Real-time Manufacturing Integration and Intelligence Solution Applied in Global Process Industry

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***Abstract*—Global manufacturing companies meet a lot of challenges on enterprise level, plant level and shop floor level. To solve these challenges, a kind of real-time Manufacturing Integration and Intelligence (xMII) Solution is introduced to realize Adaptive Manufacturing (AM), where MII's key technologies, such as its connection with ERP modules, integration functionality with shop floor information technology (IT) systems, and xMII server, are generally described. By using the practical project executed in one global chemical company as background, the paper firstly introduces the project's "AS IS" situations, its "TO BE" targets, and its ERP solution. Then, MII solution of the project is discussed in more details, which include its business scopes, requirements, server selection, high availability solution, its technologies, and its main functions like Unloads, Customer Response Time. Finally, tactical benefits of this MII solution are listed, and some conclusions are drawn out.**

***Key words*—Manufacturing Integration and Intelligence (xMII), Enterprise Resource Plan (ERP), Manufacturing Execution System (MES), Shop Floor Systems, Adaptive Manufacturing (AM)**

I. Introduction

A. Manufacturing Enterprise Challenges

With the development of economy globalization, manufacturing enterprises meet many typical challenges [1]. To keep competence, manufacturing plants of global enterprises are distributed to distant foreign locations leading to a loss of visibility and control [2], so the enterprises starve for 360 degree view of global plants, like Asset performance, Plant execution, Operational planning. Real-time data provides more value than the conditioned data. One vision of KPI's (Key Performance Indicators) visibility has more value than multiple versions of data.

In fact, many enterprises have poor alignment of goals, measures and roles. There is no common visibility among departments, from corporate to plants, resulting in inconsistent decision making. Production output is decreased due to lack of real-time response ability to manufacturing disruptions and demand changes. Maintenance cost is high due to real-time disconnection between production plan making and production plan execution. So, the paper mainly discusses and describes one suitable solution for those challenges.

B. Challenges of Current IT Systems for Manufacturing

Information technology (IT) systems used for Manufacturing can be divided into three levels: ERP (Enterprise Resource Planning), MES (Manufacturing Execution System), and SFAC (Shop Floor Automation and Control Systems). For Pharmaceuticals and Specialty Chemicals, their IT applications can be summarized as Fig.1. The main challenges of current IT systems for Manufacturing can be summarized as:

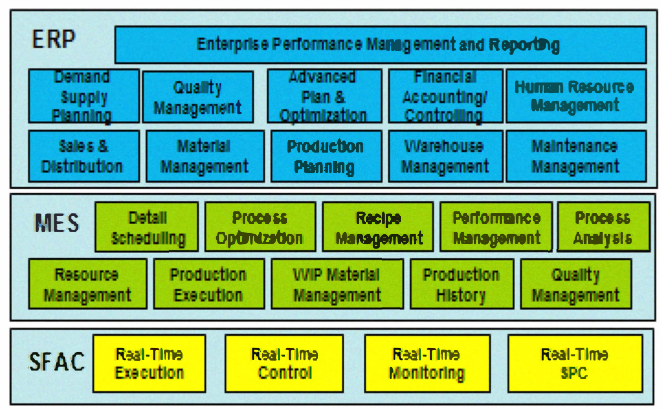

Fig.1. Typical IT Applications for Manufacturing Enterprise

1) Connecting the IT systems of Factory to the IT systems of Enterprise and Supply Chain, and enabling production personnel, are critical to cost-effectively deliver on customer expectations. The contents of ERP-MES integration are: a). Production capacity information to answer the question: What is available for use? b). Product definition information to answer the question: How to make a product? c). Production schedule to answer the question: What to make and use? d). Production performance to answer the question: What was made and used?
2) Unfortunately, most of current ERPs are disconnected to MES! According to the Customer Survey executed by Managing Automation and AMR Research in September 2005, "Less than 1% of respondents indicated that manufacturing data is automatically integrated with ERP without manual intervention".
3) Lack of ability to support the disconnected environment, execution systems are not easily integrated into business

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systems. MES of plants uses copies of master data from ERP, and then creates compliance and quality issues.

4) Lack of comprehensive platform to enable composite applications, Plant, Business and SNO (Supply Network Operations) information is not fully contextualized.
5) Customization of business application will result in additional cost moving forward to plant and enterprise level.

C. *Literature Reviews*

C. Temponi proposed the integration of business function models into an aggregate enterprise systems model [3]. F.B. Vernadat gave current status and research perspectives reviews of Enterprise Modeling and Integration (EMI) [4]. G. Xiong *et al.* focused on SOA architecture with different perspectives and finished lots of studies in this field [5, 6]. Especially G. Xiong *et al.* discussed push/pull production mode used in CIMS and its application in refinery [7]. V. Filipov *et al.* presented an industrial software solution for integrated Manufacturing Operation Management [8]. R. Martin presented a concept that described how companies can manage their international operations so as to facilitate the coordination of their manufacturing networks [9].

P. Hervé *et al.* described challenges, trends and issues in order to support the generation of new technological solutions [10, 11]. E. Oztemel *et al.* presented a knowledge exchange procedure for creating integrated intelligent manufacturing system [12]. C. Temponi *et al.* introduced methods that combine models of distinct business functions into an aggregate model to assist management's strategic decision making [13]. G. Xiong *et al.* made the research on realizing information integration of virtual pulp & paper enterprise (VPPE) [14].

G. Ying *et al.* presented agent-based intelligent system to support coordinate manufacturing execution and decision -making in chemical process industry [15]. I. Raffaele *et al.* proposed an efficient architecture which was able to synchronize, simply and securely, simulation models which were located in different geographical areas [16].

Based on those achievements reviewed on literature, this paper is to find suitable solution for those challenges, which is organized as follows. In Section II, we describe real-time manufacturing integration and intelligence solution, and in Section III, a case study in a global chemical company is given for demonstrating the solution. Finally, some conclusions are obtained.

II. ADAPTIVE MANUFACTURING SOLUTION

To meet those business and technical challenges described in the previous part of the paper, adaptive manufacturing solution is introduced.

Definition (Adaptive Manufacturing): the ability of a factory to profitably replenish the supply chain while dynamically responding to unpredictable change, enable companies and their production personnel to deliver superior performance through higher visibility and responsiveness. To be adaptive, companies need capabilities for Manufacturing Operations, Manufacturing Integration, Manufacturing Intelligence and Manufacturing Innovation. Manufacturing Synchronization and Manufacturing Excellence are two enabling technologies (See Fig.2. Source: SAP).

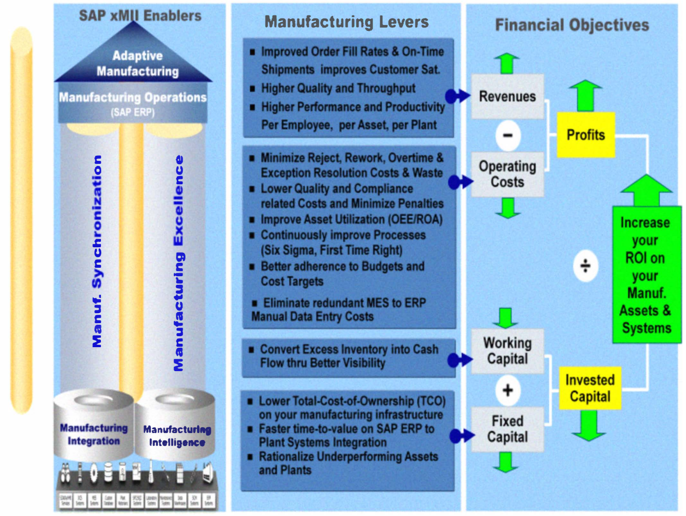

Fig.2. Adaptive Manufacturing to Maximize Return

A. *Technical Description of MII Solution*

XMII (Manufacturing Integration and Intelligence) Solution enables Adaptive Manufacturing, automatically synchronizes the orders, materials, maintenance, quality and master data between real-time manufacturing plants and ERP, to provide a "single version of the truth", and drive manufacturing excellence. XMII can work as a stand-alone application, which is the plant infrastructure backbone to realize manufacturing integration & intelligence. xMII is composed of a set of integrated tools, like Data Access, Business Logic, Visualization, KPI's, Alerts, Metrics, SPC (Statistical Process Control) Engine and SPC Visualization. It aggregates, transforms and visualizes data from multiple sources, like SAP Business Suite, MES, Non-SAP Business Systems, Process Control, Shop Floor, Quality, Lab Systems, PM (Plant Maintenance), and QM (Quality Management) *etc.* Its visual information for plants can drive asset reliability, extend the capability of PM, and simplify PM for managers, operators, planners, Real-time detection, and automated resolution of manufacturing exceptions.

B. *Connection between xMII and Shop Floor Systems*

SAP xMII offers a broad library of pre-built connectors (See Fig.3) for connecting to shop floor systems. Such as Alarmsuite, Simulator, XML, InSQL, IP21 and IP21OLEDB, Open, Aggregate, Xacute, OLAP, IDBC and UDC (Universal Data Connector) *etc.* For example, IDBC enables a connection between xMII and a Java Database Connectivity (JDBC) or Open Database Connectivity (ODBC) data source. UDC is a framework that allows access to SAP xMII services through proprietary server applications that you develop. The OLEDB connector is a UDC that allows access to OLEDB data sources.

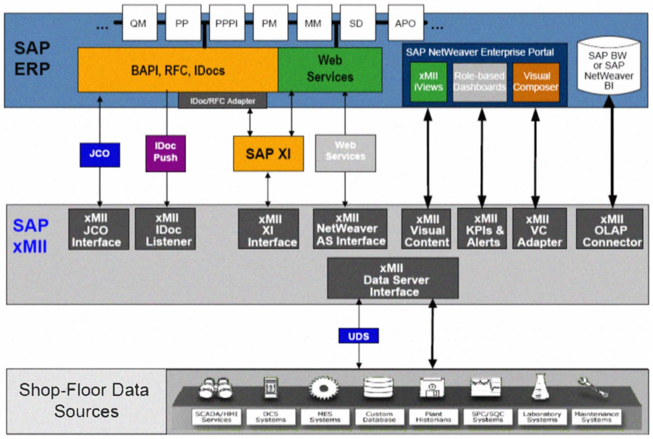

Fig.3. Technical Interface of ERP and xMII

C. XMII Server

The core of xMII, however, lies in its Business Logic Editor. The Logic Editor receives inputs in the form of queries, IDOC (Intermediate Documents), BAPI (Business Application Programming Interfaces), flat files, Web Scrapings, XML, HTML, text, and images. This graphical programming interface allows the developer to connect to data and manipulate it structurally, perform any number of calculations, and transform its output into email, XML, HTML, or PDF files. The Queries, Displays, and Business Logic transactions are then combined into role based interfaces. These interfaces are web pages that are created using JavaScript and a web authoring software such as Microsoft's FrontPage or Macromedia's Dreamweaver. The interfaces have drilldown capability and can be displayed securely over intranets, extranets, or the Internet. Examples of role based user interfaces include Dashboards, Scorecards, Manufacturing Analytics, Trends, Reports, SPC, and a SAP ERP interface. XMII Process Actions include: Access lists, Access details, Create. Change, Confirm, Move, Consume, Report, and Complete.

D. Connection between xMII and other SAP Modules

XMII can use any BAPI, RFC (Remote Function Call), IDOC, or any remote enabled function module to provide visibility and transaction execution capability into any SAP component. Once connected, Query and Display Templates can be created to assemble the desired data. Queries can be in the form of Tag, SQL, Alarm, XML, Xacute, OLAP, or Aggregate, while Displays include Line, Bar, Gauge, Regression, Pie, Grid, Scoreboard, Lights, Browsers, *etc.* More xMII Description can be found from the resource of SAP Company.

III. Case Study in a Global Chemical Company

A. Company background

The global chemical company of our case study, we name it "CO" company. "CO" mainly produces oil additives that improve the performance of fuels and lubricants. Its products includes: Viscosity Modifiers, Transmission, Hydraulic, Gear and Other Fluid Additives, Fuel Additives, Industrial Engine Oil Additives, Natural Gas Engine Oils, Railroad Engine Oils, Automotive Engine Oil Additives, Passenger Car and Heavy Duty Diesel Marine Lubricant Additives, Small Engine Oil Additives, Chemicals & Components *etc.*

Before the project, there are many disparate IT systems in four plants, seven different ERPs in enterprise, and MES is NOT integrated with ERP. Process Control Systems are different between different regions. There is no current global roadmap on the future of PCN (Process Control Network) systems. MES are vastly different among regions in terms of functionalities and integration.

B. Project Description

The project is a global implementation of SAP which will result in a single global system. The system will provide access to global real time information (no more than 24 hour refresh), provide a global view of demand, production and cost information to manage our supply chain and reliably service our customers, provide an improved ability to identify and interpret trends (*e.g.* regional demand & reliability), enable "CO" company to increasingly differ from competition, by taking full global advantage in the delivery of products and services to customers, enable the capability to cost and price innovative solutions to global customers, provide a solid IT foundation to support future functionality additions that will support long term strategy of "CO".

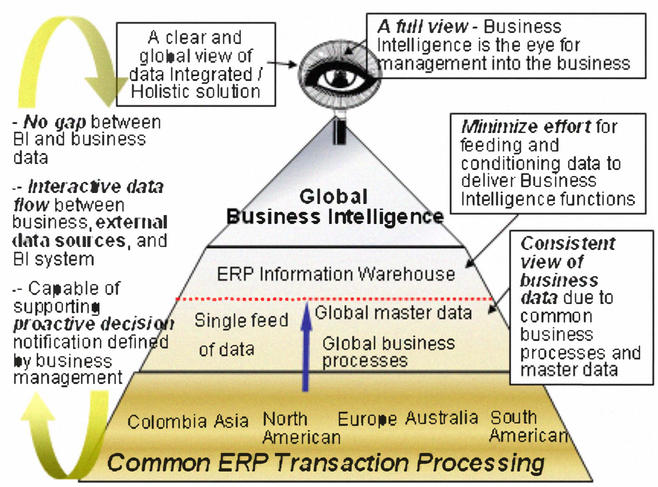

Fig.4. "TO BE" IT Situation in Enterprise Level

"TO BE" IT situation in enterprise level of "CO" is as Fig.4. Project's objectives are to consolidate older technologies and reduce annual maintenance fees, to keep long-term stability and reusable content throughout SAP systems, and to reduce the hand-off of information and failure points between technologies. The purpose of xMII sub project is to serve as MES of all four manufacturing plants, to provide a front end for shop-floor operators, and integration between SAP R/3 and existing PCS/DCS shop-floor systems.

C. ERP Solutions of "CO"

1) Provide a 360 view of Manufacturing Operations: To deliver real-time production schedules & visibility to the front-line operators, then critical events of manufacturing execution can be easily identified, and better planning can be made and executed. Utilization of manufacturing assets (People, Machine, *etc.*) can be monitored to improve operational effectiveness.
2) Support Cultural & Clinical Initiatives, like lean production, Six-Sigma, OEE (Overall Equipment Effectiveness), TPM (Total Productive Manufacturing), Demand Flow *etc.*
3) Radical User Simplification for Plants. Operator front-end for QM, PM *etc.* is simplified *e. g.* Automated and/or Manual production confirmations are simplified.
4) Support the disconnected operation, then improve the limited local survivability (run disconnected from the mother-ship)

D. XMII Business Scope and Requirements

Across the globe, all shop floor personnel perform the same basic business functions. The Business Process Mapping between ERP and xMII includes: Receiving Product, Manufacturing Product, Moving Product, Shipping Product, PM, MM (Material Management), PP (Production Planning), QM.

In Asian plant, there are about 80-120 xMII users, like contract operators, full time operators, supervisors. Business will decide xMII user roles, and their access right lists. XMII will be the main tool for operators to do their daily work list. If xMII is not available, production will be effected or even stop. So, xMII architecture design should assure xMII availability as high as possible, which is decided by xMII itself, related computer network, SAP systems and shop floor systems.

E. About xMII Server

According to SAP xMII product roadmap, "CO" decides to select xMII 12.0, where Net Weaver WAS is used to support user administration and support function of xMII. Its system requirements can be found from Table I. Those services created in xMII can be used by other SAP modules.

At least those shop floor systems of Asian plant will have

TABLE I
SYSTEM REQUIREMENTS FOR XMII 12.0 SERVER

	For 11-100 Concurrent Users	For 501+ Concurrent Users
Processor	Dual processor recommended, 3.4 GHz or faster	Dual processor recommended. 3.4 GHz or faster
RAM	See NetWeaver 04s Documentation (4096 MB minimum recommended)	See NetWeaver 04s Documentation 8192 MB minimum recommended)
Operating System	Windows 2003 Server	Windows 2003 Server
Java Virtual Machine	SUN JSDK 1.4.2_13	SUN JSDK 1.4.2_13
File System	NTFS	NTFS

connection with xMII server (See Table II). Interfaces between xMII with different shop floor systems are decided by IT rules of "CO", which can be JDBC or ODBC Connector, Adapter, and API (Application Protocol Interface). Production environment can be described as Fig.5

TABLE II
SHOP FLOOR SYSTEMS IN "CO" PLANTS

Application (Version)	Data Resource	Data read	Data Write
Weight Bridge 6.03.01	Microsoft Access version 2000	Weight	DB
StarLims 9.31	Oracle 8.1.7.6 to 9.2.0.6	Test Results	Adapter
Honeywell's TPB v4.0	(MSDE) SQL Server Desktop Engine 8.00.2039	Status Messages	Recipe Information Adapter
Honeywell's Uniformance 210.1.1	Oracle DB Version 9.2.0.6	Quantity Information	Adapter
MMS 4.04	Oracle DB Version 9.2.0.6		
Blend Program	Oracle 8.1.7.6 to 9.2.0.6		

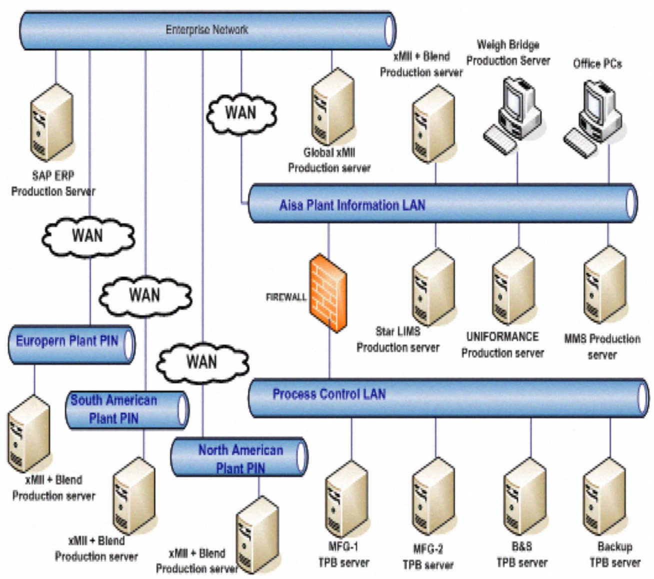

Fig.5. XMII Production Environment Used in "CO" Asian Plant

F. High Availability Solution

SAP has main server and backup server. There will have duplicate network connection between SAP and xMII. XMII itself can cash all inbound and outbound files/message as long as desired. When xMII cannot get data from SAP, cashed data can assure production continuity. We can design xMII backup server, which will be better if it can be online all the time, have real-time synchronization with xMII main server, and can realize automatic switch (server and client) from xMII main server to xMII backup server.

G. XMII Functional Areas

In this project, xMII are mainly used to develop those functional areas: Loads (Goods Issue), Unloads, Transfers, DOI(Digital Object Identifier)/Special Instructions, Inventory, Blending, Component Manufacturing, Data Maintain, and Dashboard/ KPI's, Customer Response Time *etc*.

1) Use case 2: Unloads

All inbound for unloading is scheduled before it can come into plant. If it is also indicated in the DOI, MMS (Materials Movement System) Instruction and the Plant unloads based on the MMS instruction and the Purchase Order (PO). The inbound drive is accompanying with the documentation, *e.g.* Bill of Lading or delivery orders documents before plants can accept the inbound shipments. There are four modes of incoming materials: ISO Tank (Tank truck), Lorry Drums, Bulk, and Container (Bags, Bins and Drums).

The weigh bridge and warehouse contractor do the Good received in ERP system and variance quantity will then adjusted by the finance. Based supply documents compared our in-house weigh with bridge weight.

All the in-bound bill data will store in the weight bridge system and upload daily into MMS. Historical data for all in-bound are stored in the MMS system. For activities payment to contractor, track the truck/ISO tanks demurrage and waste send out to third party for disposal.

For bulk vessel in bound: we engaged the surveyor for all the tanks gauging and confirm the actual quantity received. For activities base payments, we pay them by each movement In/Out of the plant. The unloading process involves the following steps:

(1) The current quantity of the inbound materials is ascertained (Tank and Marine vessels are gauged, trucks and contains are weighed, *etc.*).
(2) The current quantity of the destination vessel is ascertained.
(3) Weigh Bridge Operator picks up the stock based on the Bill of Lading document in ERP and Bulk vessel stock is inputted by the Operation Planning Group using the vessel surveyors report.
(4) In order to ensure the incoming materials meeting the "ID" test, except incoming drums, material inspection is based on the QC (Quality Certificates).
(5) The new quantity of the destination vessel is ascertained.
(6) The new quantity of the source vessel is ascertained.
(7) All the inbound status will be uploaded into MMS from weigh bridge system.

To calculate the amount of material received the quantity identified in step (5) is subtracted from the quantity in step (1). To calculate the amount of material unloaded, the quantity identified in step (2) is subtracted from the quantity returned in step (4).

The mass computing for tank gauging: the apparent volume of the product in the tank at the observed temperature is determined by referring to the Calibration Table in control. Note that the gauge is OUTAGE and not INNAGE in the calculation. The volume must be converted to 15.6 deg C by the following method:

Volume at 15.6 deg C = Volume at Observed Temp [1 - CTE (T-15.6)]

Where T = Observed Temperature

CTE = Co-efficient of Thermal Expansion

Mass at 15.6 = 15.6 deg C = Volume at 15.6 deg C * Density at 15.6 deg C.

If Volume is kilo-liters, Mass is Metric Tons.

2) Use case 2: Customer Response Time (See Fig.6)

(1) Look up customer PO from SAP, view the list of PO downloaded from SAP PP-PI that needs to be executed, return PO.
(2) Create batch for PO where queuing is not complete. Find Batch created to satisfy PO.
(3) Try to allocate the batch to a resource for production. Get Historian and LIMS data for batches, run xMII Analytics.
(4) System allocates the batch after checking the feasibility of production on the requested resource. If SPC Alarm it is a batch production problem–provide aggregate view of LOTS & CUSTOMERS.
(5) The batch gets into production once the preceding batches are completed.
(6) Actual productions are uploaded to SAP PP-PI automatically by the system. Email report to Product Manager, Disposition to SAP QM, and Close record in QN (Quality Notifications) System.

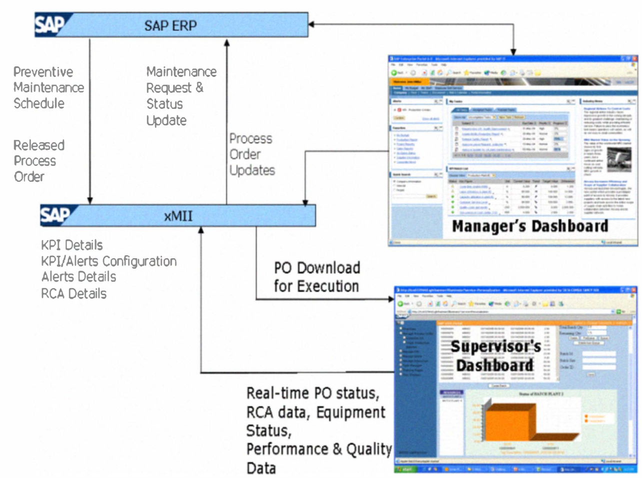

Fig.6. Customer Response Time Use Case

H. Tactical Benefits of xMII Solution

1) Reducing manufacturing costs 3%-5% by monitoring manufacturing process and increasing visibility.
2) Increasing plant efficiencies 20%-25% by optimization of manufacturing processes and integrating with the enterprise.
3) Increasing production yields 8%-10% by proactively monitoring the manufacturing events.
4) Reducing maintenance costs 8%-10% by streamlining maintenance processes and aligning with manufacturing metrics.
5) Reducing asset capital investments 8%-10% by

improving asset performance through greater asset reliability.

6) Reducing inventory 8%-10% by manufacturing lean process enablement streamlining and reducing variability of execution.
7) Reducing premium freight costs 15%-20% by integrating manufacturing events with the enterprise and supply chain.
8) Increasing value chain agility and customer responsiveness by integrating complete value chain with visibility.

IV. Conclusion

The paper describes the industrial story of Real-time Manufacturing Integration and Intelligence Solution in one Global Chemical Company. The solution can be applied to the similar process industries.

At the same time, the paper also gives many theoretic challenges to academic experts. For example, by using traditional mathematic methods, the latest intelligent theories and methods, how to model, analyze, and then optimize the manufacturing operation on different level, realize manufacturing intelligence on different level, different areas, and different ranges? Then, more and more margins and profits, social and economic benefits can be made.

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References

[1] H. Panetto and A. Molina. "Enterprise integration and interoperability in manufacturing systems: Trends and issues," *Computers in Industry*, Vol.59, No.7, pp.641-646, Sep. 2008.

[2] G. Morel and C. E. Pereira. "Manufacturing plant control: Challenges and issues," *Control Engineering Practice*, Vol.15,No.11, pp.1319-1320, Nov. 2007

[3] C. Temponi and M. D. Bryant. "Fernandez. Integration of business function models into an aggregate enterprise systems model," *European Journal of Operational Research*, Vol.199, No.3, pp.793-800, Dec. 2009.

[4] F. B. Vernadat. "Enterprise modeling and integration (EMI): Current status and research perspectives," *Annual Reviews in Control*, Vol.26, No.1, pp.15-25, Jan. 2002.

[5] G. Xiong, Y. X. Gang, A. Litokorpi, and T. R. Nyberg. "Middleware-based solution for enterprise information integration," *The 8th International Conference on Emerging Technologies and Factory Automation (ETFA 2001),* Antibes-Juan les pins, pp. 687-690, Oct. 15-18 2001.

[6] G. Xiong, Y. X. Guang, and T. R. Nyberg. "To Realize Enterprise Integration of Virtual Pulp & Paper Enterprise," *The 12th International Flexible Automation and Intelligent Manufacturing (FAIM) conference*, Dresden, Germany. pp.603-613, Jul. 15-17, 2002

[7] G. Xiong and T. R. Nyberg. "Push/pull production plan and schedule used in modern refinery CIMS," *Robotics and Computer-Integrated Manufacturing,* Vol.16, No. 6, pp.397-410, Dec. 2000.

[8] V. Filipov and N. Christova. "A Solution for Integrated Manufacturing Operation Management," *International Conference on Computational Intelligence for Modeling Control & Automation*, pp.527-532, Dec.10-12 2008.

[9] R. Martin and W. B. Martin. "Global operations strategy: Coordinating manufacturing networks," *Omega*, Vol.36, No.1, pp.91-106, Feb. 2008.

[10] P. Hervé and M. Arturo. "Enterprise integration and interoperability in manufacturing systems: Trends and issues," *Computers in Industry*, Vol.59, No.7, pp.641-646, Sep. 2008.

[11] Z. Z. David, I. A. Anthony, and K. L. Ming. "An agent-based approach for e-manufacturing and supply chain integration," *Computers & Industrial Engineering*, Vol.51, No.2, pp.343-360, Oct. 2006.

[12] E. Oztemel and E. K. Tekez. "Integrating manufacturing systems through knowledge exchange protocols within an agent-based Knowledge Network," *Robotics and Computer Integrated Manufacturing*, Vol.25, No.1, pp.235-245, Feb. 2009.

[13] C. Temponi, M. D. Bryant, and B. Fernandez. "Integration of business function models into an aggregate enterprise systems model," *European Journal of Operational Research*, Vol.199, No.3, pp.793-800, Dec. 2009.

[14] G. Xiong, T. R. Nyberg, and Y. Z. Zhi. "To Realize Information Integration of Virtual Pulp & Paper Enterprise," *IEEE International Symposium on Industrial Electronics*. L'Aquila, Italy, pp.276-281, Jul. 8-11 2002.

[15] Y. Gao, Z. Shang and A. Kokossis. "Agent-based intelligent system development for decision support in chemical process industry," *Expert Systems with Applications*, Vol.36, No.8, pp.11099-11107, Oct. 2009.

[16] I. Raffaele, M. Salvatore, and R. Stefano. "Supply chain distributed simulation: An efficient architecture for multi-model synchronization," *Simulation Modeling Practice and Theory*, Vol.15, No.3, pp.221-236, Mar. 2007.