All the input listed above, as captured from BU, is to be used in the data manipulation process. The results are to be used to facilitate decision making on MES focus areas i.e. areas of potential MES system implementation. The key calculations relating to outputs of the current tool are detailed below.

The Current output indicator, serves as an indication of the current status of MES systems at the business unit. It is calculated based on the business representative's responses to questions. The BU representative's responses are captured in two key categories. The first is relevant to the current/required status and the second is based on BU benefits. The responses are converted to numeric ratings on a scale of 1-5.

It is extremely important to note that the evaluation questions are supported with detailed notes, elaborating on the details of the questions and supporting an understanding of perspective, see Appendix 1.

These responses are used to calculate the current and required status. The calculations incorporate the current status relative to the level of importance the system is to the business. The Current status per category is then normalized by summing up the values for all the questions and dividing by the number of questions.

V. ANALYSIS OF RESULTS

The Required value is the status that the business needs to achieve for the MES component under consideration. The inputs and calculations for the "Required Status", together with the feedback from the benefits questions are used to calculate the BU "Required Status". The research results is presented as per the Tiers described in the methodology, the Tier

one (Overall business), Tier two (Functional area) and Tier three (Detailed analysis).

The primary analysis (Tier 1) of results is designed to assist the business unit identify which of the five modules, as defined, is most significant. Based on analysis of the data obtained a graphical output is presented in Figure 5 . The results indicate that maintenance, production and quality are the three key modules requiring interventions for MES development at the particular BU. The data directs the business to review the potential benefits of integration in the production system space as highest priority. The To-Be requirements is high, matched with the uppermost Business significance (Business significance is the difference between As-Is and To-Be). This implies that the most significant benefits to business can be found in implementing integration in the Production area followed by maintenance.

Fig. 5. Category specific analysis

G. Tier 2 analysis: Analysis of business priorities

Bases on the case presented it is apparent that the business would benefit most significantly by integrating and maturing in the production area(Tier 1) with Production Planning(Tier 2) been the most significant system to implement delivering the most business benefit. The evaluation toolset facilitates the extraction of the top 5 priorities (Tier 2), specific to this case study been(extracted from Figure 5),

- Production planning
- Inventory scheduling
- Inventory tracking
- Quality data management
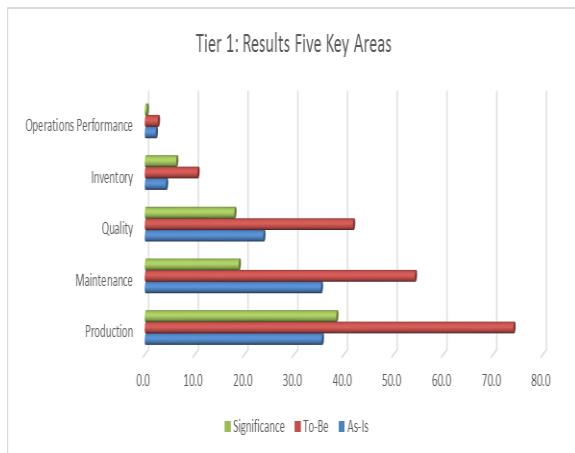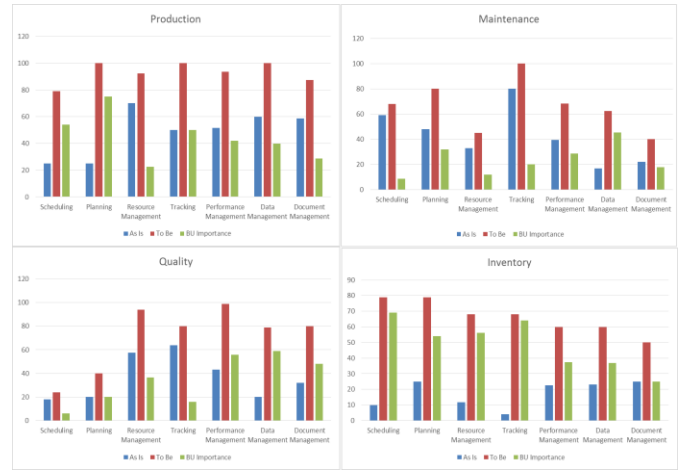- Inventory resource management

Fig. 4. Tier 1 results

The research results are further detailed below with the Tier 2 & Tier 3 analysis. The business Unit has the potential to review results for each of the seven categories outlines, Figure 2. The results indicates the three most important "required" areas to be in the operations performance management and operations tracking whilst data management enjoyed the lowest "required" area maturity.

The key objective of the toolset is to evaluate the key systems that would enhance business optimization and integration.

The Tier 3 results are considered detailed and are extracted via the individual questions, (an overall view of the Question Tier). As the system is configured to determine the priority system which is driven by an analysis of the difference between the current/ required and the importance. It is apparent from Figure 4 that the business considers Production (data , tracking and planning) as the most important systems that must be prioritized and would benefit the business most significantly. The detailed individual questions specific to these areas are reviewed to understand the exact functionality to be enabled. The two detailed functionality to consider are, System to store archive and backup plant date and Is the data reviewed/ used for trouble shooting/ optimization. The business response indicates that a fully integrated system is required with very high cost benefits and weighted benefits.
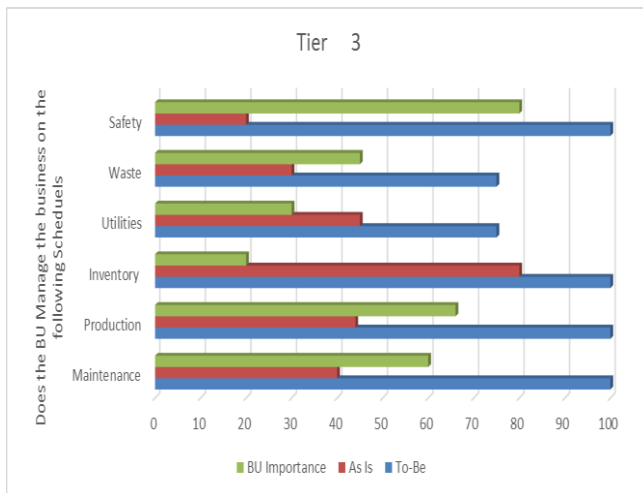
Fig 6. Importance comparative, Tier 3

Detailed, Tier 3, analysis can be conducted delivering specific functional enablement. As per the results of the scheduling question above (Exhibit 7) safety scheduling is highlighted as the most significant. The results interpretation is analyzed on the tiered or cross functional basis providing details on enablement priorities.

VI. CONCLUSION

The key objectives of the study is to develop a comprehensive, international referenced best practice tool, requiring minimum role out time. Based on the approach and simulated sample it is apparent that the tool is comprehensive and effective in evaluation of a BU's MES status and prioritizing BU's needs. The tool is able to assist in the delivery of a comprehensive MES evaluation in under two hours as compared to traditional approaches taking days to complete. The tool is structured so as to focus on securing priority system requirements enabling the business to plan a structured role out based on a hierarchy of system requirements.

ACKNOWLEDGMENT

REFERENCES

[1]   ANSI/ISA-95.00.01-2000. Enterprise-Control System Integration. Part 1: Models and terminology, 2000. ISBN: 1-55617-727-5.
[2]   ANSI/ISA-95.00.02-2001. Enterprise-Control System Integration. Part 2: Object Model Attributes, 2001. ISBN: 1-55617-773-9.
[3]   ANSI/ISA-95.00.03-2005. Enterprise-Control System Integration. Part 3: Activity models of manufacturing operations management, 2005. ISBN: 1-55617-955- 3.
[3]   F. Almada-Lobo, "Define, integrate, implement MES with controls, ERP.", *Control Engineering,* vol. 62, no. 7, pp. 38-40.
[4]   H. M. Beheshti, "What managers should know about ERP/ERP II", *Management Research News,* vol. 29, no. 4, pp. 184-193. 2006,
[5]   M. Bradford, J.B. Earp, & S. Grabski, "Centralized end-to-end identity and access management and ERP systems: A multi-case analysis using the Technology Organization Environment framework", *International Journal of Accounting Information Systems,* vol. 15, no. 2, pp. 149-165.
[6]   I. Brambilla, 2009, "Multinationals, technology, and the introduction of varieties of goods", *Journal of International Economics,* vol. 79, no. 1, pp. 89-101.
[7]   S. Chakraborty, & E.K. Zavadskas, "Applications of WASPAS Method in Manufacturing Decision Making.", *Informatica,* vol. 25, no. 1, pp. 1-20.
[8]   P. Copello, & A. Raviola, "electronic work instruction configured for isa-95 standard"
[9]   J.M. Denolf, , J.H. Trienekens, P.M Wognum, J.G.A.J van der Vorst,. & S.W.F Omta, "Review: Towards a framework of critical success factors for implementing supply chain information systems", *Computers in Industry,* vol. 68, pp. 16-26.
[10] A. Dossi, & L. Patelli, 2008, "The decision-influencing use of performance measurement systems in relationships between headquarters and subsidiaries", *Management Accounting Research,* vol. 19, no. 2, pp. 126-148.
[11] S. Girma, R. Kneller, & M. Pisu, "Do exporters have anything to learn from foreign multinationals?", *European Economic Review,* vol. 51, no. 4, pp. 993-1010, 2007,.
[12] L.M. Hitt, D.J Wu,. & Z. Xiaoge "Investment in Enterprise Resource Planning: Business Impact and Productivity Measures.", *Journal of Management Information Systems,* vol. 19, no. 1, pp. 71-98.
[13] T. Hyvönen, J. Järvinen, & J. Pellinen, "A virtual integration—The management control system in a multinational enterprise", *Management Accounting Research,* vol. 19, no. 1, pp. 45-61. 2008,
[14] A.P. Kakouris, & G. Polychronopoulos, "Enterprise Resource Planning (ERP) System: An Effective Tool for Production Management", *Management Research News,* vol. 28, no. 6, pp. 66-78. 2005,
[15] A.P. Kakouris, & G. Polychronopoulos, 2005, "Enterprise Resource Planning (ERP) System: An Effective Tool for Production Management", *Management Research News,* vol. 28, no. 6, pp. 66-78.
[16] B. Li, "Multinational production and choice of technologies: New evidence on skill-biased technological change from China", *Economics Letters,* vol. 108, no. 2, pp. 181-183. 2010,
[17] R. Moss kanter, "Mergers That Stick", *Harvard business review,* vol. 87, no. 10. 2009,
[18] E.N. Ntabe, L. LeBel, A.D. Munson, & Santa-Eulalia, L.A. "A systematic literature review of the supply chain operations reference (SCOR) model application with special attention to environmental issues.", *International Journal of Production Economics,* vol. 169, pp. 310-332.
[19] S. Pattanayak, & S. Roy, "Synergizing Business Process Reengineering with Enterprise Resource Planning System in Capital Goods Industry", *Procedia - Social and Behavioral Sciences,* vol. 189, pp. 471-487.
[20] M.A. Quintás, Vázquez, X.H., Garcia, J.M. & Caballero, G. 2008, "Geographical amplitude in the international generation of technology: present situation and business determinants", *Research policy,* vol. 37, no. 8, pp. 1371-1381.

[21] M.A. Quintás, Vázquez, X.H., Garcia, J.M. & Caballero, G. 2008, "Geographical amplitude in the international generation of technology: present situation and business determinants", *Research policy,* vol. 37, no. 8, pp. 1371-1381.

[22] D. Stadnicka, & K. Antosz, "continuous improvement practice in large enterprises: study results.", *International Journal for Quality Research,* vol. 9, no. 1, pp. 9-26.

[23] J.Y. Tsai, T.S. Raghu, & B.B.M. Shao, "Information systems and technology sourcing strategies of e-Retailers for value chain enablement", *Journal of Operations Management,* vol. 31, no. 6, 345-362.

[24] E. Tsui, & Y. Malhotra, "Integrating knowledge management technologies in organizational business processes: getting real time enterprises to deliver real business performance", *Journal of knowledge management,* vol. 9, no. 1, pp. 7-28. 2005,

[25] H. Unver, "An ISA-95-based manufacturing intelligence system in support of lean initiatives.", *International Journal of Advanced Manufacturing Technology,* vol. 65, no. 5-8, pp. 853-866.

[26] S. Uwizeyemungu, & L. Raymond, "Linking the Effects of ERP to Organizational Performance: Development and Initial Validation of an Evaluation Method.", *Information Systems Management,* vol. 27, no. 1, pp. 25-41.

[27] M.C. Vidoni, & A.R. Vecchietti, "An intelligent agent for ERP's data structure analysis based on ANSI/ISA-95 standard", *Computers in Industry,* vol. 73, pp. 39-50.

Appendix 1: Structure of detailed response Metrix

Question	Maturity (Current)	Maturity (Required)	Is the System Required	Cost Benefit	Weight Benefit
Scheduling	Column1	Column2	Column4		
Does the BU manage the business based on the following schedules?:					
Maintenance	2-Paper System: No Cont. Assessment	5-Fully Integrated System	Yes	5	4
Production	2-Paper System: No Cont. Assessment	5-Fully Integrated System	Mandatory	5	4
Inventory	4-Basic Software Based System	5-Fully Integrated System	Yes	5	4
Utilities	3-Paper System: Cont. Assessments	5-Fully Integrated System	Yes	5	3
Waste	2-Paper System: No Cont. Assessment	5-Fully Integrated System	Yes	5	3
Safety	1-No System	5-Fully Integrated System	Yes	5	4
Planning					
Is there a production planning system in	1-No System	5-Fully Integrated System	Yes	4	5
Resource Management					
Feedback form Type and configuration	4-Basic Software Based System	5-Fully Integrated System	Yes	5	4
Configuration	4-Basic Software Based System	5-Fully Integrated System	Yes	5	2
Performance	5-Fully Integrated System	5-Fully Integrated System	Yes	5	3
Process system software-Form-Perform	5-Fully Integrated System		Yes	5	4
Is there a system to mange personnel W	3-Paper System: Cont Assessment	5-Fully Integrated System	Mandatory	5	5
Tracking					
Is there a quality system in place at BU	2-Paper System: No Cont. Assessment	5-Fully Integrated System	Yes	5	4
Performance Management					
Is there a equipment calibration system	4-Basic Software Based System	5-Fully Integrated System	Yes	5	5
Is there a financial management system	5-Fully Integrated System	5-Fully Integrated System	Yes	5	4
Is the system linked to production	5-Fully Integrated System	5-Fully Integrated System	Yes	5	3
Does the business unit have systems for	1-No System	5-Fully Integrated System	Yes	5	4
Does KPI exist for performance of:	2-Paper System: No Cont Assessment	5-Fully Integrated System	Yes	5	5
Production cost	1-No System	5-Fully Integrated System	Yes	5	5
Data management systems	4-Basic Software Based System	5-Fully Integrated System	Yes	5	4
Lab data	4-Basic Software Based System	5-Fully Integrated System	Yes	5	3
Inventory/utilities and waste	2-Paper System: No Cont Assessment	5-Fully Integrated System	Yes	5	3
Safety	2-Paper System: No Cont Assessment	5-Fully Integrated System	Yes	5	4
Quality	4-Basic Software Based System	5-Fully Integrated System	No	1	1
Is the BU safety fully aligned to PSM?	4-Basic Software Based System	5-Fully Integrated System	Yes	5	5
Data management					
Is there currently a system to store, arch	2-Paper System: No Cont Assessment	5-Fully Integrated System	Yes	5	4
Is data reviewed and used for process t	5-Fully Integrated System	5-Fully Integrated System	Yes	5	4
Document management					
Is there a system implemented for all BU	4-Basic Software Based System	5-Fully Integrated System	Yes	5	4
Is there data exchange between plant an	4-Basic Software Based System	5-Fully Integrated System	Yes	5	3
BU upstream suppliers and dow	4-Basic Software Based System	5-Fully Integrated System	Yes	5	4
R & D/Tech	2-Paper System: No Cont Assessment	5-Fully Integrated System	Yes	5	3