Real-time Manufacturing Integration and Intelligence Solution: Case Study in Global Chemical Company

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***Abstract*—Global manufacturing enterprises meet a lot of challenges on enterprise level, plant level and shop floor level. To solve those challenges, a kind of real-time Manufacturing Integration and Intelligence (MII) solution is proposed, and its standard interfaces with ERP modules and shop floor systems, standard integration functionalities, and typical use cases and typical benefits, are described. By using of the practical project executed in one global chemical company as background, the paper introduces the project's "AS IS" situation, and "TO BE" target. Then, the MII solution is discussed in more detail, including its business scope, customer requirements, server selection, high availability solution, core technologies, and its main functions: load; unload; transfer; special instruction; inventory; blending; KPI dashboard. The tactical benefits, which have been made for the customer with the MII solution, are summarized. Finally, some conclusions are drawn out.**

***Index Terms*—Manufacturing integration and intelligence, enterprise resource plan, manufacturing execution system, shop floor system, chemical enterprise**

I. Introduction

With the development of economy globalization, many manufacturing enterprises have met some typical challenges [1], like revenue growth becomes slow, margin pressure becomes high, and operating efficiency becomes low; Their macro-economic environment is also becoming worse than before, like persistent low development speed in developed countries, continuous mergers and acquisitions, depends more on raw materials' suppliers, higher energy and feedstock costs; There is more intensive competition from developing countries, and so place tremendous pressure on cost, quality and responsiveness; Expenses on E-commerce, IT consolidation and rationalization are increasing; There are more innovation pressure due to commoditization; These enterprises depend more on a fewer large customers, who have more rights than before. For example, customers are getting more control of product pricing, have growing list of demands, such as compliance, quality, and services etc.

At the same time, those chemical manufacturers need to comply with the strict government regulations, chemical trade & security regulations, like Sarbanes Oxley, Environmental, Health and Safety (EHS) compliance, FDA 21CFR part 11 which is the Code of Federal Regulations deals with the Food and Drug Administration (FDA) guidelines on electronic records and electronic signatures in the United States. Otherwise, they will face stiff penalties.

To keep their competence, manufacturing plants of global enterprises are distributed to distant foreign locations, leading to its loss of visibility and control. Business and financial impact of production exceptions cannot be monitored or controlled at the enterprise level. On the other hand, production personnel lack the decision support information from top level to meet their targets, can't monitor and optimize the manufacturing process based on current operating conditions.

There exist some typical challenges on the plant level [2]. The enterprises must take proactive steps regarding process safety management, change management, safety & incident report, and regulatory compliance. So the enterprises starve for 360 degree view of plants, like asset performance, plant execution, operational planning. Real-time data provide more value than conditioned data, so one vision of Key Performance of Indexes (KPIs) visibility has more value than multiple versions of the same data.

In fact, many enterprises have poor alignment of goals, measures and roles. There is no common visibility among departments, plants, and corporate headquarter, resulting in their 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

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between production plan making and production plan execution.

A. Chemical Business Issues

Here chemical business issues are described as example. According to SAP's customer interviews report of chemicals segment, chemical business issues can be summarized as Table.1.

TABLE.I
CHEMICAL BUSINESS ISSUES

Strategic areas: facts and figures	Key drivers of business value
Improved supply chain efficiency. Total SCM costs in % of revenue: median: 10.6%; best in class: 5.6%	1.Reduce inventory (scrap and Work in Process: WIP) costs 2.Improve cycle time with supply chain visibility and efficiency 3.Reduce material costs with strategic sourcing 4.Collaborative demand and supply planning to reduce working capital
Managed plant operations. Plant integration projects can provide Return on Investment (ROI) >100% in the first year	1.Improve asset productivity with capacity utilization and investment management 2.Increase operating efficiency with improved scheduling
Support new product development. Companies with >50% of sales from products and services introduced in the previous 5 years increased their revenue by an average of more than 10% over the 5-year period	1.Avoid early commoditization by actively managing the product life cycle and anticipating future requirements 2.Maintain a competitive advantage with collaborative design and rapid response to customer requirements
Improved customer service and profitability; Increase customer satisfaction by 10–35% ; Go-to-market time reduced by 25%	1.Quickly react to changing demands in product specifications 2.Optimize operating efficiency with improved scheduling. 3. Business transparency

B. Current Problem of IT Systems

For manufacturing enterprise, IT systems' connection among factory level, enterprise level and supply chain level is critical for production personnel to cost-effectively deliver on customer expectations. Unfortunately, the most of existing Enterprise Resource Planning (ERP) systems are separated from Manufacturing Execution Systems (MES), the situation can be shown as Fig.1. According to the customer survey executed by Managing Automation and AMR Research, "Less than 1% of respondents indicated that manufacturing data is automatically integrated with ERP with no manual intervention".

In fact, ERP-MES integration is very important, which main contents include: Production capacity information (What is available for use?); Product definition information (How to make a product?); Production schedule (What to make and use?); Production performance (What was made and used?).

More and more IT systems are applied, but they are separated, or have disconnected components. For example, execution systems are not easily integrated into business systems; most MES packages only provide partial functionalities, use the different copies of ERP master data, and then create compliance and quality issues.

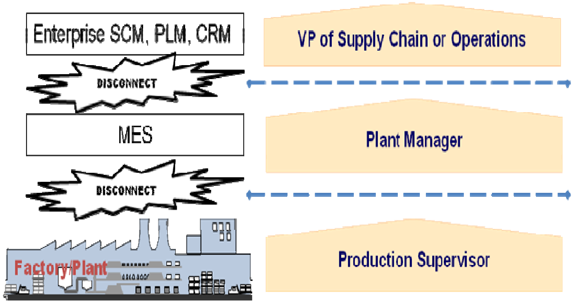

Figure 1. Typical Scenario existing in manufacturing enterprise

According to AMR Research, about 27% of chemical enterprise software investment is for ERP. About 24% is manufacturing operations. And about 22% is for Supply Chain Management (SCM). Their integration is the key to realize MII, and then to create more profits, benefits and competences for the chemical enterprises.

C. Literature Reviews

In academic areas, Gérard M. summarized some key problems and accomplishments in manufacturing plant control and forecasted in deploying automation over networks [3]. Vernadat F.B. gave current status and research perspectives reviews of enterprise modeling and integration (EMI) [4]. Paulo L. surveyed the literature in manufacturing control systems using distributed artificial intelligence techniques [5]. Raffaele I. proposed an efficient architecture which was able to synchronize, simply and securely, simulation models which were located in different geographical areas [6]. Temponi C. introduced methods that combine models of distinct business functions into an aggregate model to assist management's strategic decision making [7]. Martin R. answer: how companies can manage their international operations so as to facilitate the coordination of their manufacturing networks? [8]

In technical areas, Contreras M. showed an agent-enabled SOA which could play an important role for service integration [9]. Shen W. proposed agent-based service-oriented integration architecture to leverage scheduling services on a network of virtual enterprises [10]. Estrem, W.A. [11], Gang X. [12] focused on SOA architecture study with different perspectives. Filipov V. presented an industrial software solution for integrated Manufacturing Operation Management [13]. Oztemel E. presented a knowledge exchange procedure for creating integrated & intelligent manufacturing system [14]. Ying G. presented agent-based intelligent system to support coordinate manufacturing execution and decision-making in chemical process industry [15]. Gang X. discussed push/pull production mode used in CIMS and its application in refinery [16], and proposed information integration method of virtual pulp & paper enterprise [17].

Unfortunately, there is no practical IT system or standard solution is proposed and accepted by industry. Based on those R&D achievements reviewed on the above literatures, this paper is to put forward suitable solution for those challenges, which is organized as follows. In section 2, real-time MII solution is described in detail, and Section 3, a case study of the MII solution is done in one global chemical company. Finally, some conclusions are drawn out.

II. Manufacturing Integration & Intelligence Solution

Adaptive manufacturing can solve those business and technical challenges described in the previous part. It is important for one company becomes adaptive, then its plants profitably replenish the supply chain while dynamically responding to unpredictable changes, enables the company and their production personnel to deliver superior performance through higher visibility and responsiveness. Adaptive manufacturing enterprise owns such capabilities as Manufacturing Operations, Manufacturing Integration, Manufacturing Intelligence and Manufacturing Innovation, where Manufacturing Synchronization and Manufacturing Excellence are two enabling technologies (Fig.2. Source: SAP). More explanations are described below.

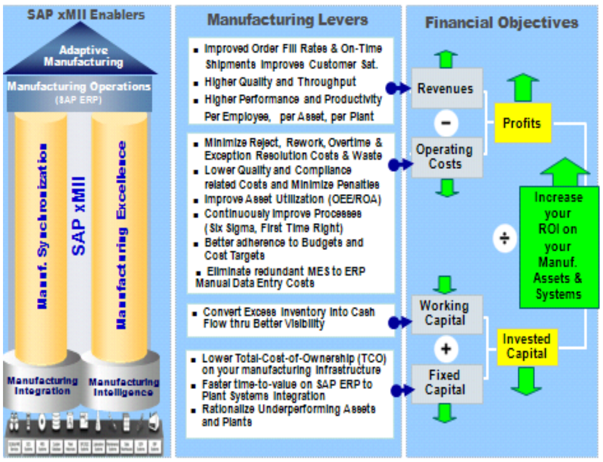

Figure 2. Manufacturing integration and intelligence for the maximum return

a) Manufacturing Operations: To manage manufacturing workflows to realize closed-loop operations. Operations intelligence includes dashboards, asset monitoring, Statistical Process Control (SPC) & 6-Sigma, manual entry, data integration with ERP. The operation functions below can realize asset utilization as high as up to 25%:
   - A dashboard provides real-time tracking and proactive event monitoring of manufacturing assets;
   - Proactive monitoring enables preventive maintenance and can reduce production downtime;
   - Plant is fully integrated into cost, quality & compliance functions. And the integration of manufacturing systems with SCM, Human Resource (HR), Customer Relationship Management (CRM), and Supplier Relationship Management (SRM) modules, provides full disclosure of all constraints and capabilities.

b) Manufacturing Integration: A manufacturing integration platform seamlessly connects manufacturing processes with enterprise operations and supply chain processes, and provides a single, standards-compliant (like ISA-95) layer connection between real-time shop-floor applications, enterprise systems, manufacturing execution, and sales-force automation, to drive plant-to-enterprise business process interoperability. It provides two kind of services:
   - Data Services: All services, including user-defined composite services, are exposed as web service. For example, Bi-directional data access & integration service extracts and aggregates those data from different sources.
   - Business Logic Services (BLS): By connecting to business suite applications, BLS enforces business processes, model workflow, and schedule tasks. BLS includes logic services, integration services, notification services, statistical calculation and data transformation, content creation, automated data extraction & input, data manipulation, analytics, alerts messaging, data reduction, schedule tasks, file generation, digital dashboard generation.

c) Manufacturing Intelligence: Real-time actionable analytics and decision support to production personnel, so they can deliver on their performance goals. The real-time analytics engine aggregates, calculates and delivers a single visualization of relevant events, alerts, warnings, KPIs and decision support. Production personnel can access all relevant information through a single, role-based dashboard, and make fast and accurate decisions to improve manufacturing bottom line. It is used to control, monitor and optimize automated manufacturing processes to realize very short time-to-benefit. Its main functions are:
   - Visualization services: charts, grids, tickers, UI controls, Dashboard components.
   - Analytic services provide SPC, Statistical Quality Control (SQC), 6-sigma analyses, and other mathematical analyses etc.
   - Real-time 6-sigma analytics engine that aggregates and delivers unified visualization of events, alerts, KPIs and decision support to production personnel through role-based dashboards.

d) Manufacturing Synchronization: Electronically links enterprise business processes and master data with plant manufacturing processes to realize a "single version of the truth" (Fig.3). To synchronize manufacturing with the enterprise, and to enable manufacturing excellence, are mission critical for competitiveness. There are four levels of synchronizations, some typical use cases are: Director of customer service receives customer calls, order creation and cancellation, investigates exception, so the related data should be synchronized once every 48 hours. Plant managers need the related data to be synchronized once every 24 hours, to keep visibility into alternatives, to assure delivery due date, to decide to drive overtime next day, and to learn about issue not too late. Production supervisors need the related data to be synchronized once every 5 hours, to find spare capacity available, overtime in the next shift. Operators need the related data to be synchronized once every 30 minutes, to stop production as soon as product defects happen, call maintenance, and inform production supervisor. Currently, there are some customer pain points, which are improvement opportunities:

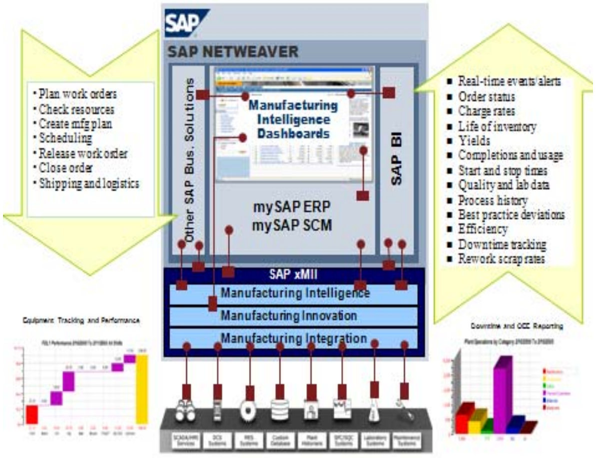

Figure 3. MII synchronizes manufacturing operations

- Inability to connect multiple plant floor systems cost-effectively to the enterprise, leads to loss of visibility and control in a multi-plant environment, and then leads to higher operational costs.
- Inability to aggregate real-time plant floor information for analysis onto enterprise desktop, so plant managers can't analyze the business impact of manufacturing exceptions, leads to wrong and costly choices.
- High avoidable cost, errors and latency of manual entry of production data into ERP, so multiple copies of master data exist across the plants and the enterprise.
- Extremely high Total Cost of Ownership (TCO) on manufacturing IT Infrastructure, because point-to-point integration of plant floor systems with ERP is prohibitively expensive. As one European chemicals manufacturer said: "We haven't integrated our MESs with ERPs. We have over 600 people across 200 plants manually punching in production batch data into our ERPs. This is costly and detracts severely from performance."

e) **Manufacturing Excellence:** It means reliably produce to target with year-to-year cost reductions and quality improvement. One leading North American chemical manufacturer said: "We want to drive decision making onto the manufacturing floor and deliver superior performance. Our plant managers and supervisors need actionable intelligence that can tell them the health of the plant or production line at a glance, show them exceptions in real time, how they can be resolved, and the KPIs that will be impacted." Manufacturing excellence includes production operator, root cause analytics of quality, work center analytics and 6-sigma analytics. Currently, there are some customer pain points, which are improvement opportunities:

- Inability to measure and control actual production costs against targets, which leads Line of Business (LOB) and plant managers frequently miss their budgets, and raise operational expenses.
- Inability to see manufacturing exceptions and respond. When they happen, production personnel are in a constant state of firefighting, which causes high expedition costs.
- Production personnel can't monitor, measure, analyze, control and improve KPIs against the targets, and then is unable to meet continuous process improvement goals.
- 40% of production personnel's time is wasted in looking for the necessary data across multiple systems, which causes the wide variation in manufacturing performance across shifts, lines and plants.
- Lack of accurate and timely asset-to-asset and plant-to-plant comparison data, so it is difficult to improve the performance across underperforming assets and plants.

A. *Technical Description of MII Solution*

MII solution automatically synchronizes the orders, materials, maintenance, quality and master data between real-time manufacturing plants and enterprise business processes, to provide a "single version of the truth", and drive manufacturing excellence. MII is composed of a set of integrated tools, like data access, business logic, visualization, KPI's, alerts, metrics, SPC engine and 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, Plant Maintenance (PM), and Quality Management (QM) *etc.* Its visual information for plants can enhance asset reliability, extend PM capability and simplify PM operation for managers, operators, planners *etc.*

1) *Connection between xMII and Shop Floor Systems*

xMII offers a broad library of pre-built connectors (Fig.4) for connecting to shop floor systems. Such as AlarmSuite, Simulator, *XML, InSQL, IP21 and IP21* OLEDB, *Open*, Aggregate, Xacute, OLAP, IDBC and Universal Data Connector (UDC) *etc.* For example, IDBC enables a connection between xMII and JDBC or ODBC data source. The UDC is a framework that allows access to MII services through your proprietary server applications. The OLEDB connector is a UDC that allows access to OLEDB data sources.

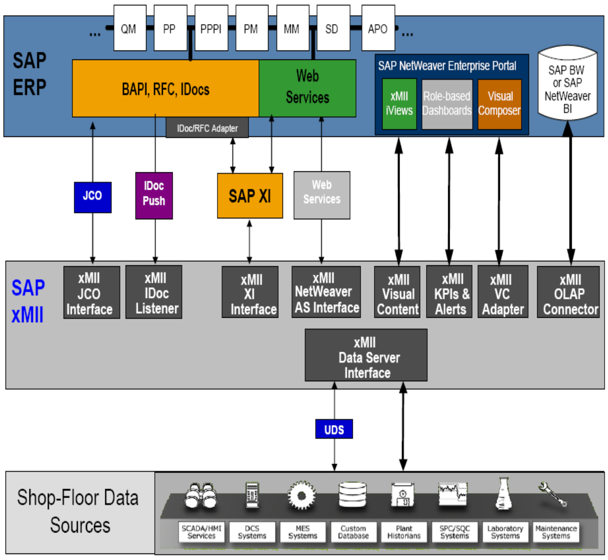

Figure 4. Technical Interface of ERP and MII

2) *xMII Server*

The core of MII, however, lies in its business logic editor. The logic editor receives inputs in the form of queries, Intermediate Documents (IDOCs), Business Application Programming Interfaces (BAPIs), flat files, Web scrapings, XML, HTML, text, and images etc. This graphical programming interface allows the developer to connect to all data and manipulate them 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 by 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 ERP interface. MII process actions include: access lists, access details, create; change, confirm, move, consume, report, complete etc.

3) *Connection between MII and ERP Modules*

MII can use BAPIs, RFC, IDOCs, or any remote enabled function module to provide visibility and transaction execution capability into any ERP 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.

B. Typical MII Use Cases

1) *Use case 1: Customer Response Time*

The use case is shown in Fig.5, and can be described as below:

a) Look up customer Process Order (PO) from SAP, view the PO list downloaded from SAP PP-PI that needs to be executed, return PO.
b) Creates batch for PO where queuing is not complete. Find the batch which is created to satisfy PO.
c) Tries to allocate the batch to a resource for production. Get Historian and LIMS data for batches, run MII analytics.

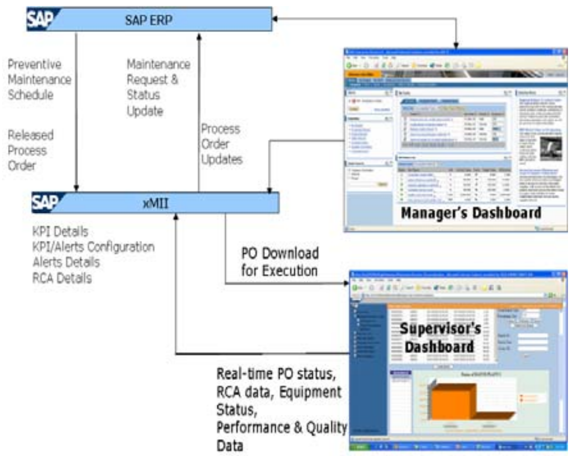

Figure 5. Customer response time use case

d) System allocates the batch after checking the feasibility of production on the requested resource. If SPC alarm is about a batch production problem – provide aggregate view of lots & customers.
e) The batch gets into production once the preceding batches are completed.
f) Actual productions are uploaded to SAP PP-PI automatically. Email report to product manager, disposition to SAP QM, close record in Quality Notifications (QN) system.

2) *Use Case 2: Asset Performance Optimization Cockpit*

The use case can be described as below:

a) Equipment status changes and associated status codes are immediately detected from existing shop floor automation systems.
b) Status codes are compared to maintenance system for standard event descriptions.
c) Status codes are compared to operational excellence and Total Productive Maintenance (TPM) system for current acceptable cause codes for that asset.
d) Operators enter additional commentary as needed.
e) Maintenance can be alerted if the issue is beyond the operator's abilities.
f) Real-time performance is feedback according to standard run rate and actual through-put for order in process.
g) Every event, including associated data, is captured for further review and analysis. Only events over a certain threshold are shown on-screen or require operator input.

The mobile dashboard enables a plant or production manager to access up to the minute production information, exceptions and KPI such as: Overall Equipment Effectiveness (OEE); production yield, and material availability; made Vs shipped order; product quality exceptions. Its bottom line benefit is that actionable intelligence, such as exceptions, reports and KPI, can be delivered in real-time to multiple roles.

3) Use Case 3: Manufacturing Exception and Performance Management Scenario

The use case can be described as below:

a) Production schedule sent from ERP to MES via MII.
b) Plant manager sees notification in his intelligent MII dashboard. MII initiates production on the batch via MES, and monitors progress.
c) Quality exception is detected in real-time and communicated via MII. Plant manager sees alert on his dashboard and drills down for root causes.
d) Quality data reveals excess moisture in the batch, caused by faulty dryer. ERP quarantines batch and issues maintenance notification to fix the dryer.
e) Plant manager drills down on OEE KPI in his dashboard, and analyzes OEE availability, performance and yield data in detail.
f) Plant manager then drills down on actual vs. budgeted production cost KPI on his dashboard, and sees details of actual production costs vs. target to identify variances, to identify problem areas for improvement.

C. Typical Benefits of MII Solution

Generally to say, typical benefits of MII solution include the improvement of visibility, responsiveness, and performance:

Visibility improvement, like:

- Near-time visibility into customer orders across multiple plants, from scheduling to dispatching;
- Proactively detect machine, material, labor, and quality issues before customers do;
- Evaluate real-time KPIs and actual production costs and variances against targets.

Responsiveness improvement, like:

- Respond rapidly and cost-effectively to manufacturing exceptions;
- Monitor, measure, analyze and control cost and target variances;
- Balance manufacturing priorities against changing demand conditions, and align with business objectives.

Performance improvement, like:

- Improve manufacturing processes and customer satisfaction to leverage new revenue opportunities;
- Minimize inventory, rework, overtime, and expediting costs to consistently meet budgets,
- Improve employee's productivity, morale and quality of work life.

III. Case Study in a Global Chemical Company

A. Company Background

We name the global chemical company of our case study as CO Company. CO mainly produces oil additives that improve the performance of fuels and lubricants, such as: viscosity modifiers; industrial engine oil additives; automotive engine oil additives; passenger car and heavy duty diesel marine lubricant additives; chemicals & components etc.

B. "As Is" ERP Situation

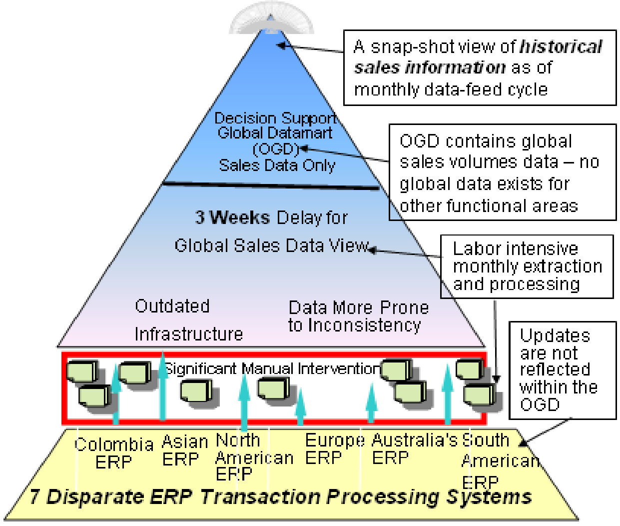

Figure 6. "AS IS" IT situation in CO's enterprise level

Before the project was executed, there are many disparate IT systems running in four plants and many sale offices, seven ERPs running at the same time in the enterprise (Fig.6), MES is not integrated with ERPs. And, it's bad business implications for the customer can be described as:

1) Machine breaks down on factory floor. The operator shuts down the machine, and then looks for and calls maintenance supervisor and production supervisor in turn. The maintenance supervisor does an initial diagnosis of the machine and finds out that some critical parts are missing and need to be ordered from the supplier. It takes 2-3 hours.
2) The production supervisor learns about the situation on his rounds and then looks for spare capacity or explores overtime in the next shift. Since the machine that has broken down is a bottlenecked resource, space capacity is not available. Neither is overtime in the next shift possible at such short notice. Five hours go by since the machine breakdown.
3) Production Supervisor escalates the issue to Plant Manager in person. Unfortunately it is already too late for the Plant Manager to resolve this. Plant Manager decides to drive overtime the next day, but misses the customer delivery due date which was this evening.
4) The director of customer service gets a call from the irate customer next morning informing him that the delivery of what were critical components for the customer was missed without any alert or information. Customer is really angry and cancels the order since he has found alternative supply from another vendor.

So, learning about the exception too late to address and resolve it costs a huge customer order and thereby lost revenue opportunity.

C. "As Is" Shop Floor Situation

Process Control Systems (PCS) and MES are vastly different among regions in terms of functionalities and integration. Some has functions belong to ERP. Some has only partial functions of typical MES. For example, Asian plant doesn't have existing MES. Some parts of MES are done by Material Movement System (MMS), Daily Operating Instructions (DOI) and blend program. North American plant uses Production Tracker (PT) as MES. Europe plant uses GESCOM as MES, which has downloading process (order, recipe and QM) from SAP to PCS, Uploading process (status, material consumption) from PCS to ERP, Optimal blend calculation etc. South American plant doesn't have existing MES system.

D. "To Be" Shop Floor Design

Although MII solution was rolled out first in Asian plant as part of the scope of ERP project, the goal is to create a single global design to cover the business requirements of all four regions. Because shop floor operators will be the primary MII users, local language support, documentation and training (English, French and Portuguese) are one of business requirement. Local units of measurement will be used for all input and display. Internal ERP numbering will always be translated to its human-readable form. MII is designed to allow regional configuration to support local legal or regulatory requirements, and allows a plant to continue 24x7 operations if its link to ERP is disrupted for any length of time; this will be accomplished by passing the necessary data in each order to prevent from having to look up information in supporting data structures. No ERP functionality should be reproduced in MII. ERP will be the "system of record" for all enterprise level data; MII is an offline "work space" which will receive data from ERP and return results to ERP. MII may contain some data that is not sent to ERP; however, if the data needs global visibility, it will also be saved into ERP. The design should be as modular as possible so that an individual building block can be modified or replaced without disrupting or redesigning the remaining blocks.

MII connects many IT systems, like SAP R/3, DCS, blend program, MMS, Plant Information Management System (PIMS), Drumming Scheduling System, and StarLIMS. MII develops those functionalities not covered by ERP and requested by actual business, like optimal blend calculation, component manufacturing system, Weight Bridge, drums field management, drums labeling and bar coding.

E. CO's mySAP ERP Solutions

The project, a global implementation of SAP ERP, results in a single global system, which provides access to global real time demand, production and cost information no more than 24 hour refresh to assure reliably service for our customers, provides an improved ability to identify and interpret trends, enables CO company to increasingly differ itself from its competitors, 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 CO's long term strategy.

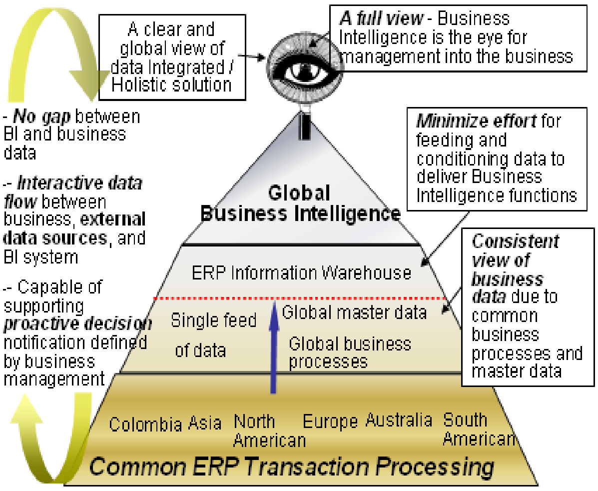

Figure 7. "TO BE" IT situation in CO's enterprise level

"TO BE" IT situation in enterprise level of CO can be shown as Fig.7. Project's objectives are to consolidate older technologies and reduce annual maintenance fees, to keep long-term stability and reusable content throughout mySAP ERP systems, and to reduce the hand-off of information and failure points between technologies. The purpose of MII sub project is to serve as MES of all four manufacturing plants, to provide a front end for shop-floor operators, and integrate mySAP ERP and existing shop-floor systems (Fig.8) through integration technologies like XI and MII *etc.*

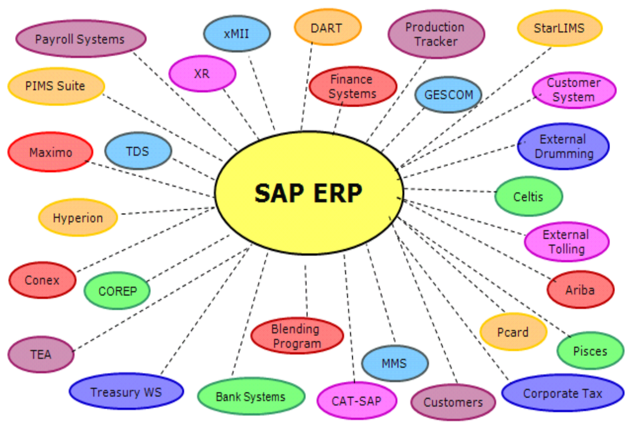

Figure 8. CO's IT Systems Scenario

The business purposes of the project are:

- 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.
- Support cultural & clinical initiatives, like lean production, 6-sigma, OEE, TPM, Demand Flow etc.
- Radical user simplification for plants. For example operator front-end is simplified; automated and/or manual production confirmations are simplified.
- Support the disconnected operation, and then improve the limited local survivability.

F. MII's Business Scope

Across the globe, all shop floor personnel perform the same basic business functions. Table 2 shows a summary of the business functions and activities performed by shop floor personnel at all plants, which then decides MII's technical design.

TABLE.II
BUSINESS PROCESS MAPPING BETWEEN ERP AND MII

Business Function	Activity
Receiving Product	Display Purchase Orders; Create or Cancel Goods Receipt
Manufacturing Product	Display Process Orders; Create Process Messages
Moving Product	Display Stock Transfer Orders; Create or Cancel Goods Movement; Create or Cancel Goods Issue
Shipping Product	Display Sales Orders; Create or Display Deliveries; Create or Cancel Goods Issue; Print Shipping Documents
Plant Maintenance (PM)	Work order; Time tickets; Work assignment; Component consumption.
Material Management (MM)	Inventory Control; Goods Movement; Batch information; Material reservations; Material characteristics; Purchasing
Production Planning (PP)	Production /Process orders; Operations; Time tickets; Production Results; Material consumption
Quality Management (QM)	Inspection tasks; Inspection lots; Sample management; Usage decision; Test result recording
Others	Weight; Test Results; Recipe Information; Status Messages; Quantity Information

G. MII's Other Requirements

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

According to SAP xMII product roadmap, CO decides to select xMII 12.0, where Netweaver Web Application Server (WAS) is used to provide the customer with scalability, high availability and built in clustering support, also support better monitoring and administration tools, and support function. Those services created in MII can be called by other SAP modules.

Currently, those shop floor systems of Asian plant have connected to MII server, where the interfaces can be selectable from JDBC, ODBC Connector, Adapter, or API (Fig.9). Production environment can be described as Fig.10.

H. High Availability Assurance

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

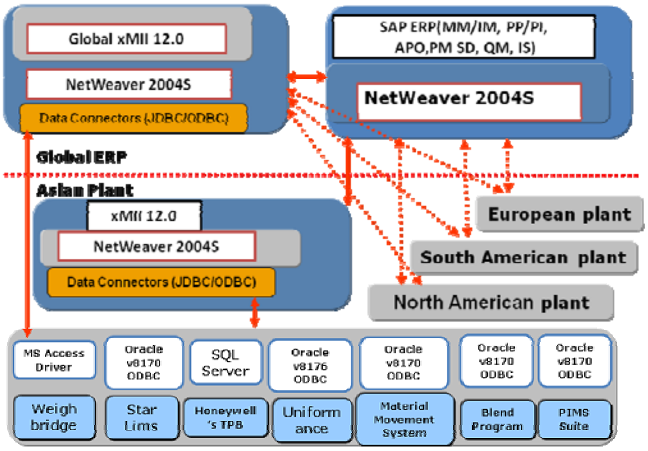

Figure 9. mySAP ERP and MII system used in CO's Asian plant

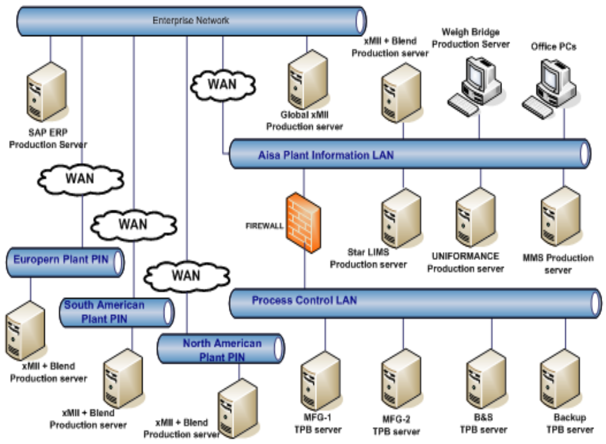

Figure 10. MII production environment used in CO's Asian plant

I. MII 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; and Dashboard/ KPI's. They are described in detail below.

1) Loads

Loads mean Goods Issue. The plant physically loads product into vessels for outbound shipment or return product to a vendor. The loading is based on the Sales orders or Stock issue to third-party sub contractor for storage or stock transport order. Shipping documentation is always required for a load. A load is a separate process from an intra-plant transfer. Product can be loaded on top of product which already exists in the destination vessel.

The process of loading a vessel involves the following steps:

Step 1: The current quantity of the source vessel is ascertained (tanks, rail cars and marine vessels are gauged, trucks, tote bins and contains are weighed, etc.);

Step 2: The current quantity of the destination vessel is ascertained;

Step 3: The product is physically transferred (manually or automatically through dedicated piping, vacuum truck, or physically picked and placed);
Step 4: The new quantity of the destination vessel is ascertained;
Step 5: The new quantity of the source vessel is ascertained;
Step 6: The material is either "ID" tested if the material was loaded from a fully tested tank or "full" tested if the source wasn't full tested in the destination vessel before it is allowed to leave the Plant.

To calculate the amount of material consumed, the quantity identified in step 5 is subtracted from the quantity in step 1. To calculate the amount of material loaded, the quantity identified in step 2 is subtracted from the quantity returned in step 4.

Because of the inaccuracies in gauging (Automatic radar gauging: +/- 1%, Manual physical gauging: +/- 2%) and weighing (+/- ½%) and the effects of temperature changes which affect the total observed volume based on a product's thermal expansion coefficient, the consumed product quantity will never equal its loaded quantity. A tolerance has to be set to warn the operator when the difference between the consumed quantity and the loaded quantity exceeds the threshold.

The quantity loaded in the destination vessel is considered the loaded amount. The procedure for releasing a loaded vessel needs to be defined after its testing has been completed.

For some customers and for some tests that may take a very long time to run, a method must prepare to manually release the shipping vessel with a supervisor's permission.

2) Unloads

All inbound for unloading is scheduled before it can come into plant. If it is also indicated in DOI, MMS Instruction, and then Plant unloads is based on the MMS instruction and the Purchase Order. The inbound drive is accompanying with the documentation, *e.g.* bill of loading 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 receiving from ERP system, and its variance quantity will then adjusted by the finance. In-house weigh is compared with bridge weight according to its supply documents.

All the in-bound data will store in the weight bridge system and upload daily into the MMS. Historical data for all in-bound are stored in the MMS. 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:

Step 1: The current quantity of the inbound materials is ascertained, where tank and marine vessels are gauged, trucks and contains are weighed, etc.
Step 2: The current quantity of the destination vessel is ascertained.
Step 3: Weigh bridge operator picks up the stock according to the bill of loading document in ERP, and bulk vessel stock is inputted by the operation planning group by using the vessel surveyors report.
Step 4: To assure the incoming materials meet the "ID" test, except incoming drums, material inspection is based on the quality certificates.
Step 5: The new quantity of the destination vessel is ascertained.
Step 6: The new quantity of the source vessel is ascertained.
Step 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 inn age 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 = 15.6deg C = Volume at 15.6 deg C * Density at 15.6 deg C.

If Volume is kilo-liters, Mass is metric tons.

3) Transfers

The transfer activity is scheduled through the daily activity report (Excel spreadsheet). This document is generated by production planning and control department on the day before. Before the transfer begins, the shift supervisor fills in an "Instruction Sheet", which has relevant information about the transfer, like: product, quantity to be transferred, source tank, and destination tank. This instruction sheet is then sent to the process operator for execution.

- The current quantity on the source tank is ascertained.
- The current quantity on the destination tank is ascertained.
- The new quantity on the source tank is ascertained.
- The new quantity on the destination tank is ascertained.

The quantities are all based on manual gauging, mass flow or tank monitoring systems. After completion, the shift supervisor creates and completes the transfer order (document type "IT") on ERP system.

4) DOI/Special Instructions

All blending (except drum mode) DOI are based on sales order. The DOI is issued for the safe and efficient operation of the blending & shipping unit, drumming, ISO-tank loading & discharging, ship loading &

discharging, tanks transfer, process units and other activities, such as equipment preparation for maintenance, special sampling, system flushing for the compatibility, and any non-conformance product or short weigh drum recovery.

View the process order list for specific process units and input the list, which needs to be executed, into the DCS system. The batch gets into production once the preceding batches are completed.

5) Inventory

Step 1: Tank Inventory is using PIMS.

Step 2: Drums, Solid bags, Tote bins and Drum warehouse storage, contain stuffing instructions, ISO inbound and outbound storage in the plant, are using the MMS for tracking the inventory.

Step 3: Track the invoice for plant movement & warehouse activities charges.

Step 4: Track the ISO tanks demurrage charges activities for payments in MMS.

Step 5: Track the drums product shelf life, rebrand name in MMS

For month-end closing inventory tracking
= tank opening – tank closing + incoming material
= monthly consumption.

6) Blending

The DOI is issued for the safe and efficient operation of the blending unit. Priority of the specific blend products order, destination of the vessel, batch numbers, quantity and date of the requirements before the plant execution, the blend program is downloaded into DCS for production.

The process steps and key component modules of the blend program are: a) ERP imports to blend program; b) Update product package mode; c) Blend demand; d) Upload blend calculation into DCS recipe.

There are nine masters maintained by the blend program: Destination such as vessel/blend tank; Key metal; Component; Component source; Component key metal; Product package; Product ERP instructions; Product blend instructions; Product component.

The product master maintenance screen is organized at two levels. The first level is the header where the product parameters are entered once for each product (Product master). The second level is a combination of three sections: one that maintains multiple components for each product (Product Component master), another that maintains multiple ERP instructions for each product (Product ERP Instructions) and the third that maintains the blend instructions for each product (Product Blend Instructions master).

7) KPI's Dashboards

Fig. 11 is one screen of KPI's Dashboards. Measurement of the daily, weekly, and monthly production unit performance can be shown.

Planned & unplanned equipment's down times attribute to the production delay, and measure the plants overall equipments availability, performance and quality. Production planner sees the alerts on his dashboard and drills down for the root causes.

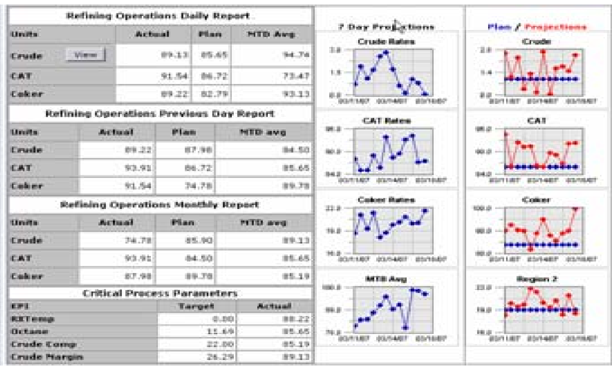

Figure 11. One screen of MII KPI's Dashboard

J. Tactical Benefits the MII Solution has Made for CO

After xMII solution is applied into the chemical company, the tactical benefits below are made.

- Reduced manufacturing costs 3-5% through the enhanced manufacturing process monitoring and the increased visibility.
- Increase plant efficiencies 15-20% through manufacturing processes optimization and its integration with the enterprise.
- Increase production yields 5-8% through proactive monitoring of manufacturing events.
- Reduced maintenance costs 8-10% through streamlined maintenance processes and alignment with manufacturing metrics.
- Reduced asset capital investments 6-12% through the improved asset performance and the greater asset reliability.
- Reduce inventory 8-15% through streamlining lean process enablement and reducing execution variability.
- Reduced premium freight costs 10-15% through manufacturing events integration with the enterprise and supply chain.
- Increased value chain agility and customer responsiveness. Complete value chain integration and visibility.

IV. Conclusions

The paper describes the successful story of real-time MII solution applied in one global chemical company. The solution can be applied to the similar process industries, like pulp & paper, petroleum etc.

At the same time, the paper also shows many challenges to academic experts. For example, by combining of traditional mathematic method and the latest intelligent method, how to model, analyze, and then optimize the manufacturing operation on different level, to persuade for manufacturing intelligence on different level, different areas, and different ranges? Then, more and more margins and profits can be made, social and economic benefits can be achieved.

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