Productivity Improvement in Downstream EPC Projects using Value Streams based Organization

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Abstract

Productivity improvements in manufacturing facilities have been studied in detail and there are many standardized tools and frameworks readily available to the industry for implementation. However the concept of productivity improvement in large engineering projects that involve high white-collar job content is less clearly understood. While lean concepts like value streams or continuous improvement apply to this environment there are no ready tools available for implementing a lean improvement initiative. This thesis applies lean and concurrent engineering concepts to large scale engineering design and development projects.

ABB Lummus, the sponsor company for the internship behind this thesis, is in the business of executing such large-scale projects. Lummus is an EPC contractor providing engineering, procurement and construction (EPC) services for building manufacturing plants. EPC projects run for few years and involve coördination of efforts by hundreds of engineering staff. There are inherently many productivity and information flow issues in such projects.

EPC industry in general has been facing significant operational efficiency difficulties leading to cost and schedule overruns in recent years. The main issue was identified as rework due to the fact that the existing project structures do not deal with concurrent engineering nature of the projects. In this thesis we leverage the concepts a combination of lean value streams, Design Structure Matrix (DSM) and Theory of Constraints (TOC) to propose a value streams based organization for EPC projects. We show how this approach addresses the common problem in the EPC projects and sets the stage for improving productivity. The discussion in this thesis has helped launch an initiative that has enabled the acceptance of value streams and DSM techniques at ABB Lummus. Currently a dedicated program is planning a large (> 1 Bn Euro) EPC project along the line of value streams.

The following are the key contributions in this thesis: From first principles we define a way to decompose an EPC downstream project into nine value streams. We use DSM to analyze a key value stream in detail and show the need for a value-stream-based organization. Using value streams and DSM we enable the implementation of TOC planning in EPC projects and show how these tools complement each other.

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1 Thesis Overview

1.1 Subject of study

At a conceptual level the core challenge in managing an EPC project is to co-ordinate timely generation and orderly flow of information between the various engineering, procurement and construction groups (chapter 2.) EPC industry over the decades has well defined procedures and processes to facilitate this information flow. However in recent years this information flow has been disrupted due to many significant changes in the industry, the key ones being dramatic increase in client power and globally distributed execution (chapter 3). The biggest effect of these changes is project schedules have shortened while the scope of activities has increased notably in areas of safety requirements and information systems handover to clients. As a result, activities that were finish-to-start in traditional CPM/ PERT relationships have become highly overlapped. The root cause of the problem of declining productivity in EPC projects is the inability to properly manage the issues that arise from concurrent engineering.

Concurrent engineering has led to difficulties in ensuring orderly and timely flow of information between engineering, procurement, vendors and construction teams. This thesis deals with ways to address this problem using a combination of techniques based on value streams concept from lean thinking, Design Structure matrix tool (DSM) to address concurrent engineering information flow and Theory of constraints (TOC) methodology for managing projects.

The key contributions in this thesis are as follows:

1) Using value streams first principles identify value streams in downstream EPC projects
2) Using DSM as a alternative way to map value stream information flow in EPC value streams
3) Using value stream and DSM as a tool to enable TOC implementation in large EPC projects.

The basis of this thesis is a six and half month internship with ABB Lummus. The author has worked as part of teams at The Hague and Houston offices of ABB Lummus that focused on improving productivity in EPC projects. The thesis is a summary of conceptual thinking and implementation efforts that happened in ABB Lummus during the internship period.

EPC projects typically span over 2-3 years and new projects takes years to materialize. Given the timeframe of the internship we were not able to fully observe a lifecycle implementation of these concepts. However we cover the phases of concept generation, value stream definition and discuss the challenges preparing a conservative industry like EPC for lean implementation. The internal initiatives launched as a result of discussions in this thesis have a horizon of 1-2 years for complete execution. We would use data from the design and planning stage and include some lessons during early implementation.

We also analyze an important value stream (isometrics preparation) using the DSM technique and analyze its results. Through the DSM analysis we demonstrated the need for value streams based project organization and show that this approach complements the TOC based project management methodology.

1.2 Thesis Structure

The thesis can be thought of in broadly four parts – providing the context to the problem, literature survey of project productivity concepts, application of concepts to EPC projects and observations from early implementation stages. In this thesis we spend much of our time in creating the required stability conditions for applying lean productivity concepts to EPC petrochemical projects. We address the issue of creating a systems wide view using value streams, TOC and DSM and assessing the impact on organization in EPC projects. The thesis proceeds as follows:

Chapter 2 Introduction to EPC Industry and Downstream EPC Projects, introduces the basic background information that is necessary to follow the rest of the discussion. It briefly goes over the key phases of EPC projects, team structure and composition, project schedules and typical project organization.

Chapter 3 Industry Trends and Productivity issues in EPC projects, discusses the significant problems caused by general industry trends that has led to decline in productivity. It also goes over key issues at ABB Lummus that formed the basis of this internship study.

Chapter 4 Literature Survey on improving productivity in Projects, briefly discusses existing work that addressed the problem of productivity in manufacturing, product development and concurrent engineering contexts. It also highlights issues that are involved in applying these concepts to EPC projects.

Chapter 5 Identifying Value Streams in EPC projects, discusses the challenges involved in applying concepts and outlines the methodology used to define value streams. It also lists the nine key value streams identified in downstream EPC projects as a result of the exercise. 4

Chapter 6 DSM Analysis of Isometrics Value stream, goes in detail about the methodology used and end results of a DSM study on a key EPC value stream. It displays the results from DSM analysis and internal interviews in a causal analysis map that traces the key causes of rework in EPC projects.

Chapter 7 Facilitating TOC implementation Using Value streams and DSM, discusses the implementation challenges of Theory of Constraints (TOC) in EPC Projects. It highlights how value streams and DSM approach completed TOC concepts during implementation.

Chapter 8 Value streams based EPC project Organization, proposes a new approach to organizing projects that will resolve many of the existing productivity problems. It discusses the impact of this approach to EPC project organization structure and the adaptations needed to existing processes to facilitate the change. It discusses the current status of the value stream implementation and goes over the key leadership challenges faced in making a case for change.

The discussion throughout this thesis is summarized in **Chapter 9**.

2 Introduction to EPC Industry and Downstream EPC Projects

In this chapter we provide quick overview of necessary background information on organization and structure of EPC projects. This will help us appreciate the issues that were dealt during the internship behind this thesis. Note that this is not a comprehensive coverage of the topic. We just provide enough information to follow the rest of the discussion intelligibly.

2.1 Introduction to EPC Industry

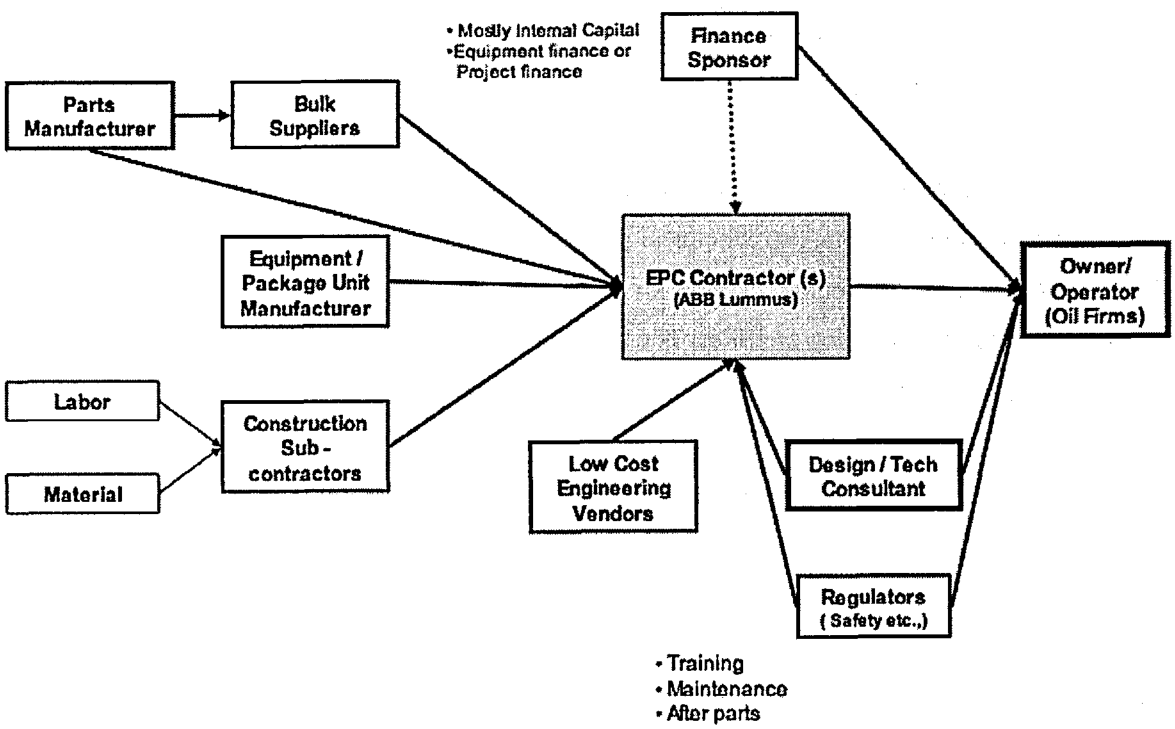
The term EPC industry refers general contractors who undertake large construction and engineering projects on behalf of their clients. EPC industry is quite broad and covers a wide range of facilities from large scale infrastructure projects like power plants, railway systems to construction projects like roads, tunnels etc., There is a separate sub-sector in EPC (EPC Oil & Gas Industry) that focuses on industrial projects like offshore platforms, chemical plants, petroleum refineries etc., EPC in industrial sector is a highly technology intensive business and is typically dominated specialized engineering firms that have over time built the necessary technology and design expertise.

ABB Lummus, the sponsor of internship behind this thesis, is an EPC contractor specializing in building downstream petrochemical plants. Petrochemical plants are broadly classified into upstream, midstream and downstream projects. Upstream otherwise known as exploration and production (E&P) business deals with oil and natural gas production facilities. The midstream industry deals with processing, storage and transportation. Downstream includes retail and distribution firms and also oil refineries and petrochemical plants that deal with producing various end products (from gasoline to fertilizers, pharmaceuticals, industrial chemicals etc.,). For the rest of our discussion we restrict our scope to EPC petrochemical downstream projects.

There are many business models for delivering EPC projects. At either end of the spectrum are lump-sum turnkey projects and reimbursable service contracts. In lump sum turnkey (LSTK) projects client gives the entire contract to a EPC firm(s) and expect handover of a fully commissioned and working facility. The contractor bids a flat contractual amount for the project and assumes all the execution risks. Any savings below the bid amount is profit for the EPC contractor who also has to bear fully any cost overruns. There are also penalties if firm delivery schedule commitments are not met. The contractor has to pay the clients liquidated damages to cover any business opportunity costs that arise due to delays. In return for taking all the risks the contractor gets a much higher premium than reimbursable contracts. In reimbursable contracts the client assumes all these risks and pays on an hourly basis for utilizing the expertise of the EPC contractor. In such projects engineering hours typically involve much higher premiums as compared to Procurement and construction hours. *To summarize, in lump sum turnkey projects EPC contractors get paid for managing the risks while in reimbursable contracts they gets paid for hiring out functional expertise.* The recent trend in the industry is toward reimbursable contracts with incentives and penalties similar to LSTK contracts, but without the overall risk transfer. This is due to the excess demand for oil and gas facilities that has temporarily increased the power of EPC contractors. Once the market cools off again we will probably return to a buyers market again and to LSTK contracts.

For our thesis discussion we focus only on lump-sum turnkey projects. Construction of industrialized facilities involves a specialized supply chain where EPC contractor acts as the channel co-coordinator. Figure 2.1 shows the typical players involved in the EPC industry value chain.

Figure 2-1 EPC industry value chain



2.2 ABB Lummus Global – A Short History

ABB Lummus Global is a leading international EPC firm with annual revenues of more than 1 billion USD. ABB Lummus Global is divided into two main business groups – The Global technology division that specializes in developing and acquiring process technologies and Downstream EPC business. The current company is a combination of 3 entities - The Lummus Company (1989), Crest Engineering (1984) and Global Technologies (1995). ABB acquired Lummus Crest in 1989. The core of the company Lummus has a 100-year history and founded by Walter E. Lummus in 1907 in Everett, Massachusetts.

The core of the downstream EPC business is the Lummus Company. As is the common practice during the time Lummus was founded based on the process design technology invention of its founders. Lummus was a leading EPC contractor during the EPC industry boom in the 70's and 80's. During the peak Lummus alone had employee base of 8000 people worldwide. In 2004 ABB Lummus Global had approximately 3000 staff with offices around the world with offices covering North America, Europe, Asia and Middle East. Each office operates as a separate business prospecting projects within their geographic area. The Hague and Houston, the two biggest offices of ABB Lummus, are the joint sponsors for this internship.

The main rationale for the Lummus acquisition by ABB is to find synergies between its industrial equipment manufacturing and the EPC business (vertical integration along the EPC industry value chain shown in figure 2.1). However the assumed synergies never materialized fully. This was partly due to quality and cost constraints of ABB engineering and imposition of preferred vendor list by EPC. ABB's planned divestment of ABB Lummus Global has been delayed as the business got hit severely by asbestos claims. ABB incurred heavy losses in late 90's and sold off its structured project finance business partly to finance the asbestos claims.

In line with the downward trend in EPC industry (section 3.1), ABB Lummus has been losing money last few years in some high profile and risky projects. ABB has divested its acquisitions in the Upstream EPC business, exited many industrial EPC sectors and reduced business scope to downstream petrochemical plants and exited power plants. In the last year EPC petrochemicals sector is going through a major expansion with the investment spurred by high oil prices. Taking advantage of the industry upswing ABB Lummus Global current priority is to improve its operational performance so as to rebuild a healthy EPC business.

2.3 Brief Overview of EPC petrochemical projects

A green-field lump-sum turnkey EPC downstream project is typically a multi-billion dollar endeavor spread over 24-36 months. As shown in Fig 2.1 the projects involve a host of players from process technology firms, equipment manufacturers to construction sub-contractors. We here look at the key

stages of an EPC project from the point of view of the EPC contractor, who is the overall coordinator of the entire project.
At the highest-level EPC project can be thought of as involving four stages: Basic design and definition, Detailed Engineering, Procurement and Construction. We briefly discuss these four stages below.

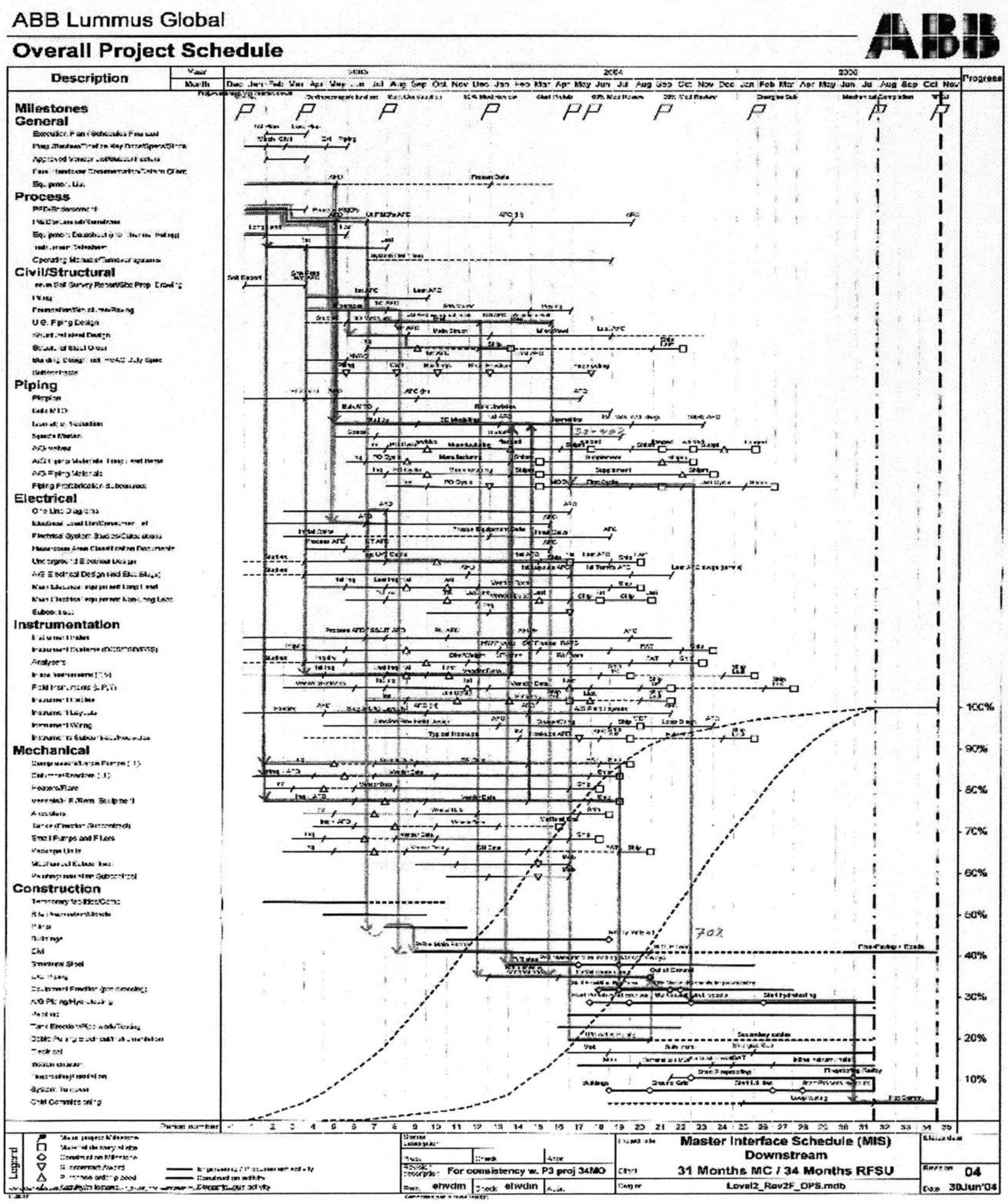
Basic Design: Basic design is the high-level process definition and plant specification that translates client needs to a design specification that can be used by EPC contractors. The key component of this stage is to provide the chemical processing technology that will be used in the manufacturing process. In addition this phase also lays out other high level engineering parameters including key equipment specification, overall plant layout, utilities specification etc., Overall thumb-rule is that this phase includes 20-25% cost estimate for the plant with 80% accuracy. The detail of information varies by engineering discipline. For instance 60% of process engineering is complete at this stage while very little plant design or Instrumentation details might be available.

Industry majors use different terminology for this phase. Commonly used terms are the BDEP (Basic Design and Engineering Phase) and the FEED (Front end engineering design). The exact deliverables and boundary definitions are vague and change on a project basis. But the intention of this phase is to provide all information that is necessary for an EPC contractor to evaluate and estimate the cost and efforts required to build the plant Usually the owners engage a specialist process technology specialist to define this phase and then bid the project out to EPC contractors. In some cases the entire project including BDEP can be awarded to a single contractor. This stage requires higher level of engineering expertise and is typically done in the western offices of EPC contractors.

Detailed Engineering: This involves finishing all the details in the design to precisely specify all areas of the plant like process and mechanical work, detailed pipe, instruments and electrical drawings, control systems, safety instructions etc., Detailed engineering is supposed to provide enough definition to be able to procure and construct the facility. Engineering is further broken down into following specializations:

- Process: Defines the overall chemical process and process parameters. Lays down the boundary for other disciplines.
- Piping and stress support: Also called as plant design involves the largest engineering man-hours and does the detailed design for transferring materials and chemicals in the plant.
- Mechanical: Defines all equipment requirements that are used by procurement.
- Civil / Structural: Defines the foundations and structural support elements of the plant.
- Instrumentation & Electrical (I&E): Defines all wiring, control values, control systems etc.,

Figure 2-2 Level 2 schedule of a typical EPC lump-sum turnkey Project



Procurement: This is typically the phase with longest lead-time in EPC projects. The early engineering designs are used to create a Request for Information (RFI) to prospective vendors. The RFI is used to gather price estimates and also design suggestions and alternatives that provide more state of the industry inputs to the engineers. The RFI is then used to prepare a detailed RFQ (request for quotes) that specifies all the engineering requirements, provides detailed quantity break-ups and also delivery & schedule requirements. Based on review of responses from short listed vendors, final purchase orders are drawn out. The entire process from RFI- RFQ – PO is highly iterative and can involve many months for key equipments.

The procurement for EPC projects can be categorized broadly into two broad categories:

Long lead equipments and modules: These are custom engineered components that have high engineering content. The main challenge here is to balance the need for favorable commercial terms with the timely flow of accurate engineering information between internal and vendor engineers. Some modules like Package units and vendor-designed equipments only require minimum system interface information from internal engineers and the entire detailed engineering design is outsourced.

- Bulk buys: These are materials are needed in mass quantities in projects like off the shelf engineering items like valves, pipes etc., and consumables like nails, adhesives, painting materials etc., The biggest challenge here is to cope with the engineering changes which can lead to large shifts in quantities required. This results in excess materials, which leads to cost overruns, and site shortages that can delay construction schedule.

Construction: Though it is the most visible phase of a EPC project, construction as we discuss in chapter 5 is the end consumer of the information and materials generated by engineering and procurement. This is the phase that puts together the engineering drawings and materials to bring the plant into reality. Figure 5.2 shows the construction sequence. A building of EPC project can be conceptually thought of as a sequence that involves site preparation, underground systems and foundation, equipment erection, installation of structural support and auxiliary systems like control, electrical, piping etc.,

In a typical EPC project engineering will represent about 15%, procurement between 40-50% and construction 35-45% of the overall project cost.

2.4 Typical Execution Sequence in EPC projects

The general flow of information between the various phases in a EPC project is as follows: Basic Design → Detailed Engineering → RFI → RFQ → PO → Construction. Between the engineering departments information can be roughly thought of as flowing from Process to Mechanical and then to Civil/ Structural, Piping and I & E. However this is only a general direction. In practice all these disciplines are highly interdependent and information flows back and forth as we will see in the discussion in subsequent chapters.

But in practice due to shorter schedules these activities are highly overlapped. A typical downstream EPC schedule at ABB Lummus is in Fig 2.2 and it shows in a Gantt chart the extent of overlap across various engineering disciplines. The lines in color identify the four key critical paths in a project. The blue line represents the long Lead items & critical equipment to provide work-front for mechanical subcontractor (nozzle avail). The red line represents the isometrics work stream (discussed in chapter) to create work-front for the piping subcontractor. The green line highlights the underground / out-of-ground work stream and yellow the pipe racks assembly spanning nozzle availability & isometrics work streams (Figure 5.3).

The schedule overlap occurs in two main ways. The first commonly accepted way is to overlap activities across different areas of a plant. One section of a plant might be in PO phase while another independent area can still be in detailed design phase. The second and more problematic type of overlap is between activities in the same work area of a plant. For instance the detailed engineering is started even while the basic design details are still being worked out. This overlap creates many problems as discussed in section 4.4 and is the core issue identified and addressed by the DSM analysis.

2.5 Project Organization structure

A typical organizational chart in a EPC project is shown in figure 2.4. We discuss the key project roles below. In section 8.2 we will later look at the ways in which some of these roles are redefined by value stream based project organization.

The project director/ manger (PM) is the executive who runs EPC projects and is ultimately responsible its profitability. As shown in Fig 2.3 supporting the PM is a host of supporting managers from each function. The engineering teams are organized along discipline lines (section 2.3) and there is a lead engineer for each discipline. Project Engineer is a staff role that assists the project director in co-

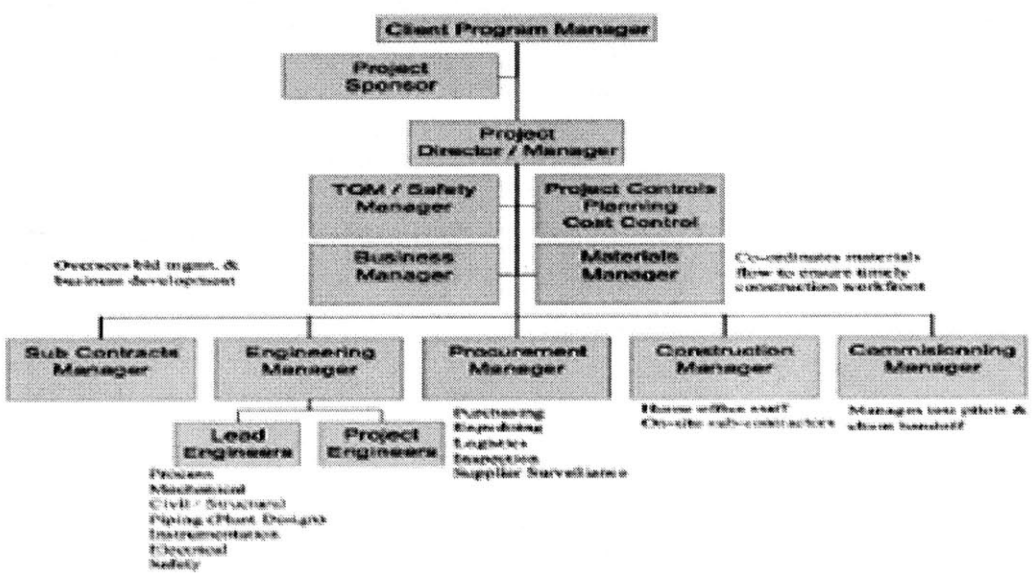
coordinating across functional groups and focus on ad-hoc troubleshooting issues as they arise in project. Typically project engineers are seasoned engineering leads and report either directly to the PM or to engineering managers.

The procurement manager leads a team of specialized experts who handle all supply chain related aspects like buying, vendor surveillance, logistics handling, onsite inspection etc., A construction director or manager heads construction and he/she reports loosely to the project director. Onsite construction work is semi-autonomous as the skills involved are very different from home office engineering and procurement work. Most construction work is typically outsourced to sub-contractors. The project mangers are all-powerful within a project, but in reality they have to deal with a matrix of organizational managers as discussed in section 2.6.

In addition to the key functional disciplines, host of other functions helps the PM to manage his project smoothly. We will be discussing about two of these functions in later - the project controls group and planning. Project controls measures project progress with respect to schedule, cost and materials and generate reports for management. Planning department develops project plans and schedules and creates a work breakdown structure based on project requirements. Other support functions include materials management, Project IT, Quality group/ TQM.

There are other groups like estimation, business development and contracts management that are heavily involved in the front-end project bid and award phase of the project.

Figure 2-3 Typical EPC Project Organization Chart



Task forces: In large projects to expedite execution in certain areas, PMs often form cross-functional operational units called as task forces. This environment brings together engineers from multiple disciplines, procurement and any other functions required to focus and solve a particular problem for the project. Teams are usually co-located in a single work area and are cut away from their departments both literally and figuratively. In this environment project becomes the main focus and functional procedures take a back seat. Task forces are a preferred way for project managers to get things done and are disliked by functional departments as it disrupts their normal functioning.

2.6 Matrix structure in EPC projects

A project has multiple functions and a firm does multiple projects at any time. So there is a matrix structure where project mangers share power with functional mangers. All personnel in the project finally report to the project manager in the context of the project. But the functional departments loan personnel to the projects and take care of personnel review and professional development. The situation, while unavoidable, creates strong conflicts when the incentives of project and functional managers are not fully aligned.

This matrix structure creates an inherent tension to balance the execution priorities and effectiveness of the project manger with emphasis on checks and balances and process quality control by functional departments. The problem is made worse by setting conflicting performance measures (section 3.2). In projects where all tasks are interdependent across functions, the matrix structure creates a complicated network where no one is accountable or responsible for ensuring high productivity. This becomes worse in a concurrent engineering environment as discussed in later chapters.

The centre of control between projects and functional departments vary across firms depending on the internal culture. This balance also oscillates over time with power shifting back and forth based on the stage in business cycle. If the firm had faced a string of losses from risky projects emphasis of control swings to functional safeguards and procedures. While in rapid expansionary phases of the business cycle the emphasis is on getting the jobs done and project management becomes more powerful.

This organizational structure has existed in EPC business for decades and the delicate balance has worked reasonably well in past. But it breaks down drastically in the new industry realities as discussed in trends and chapter 3. Organization determines behavior and as we shall discuss in chapter 8 this is one of the core issues in implementing lean productivity tools.

3 Industry Trends and Productivity issues in EPC projects

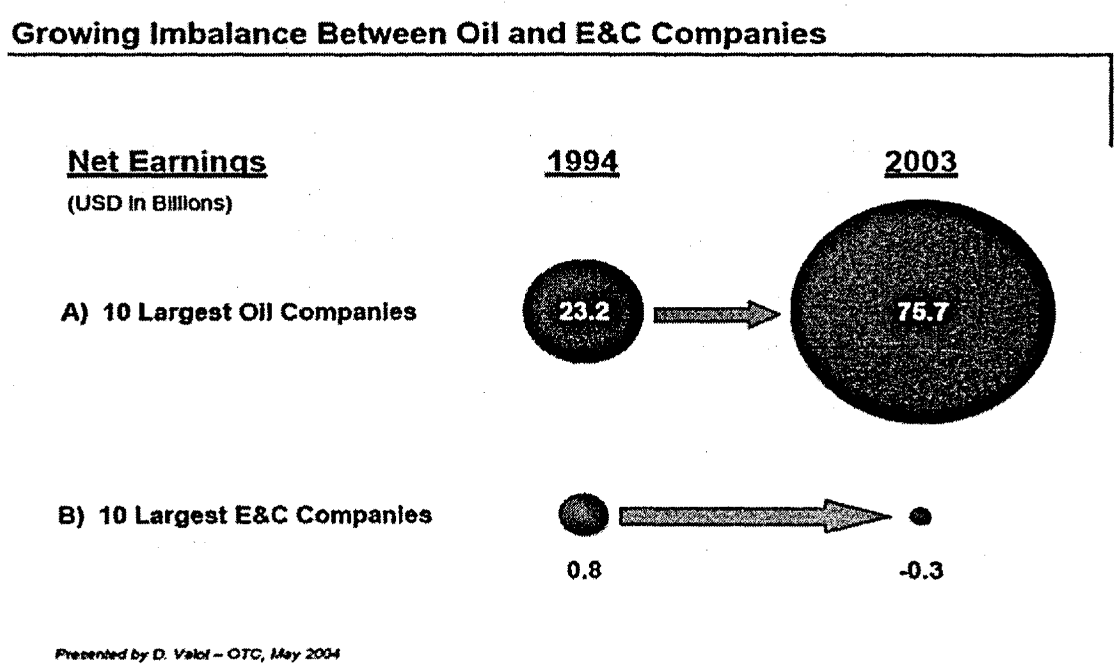
In this chapter we outline the commonly encountered productivity issues and their causes. This will help us set the stage for the discussion on operational productivity tools. Also towards the end of this chapter we discuss the problem definition for internship and hence the basis for this thesis.

3.1 Key Trends in petrochemicals EPC industry

The organization and structure of EPC projects has remained fairly constant over last few decades. However the external industry forces have changed drastically in the last decade leading to a mismatch in external environment and internal project organization. We discuss below some of the key shifts that have an impact on project productivity issues.

Shift in client power: EPC industry has become commoditized with large number of low cost players in developing markets. This has let to severe squeeze on margins, reduction in schedule time despite the increasing complexity of projects (discussed below). One of the key factors behind this trend is the lack of significant process or technology innovation in EPC industry over the last few decades. (Repenning and Sterman 2001)

Figure 3-1 Profitability Trends for EPC Oil and Gas contractors and their clients



Source: Presentation by Mr. Daniel Valot, Chairman and CEO Technip. Presented at Offshore Technology Conference in May 2004.

The fundamental shift of power in the industry from EPC contractors to their clients is clearly illustrated in the pie chart in Figure 3-1. As a result of these changes EPC Industry in the west has undergone severe consolidation and liquidations during past couple of downturn cycles. Also this total capture of value generated by clients creates fewer incentives for EPC contractors to invest in improving their productivity. Any new gains in productivity will be passed on over as lower price to clients rather than improve the bottom-line of the contractors.

Increased Globalization and Resultant Fragmentation: EPC projects have been increasingly global in two fundamental ways.

1. A majority of the projects are commissioned outside the western economies due to shift in the geographical profile of petrochemical investments increasing co-ordination complexity and
2. Partly due to the increased global execution and also due to cost pressures the projects increasingly involve outsourcing to low cost sub-contractors around the world. This has also led to fragmentation of engineering and procurement activities are spread between multiple contracting firms in projects.

Increasing project complexity: The petrochemical plants have become much bigger both in scale and also in the scope (specifically in areas like safety and client handover requirements). This leads to some new coordination challenges that might not be effectively dealt by existing structures.

Increasing IT complexity: EPC projects are all about how information is generated and communicated. IT tools from auto-simulators to 3D designs has fundamentally altered work in this industry so much so that many seasoned engineers retired from the industry in the 90's rather than cope with change. The effect of IT on project organization and productivity is not yet fully appreciated. *Rather than increase productivity, IT has led to overall declining in project performance for following reasons:*

- IT has led to a subtle but significant behavioral change where both clients and engineers make more frequent design modifications as computational cost of change has been greatly reduced. This leads to rework which saps productivity. IT also has led to loss of some work practices that formed the hidden glue in project co-ordination.
- The meaning of project deliverables has changed significantly while project procedures have not changed. For instance a major project deliverable P&ID[1] used to be physical documents finished by process department. With IT this document is no more than a report from a database where multiple

[1] Process and Instrumentation Diagram

engineering groups input information. Failure to recognize the impact of IT on work processes has complicated progress monitoring and control.

- The standards and software tools for these IT applications are also changing continuously. In an industry where projects take 2-3 years this almost means adjusting to new IT tools and practices every 1-2 projects! Also the tools have not yet matured to fully deliver on the productivity promises that made the EPC industry move to widespread IT adoption.

3.2 Common management issues in EPC Projects

- Concurrent engineering: EPC projects typically used to take 36 months to complete. In recent years clients have been demanding and getting as low as 24-month commitment from EPC contractors. However the project scope has increased while the promised productivity from IT tools have not materialized. To compress the schedules when the task durations have not reduced much, the finish-to-start relationships in project plans have broken down and tasks have become increasingly overlapped. This concurrent engineering has had a significant impact on information flows and coordination issues as discussed in chapter 6.

- Traditional coordination mechanisms no longer sufficient: The current approach to EPC projects is to have predominantly functional focus, leaving coordination to few managers. This worked well in an environment where the tasks were fairly sequential, teams were geographically co-located and there were strong interpersonal relationships between team members who often had worked together in multiple projects in the past. However this structure is not able to cope up with new changes like concurrent engineering, fragmented global execution and outsourcing. This leads to increased coordination issues where issues bubble up only at the last minute leading to costly trade-offs and adjustments.

- EPC industry structure creates wrong incentives: As we discussed in 2.3 procurement and construction represents over 80% of project cost. However from an EPC contractor point of view procurement and construction costs are pass-through expenses from client to contractors. Even in a lump sum turnkey contracts during negotiations the clients seem ready to compensate EPC contractor for their direct engineering expenses and keep tight tab on procurement and construction costs. As a result both EPC contractors and their clients mistakenly place disproportionate emphasis on controlling engineering costs (as represented by total engineering man-hours spent). However around 80% of the project cost is influenced in Engineering phase. If no proper definition is done there, the entire project is at risk. The focus should be do control the quality of engineering work so as to control risk on the project. However trying to minimize expenditure on engineering leads to sub-optimizations that create excessive cost and schedule overruns on construction and procurement phases.

- Functional focus further skews behavior with man-hour focus: The problem of excessive focus on man-hours gets further worse with the functional focus and organization of EPC projects. The project level manpower budgets get pushed down as department level budgets. As discussed in 4.1 the focus on individual functions rather than overall end result leads to sub-optimizations that have adverse affect on rest of the project. This manifests in two ways

    1. This leads to less cooperation between functions. For instance to meet the process budget a lead engineer might not allow for enough time on review cycles leading to delayed discovery of problems leading to a exponential increase in the cost of defect to the project
    2. Creates false sense of progress and hides problems. Most project deliverables are result of iterative collaboration between multiple functional disciplines. So to save on man-hours a process engineer might finish his deliverable on time but spends less time on details. The issues only surface subsequent engineering disciplines encounter difficulties and then more time has to spent on rework and clarifications thus degrading overall project performance.

- Unrealistic initial budgets: Declining pricing power both due to industry trends and poor performance of contractors means that most EPC projects start with schedule and cost targets that are inherently unattainable. This environment has an exceptionally harmful behavioral pattern leading to breakdown of execution discipline. Teams do not take their commitments seriously as they know that budgets will slip and managers knowing that teams will overshoot set even restrictive budgets leading to a downward spiral.

In addition to above problems EPC projects also face other standard issues that are typical to projects like the 90% syndrome, improvement syndrome etc. These are discussed further in section 4.1

3.2.1 Larger issues affecting project performance

The problems described above have been addressed one way or the other in the value streams based organization approach discussed in chapter 8. The problems discussed below are issues that have significant impact on project performance and hence their productivity. However these were bigger organizational issues that were beyond the scope of our discussion. We nevertheless mention them here, as they are significant issues in the EPC industry.

- Emphasis on full manpower utilization: Since EPC is a low margin, manpower intensive business the only way to improve bottom-line is to have close to full utilization of resources. So the department managers are under constant pressure to keep their staff fully occupied on projects. However projects are evaluated on man-hour utilization so they want to utilize the staff to the minimum extent possible. This works well when business is operating close to capacity. However during downturns this creates adversarial relationship over artificial currency of man-hours. Departments push people to projects whereas projects push back to avoid excess charges. Engineers also get skewed incentives to take more time for their tasks, as they are afraid of potential lay-offs leading to productivity decreases in projects. This problem is less felt in European countries with tougher labor laws and more so in US offices. There is a need to recognize and plan for certain amount of slack in manpower planning.

- Managing the risk profile of projects: There are certain key factors that set the outer envelope for project profitability no matter how well a project is organized or executed. For instance a project with adversarial client, unrealistic budgets, unfamiliar technology / geography or inexperienced team carries a higher risk for failure from the very beginning. An EPC contractor as discussed in 2.1 gets paid for managing the risks rather than on his engineering or procurement efficiency.

  While the thesis focuses on project productivity using value streams and lean, experience in EPC industry shows that the biggest determinant of project success depends on the quality of a project bid. Classifying and understand risks early in project phase is an interesting line of study in itself. Appendix A discusses a framework developed to assess project risk and hence its expected profitability based on bid conditions.

3.3 Internship Problem definition

Many of the issues discussed above have been encountered in EPC projects at ABB Lummus and manifests itself as two main symptoms: Schedule slippage and Budget overrun. To avoid the excessive liquidated damages (that can run to millions per day) project schedules are usually met, with last minute firefighting thus eroding the margins. The internship scope was defined as finding ways to productivity improvement using lean principles in order to improve operational effectiveness so as to avoid cost overruns.

Initial discussions and internal interviews with management identified following issues as the major problems.

- Rework: Concurrent engineering leads to starting tasks with partial information. In many cases this partial information from early deliverables change as the tasks evolve and this causes all subsequent tasks to be fully or substantially redone.
- Sub-optimization: A key concern was to take a system wide approach to productivity so as to avoid optimizing one function at the detriment of others.
- Lack of clear accountability and responsibility: When each deliverable is intertwined across disciplines delays or overruns cannot be accurately pinpointed to any function or person consistently. As a result though everyone in the project knows that schedule slippages or cost overruns are happening the middle level operational managers cannot act on them. By the time it gets escalated to project management things are in firefighting mode anyway leading to sub-optimal decisions.

To address these issues the internship focused on 1) using lean and value streams to take system level approach to productivity improvement 2) using DSM approach to analyzing information flow in concurrent engineering setup. The company had initiated Theory of constraints implementation to handle the schedule overruns issue. In the rest of the thesis we discuss the interplay between these concepts and adapting them for implementation in lump-sum turnkey EPC downstream petrochemical projects.

4 Literature Survey on improving productivity in Projects

In this chapter we briefly go over the concepts related to productivity improvement, concurrent engineering and project management. We first discuss lean principles, which is a dominant productivity improvement methodology. Within lean we focus on Value streams, which is the first step in lean implementation. We then look at Theory of constraints (TOC), which extends lean concepts to project management. Since the core issue in our EPC projects is caused by concurrent engineering issue we explore Design Structure Matrix, which is a powerful way to analyze information flow in iterative development processes. We briefly outline the concepts in each area, highlight some past studies that have explored this topic and discuss ways to adapt these principles to EPC projects.

4.1 Common issues in concurrent development projects

Many of the problems encountered in concurrent development and project management have been extensively studied in academic literature. We here briefly mention some papers that substantiate the observations in 3.2 on the common problems faced by EPC projects.

Backhouse and Brookes (1996) suggests implementation in concurrent development fails often due to mismatches among people, control, tools, processes and structure and the organization's need for efficiency and focus. We see these issues in the conflicts between project and functional managers in the matrix structure described in 2.6. They further add that mismatch between the technical organizational and dynamic complexity of the process and the mental models of managers responsible for them lead to in appropriate organizational structures, policies and decisions. As we discuss in chapter 5, DSM techniques provides a powerful way for managers see through the complexity and develop new perspectives that are invaluable in managing concurrent engineering projects.

Sterman (2000) analyzes an EPC project for a paper mill using systems dynamics models. The model discusses how pressure to show progress leads to behavioral patterns like out of sequence work and generates rework. Ford and Sterman [5, 6] discuss the 90% syndrome where a project appears to be on schedule for 90% of its planned time and then it stalls, finally finishing after about twice the originally projected duration. They argue that shortsighted management policies, like emphasis on engineering man-hours, shift development focus and conceal rework requirements. While this leads to temporary improvement in apparent performance it actually pushes the burden of and responsibility for change discovery away from the individual phases towards end of the project. We see these patterns repeatedly in EPC projects.

Repenning et al (2001) discuss models that help understand why firefighting, unplanned allocation of resources to fix problems discovered late in project cycle, arise consistently in multi-project development environments. They show how when managers try to "stretch" resources to do little more in short run end up pushing the systems over the tipping point. This leads to downward spiral of decreasing attention to up-front tasks and increasing problems in downstream projects. We see this fallacy of full capacity utilization consistently repeated in EPC industry as discussion in section 3.2.1.

While the literature is full of insights that identify and give solutions for the problems rampant in EPC projects it is very difficult organizational to translate them into action. Repenning and Sterman (2001) calls this gap between availability of proven solutions and inability of managers to implement them the "improvement paradox". They suggest that this inability is not due to the specific improvement tool but to the physical and psychological structures in which the new improvement program is introduced. We discuss this need for stability conditions and the prerequisite leadership structure required in chapter 8.

4.2 Lean approach to productivity improvement

The internship scope definition stated lean as the preferred productivity methodology. So we start by understanding key concepts of lean and how they can be applied to EPC project management.

Lean thinking at its core has five dominant principles – focus on creating end customer value (1), by eliminating waste (2), through continuous improvement (3), driven by process knowledge (4), by all levels in the organization (5). Other key concepts of lean include flow (seamless movement of materials / information through value creating steps) and pull (driving activities based on customer needs rather than pushing products to market) and value streams (discussed in next section). These core concepts were derived from the highly successful practices of the Toyota production system and since then evolved into a dominant manufacturing methodology with elaborate repertoire of tools and terminologies[2]. Driven by its success in improving manufacturing productivity the concept has since been extended to design and development process (Lean engineering) and to the entire organization and supply chain (Lean enterprise).

Lean requires system wide thinking and decentralized action. Hence implementing lean almost always involves huge organizational impact that needs a fundamental change in management mindset.

[2] For a good introduction to lean refer to "The Machine That Changed the World" by Womack et al (Harper Perennial, 1992) or "Lean Thinking" Womack and Jones (Simon & Schuster, 1996)

Transitioning to lean from conventional operational approach often is very difficult and involves significant organizational and process preparation called stability conditions.

Marchini (2004) studies the importance of lean enterprise in construction value system and the necessity of extending lean thinking in relationships between firms in the construction supply chain. Several industry efforts, including the Lean construction institute, are underway to adapt lean thinking and concepts to construction and EPC industry. In this thesis we focus on how to organize an EPC project along value stream lines and create an environment conducive for applying lean productivity principles.

4.2.1 Value streams - the first step in implementing Lean

Lean emphasizes systems thinking. Lean experts advocate the need for first "learning to see" the process as a whole before getting down to optimizing individual processes or process groups. Value stream mapping (VSM) helps achieve this by creating an end-to-end process map of material and information flow involved in producing a product or service to a client. By developing a high level conceptual view of the entire process, VSM helps focus productivity improvement efforts on the system level bottlenecks. Without this an improvement in one sub-process may not translate to a gain for the end consumer. Or worse it can lead to sub-optimizations that adversely affect another part of the system as we discussed in section 3.2. So most lean practitioners use value streams as the first step in lean process.

Value stream is defined as the set of activities that bring a product from conception to realization, order to delivery or raw material to finished good. The value stream analysis is aimed at eliminating waste and so enabling flow and creating processes that can react rapidly to meet customer pull. The first step in value stream mapping is to create a current state of process that maps the material and information flow and also capture various process information like lead times, inventory, capacity, availability etc., These measurements then serve as the basis for applying lean principles to develop a future-state map that results from implementing proposed process improvements. An important step in formulating a future state map is to classify the activities as value added (creating tangible end customer value), non-value added (necessary support activities) and waste (redundant activities that can be avoided with process redesign). VSM contains set of standard terminology, symbols and process improvement techniques. Rother and Shook (1999) provide tools that have been extensively used in factory floor mapping. Several efforts have extended lean from its manufacturing home base to other areas. Morgan (2004) and McManus (2002) discuss implementation of Value streams in product development in automotive and aerospace industries.

4.2.2 Adopting Lean and VS for EPC projects

In EPC project we could not directly apply standard lean tools like VSM current and future state maps for following reasons

1. Identifying VS in EPC projects is not easy as in other manufacturing or PD setting. Morgan (2002) used standard product development phase gates to demarcate end points for a value stream analysis in product development process in automotive industry. However as discussed in 5.1.1 existing mental maps or abstractions in EPC projects do not provide proper guidance in identifying Value streams. So much of the internship effort was devoted to identifying value streams from among the large complex web of activities in EPC projects.
2. EPC projects for most part involve information flow and as we show in 6.1 DSM is a better way to analyze value streams rather than traditional value stream maps.
3. Given current mindset of EPC organizations, lot of preparatory work needed to be done as discussed in chapter 8.

The thesis sets the stage for standardized value stream analysis by defining the value streams and providing proper organization structure around it. As discussed in 8.5, subsequent efforts at this firm will focus on implementing detailed VS map for the key value streams and implement lean tools for productivity improvement.

4.3 Theory of Constraints based project management

Theory of constraints (TOC) in general is about effective management of a system by managing its major constraints. TOC guides management focus towards getting maximum throughput from the constraints and eliminating the constraints wherever possible so as to extend system capacity. Originally developed by Eliyahu M. Goldrat, a business consultant, TOC is gaining wider acceptance as an effective project management tool. During the internship ABB Lummus had already initiated an effort to shift to TOC based project management in EPC Projects. In this section we briefly outline the key concepts of TOC based project management[3].

Traditional project tools like CPM or PERT does not allow for delays in tasks. However task delays are common in almost all projects. To avoid delays typically buffers are added to the estimation of task durations. However due to common behavioral patterns (like Student syndrome, Parkinson's law etc.,)

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[3] For detailed discussion on TOC see "Critical Chain" by Eliyahu M. Goldratt, *Great Barrington, MA North River Press* 1997

these tasks buffers are often wasted or used sub optimally. Another common behavioral problem is multi-tasking to show a semblance of progress across all projects that compete for a common resource. However if a resource shifts between tasks, all tasks are delayed in their completion, thereby reducing system throughput. In addition the resource capacity is potentially reduced due to setup costs associated with each transition. TOC aims to tackle such behavioral tasks by eliminating task buffers and aggregating them at the end of each network path in a project schedule. It also introduces a concept of resource buffer to give focus to bottleneck resources that are in critical path.

TOC has the following benefits:

1) It eliminates the behavioral delays at task level and encourages each team member to finish his / her task at the earliest possible time. In practice TOC plans reduce task durations by half and add the rest to the chain buffers. These chain buffers are called as project buffers (for critical chain path) or feeder buffers (for non-critical network path).
2) The feeder and project buffers are meant to absorb the variations in task duration. They are put under the control of appropriate operational manager who can take a system view of project and allocate the buffers optimally to tasks.
3) The utilization rate of these buffers is used as a forward-looking predictor of project performance. This is especially valuable, as most project metrics tends to be lagging indicators in reporting problems by which time the damage is already done.
4) TOC eliminates the tendency to multi-task by providing explicit way to prioritize resource allocation across projects. It introduces resource buffer concept that requires that constrained resources on critical path be undisturbed till their tasks are fully complete.
5) Based on the criticality of buffer in each network the resources in a project can be redeployed allowing uniform progress of entire project. In absence of TOC certain teams get things done well ahead of time whereas other tasks get delayed with a net result of overall project delay. This approach to resource management is called as resource buffers in TOC terminology.

TOC is not the only attempt at extending lean to Project management. Ballard (2004) and Lean construction institute advocates a methodology called the last planner system that gives the operational scheduler more autonomy in short term scheduling based on real time information.

TOC implementation requires a strict Finish – start network plan and calls for a new way to allocate project resources. Traditional measures of task level performance will also need to change, as tasks are expected to finish late more than half the time. Apart from these substantial behavioral and organizational challenges, TOC also faced practical network-planning issues in adapting to EPC projects. DSM and Value streams provided an excellent way to solve these issues as discussed in chapter 7.

4.4 Analyzing information flow using Design Structure Matrix (DSM)

The Design Structure Matrix (a.k.a Dependency system matrix) is a compact, intuitive and powerful method for analyzing the information flow and dependencies between various components in a system. DSM represents components of a system as rows and columns of an n-square matrix. The interaction (information exchange and / or dependency relationships) between the elements is shown in the cell at the intersection of corresponding row and column. The off-diagonal cells in the matrix indicate system interactions. DSM captures interactions between various system elements in a succinct way that visually brings out the various iterations (feedback loops) in the current state of system design. In addition DSM lends itself to mathematical analysis and there are many algorithmic tools like partitioning and tearing to improve system design so as to minimize backward information flow. Eppinger (2001) provides an excellent overview of DSM and its important role in streamlining innovation.

DSM representation is very flexible and can be used to analyze project activities, process parameters, system components or team organization. There are many variations of DSM depending on the type of system elements analyzed. Static DSM shows existing system elements simultaneously, such as components of product architecture or groups in an organization. In Time-based DSM, the order of rows and columns indicate a flow through time. Parameter-based DSM captures dependencies between decisions on design parameters. In this thesis we will be using time based DSM to analyze flow of information in EPC value streams. In time-based DSMs all interactions should be flowing below the diagonal with upstream elements of a process generating information for consumption by downstream elements[4]. Eppinger et al (1994) classify task relationships based on informational dependencies as parallel (no information flow), sequential (A feeds information to B) and coupled (A and B mutually dependent on each other for information).

Coupled tasks are a common feature of concurrent engineering and the resultant feedback loops are called as iterations. Iterations can be planned (if they are explicitly allowed for in the process or facilitated by appropriate team organization) or unplanned (ad-hoc interactions). Unplanned iterations are the most damaging and causes delays in projects. The traditional planning process ignores such feedback loops leading to delayed discovery of rework issues causing unexpected project delays. As Eppinger(2001)

[4] For a full discussion on DSM refer to The DSM home page http://www.dsmweb.org

discusses one of the big advantages of DSM analysis is to highlight the unplanned iterations loop in innovation process design. Chapter 6 shows examples of DSM as applied to a single value stream and analyses in detail the planned and unplanned iterations. Ford and Sterman (2003) use systems dynamics models to show that overlapping of activities and delay in the discovery of rework requirements can create unplanned iteration, delays, higher costs, and lower quality.

Perhaps the most important value for DSM is that it provides management the ability to see a complex system as a whole, which in itself brings many useful insights. Ford and Sterman (2003) argue that mental models of complex systems are often simplistic and durable and are very important in driving behavior. Managers traditionally have imperfect appreciation of complexity and find it to difficult to incorporate interactions and feedbacks that cut across traditional functional, disciplinary boundaries. DSM provides managers with a compelling system view by capturing in a single view the various ways information flows in real projects. In chapter 6 we show that analysis of root cause of rework in EPC projects using DSM helped convince ABB Lummus management for a value-stream based approach to EPC projects. As Eppinger (2001) puts it DSM does more than only helps managers identify the problems. It also shows ways to fix issues using multiple approaches like re-sequencing tasks, reorganizing and redesigning workflow and teams to reduce information exchange and managing un-plannable work.

Many efforts have successfully used DSM in studying concurrent product development. Eppinger (1997) demonstrates DSM as an effective tool in product development integration problem in large-scale engineering systems. Petakis and Pultar (2005) apply parametric DSM as a low level process-modeling tool to analyze design process in building construction. Krishnan et al (1997) provides a useful conceptual framework to analyze overlapped tasks and provide strategies for timing of information transfer based on evolution characteristics of upstream activity and sensitivity to upstream changes in downstream activity.

McManus and Millard (2002) suggest that DSM can be a useful tool for mapping and analyzing value streams. Since DSM maps information flows in concurrent engineering effectively they can be valuable tools for mapping value streams in product development and project management where information flow is more predominant compared to material flows. In this thesis we use DSM to do value stream mapping of EPC projects.

5 Identifying Value Streams in EPC Projects

In this chapter we look at the techniques used to identify value streams in EPC lump sum turnkey (LSTK) projects. Unlike Product development, EPC can be thought of as having characteristics of both design and manufacturing aspects and so had some unique challenges in defining the value streams. In this chapter we discuss the methodology used to determine value streams in EPC downstream projects. To follow the discussion in this chapter a general understanding of EPC projects is necessary and this is provided in chapter 2. Chapter 3 elaborates on the industry problems that we try to address here using value stream based organization. While we focus on the process of defining value streams here, in chapter 8 look at how to organize EPC projects along these value streams and the resultant implications to EPC organizations.

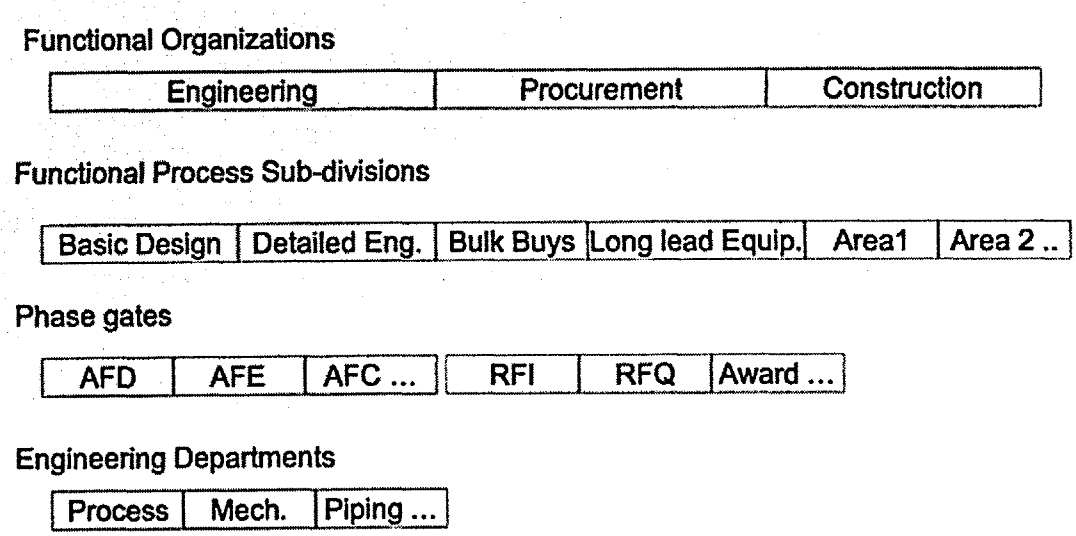
5.1 Determining the Starting point for Value Stream analysis

5.1.1 Difficulty in finding Value streams in EPC projects

The key difficulty in analyzing value streams was to define the level of abstraction and defining the start and end points for the value streams. Typical approaches that are successfully applied in manufacturing and product development applications involve using a physical area of a plant or using existing process boundaries. We found these approaches not applicable to EPC projects for following reasons:

- **Existing mental maps not sufficient:** Fig 5.1 summarizes the discussion in section 2.3 and shows the various common industry concepts used to segregate an EPC project. We here look at the limitations of the existing structures as starting point for value stream definition.

Figure 5-1 Existing Process Boundaries in EPC Projects



- EPC boundaries were not appropriate: We could not look at Engineering, Procurement and Construction as three separate value streams. Ideally given that these are done by separate functional groups, this could have served as a good boundary definition. But once we look at the activities of these groups we realize that they all have strong influences on each other and so cannot be analyzed in isolation. As we already saw in chapter 2 Procurement and construction largely depend on engineering inputs. Many of the engineering details are affected by vendor information, which is a result of a long duration procurement tasks. Onsite Construction is a separate group of activities that is done by third party sub-contractors and so was not part of our discussion. However home office construction supervision, typically a very small team, interfaces with Engineering and procurement to understand and influence information and material generation sequence and timing.
- Engineering functions were too narrow: This is by far the most common way of thinking about EPC projects. However as we see in chapter 6 there is large amount of back and forth information flow between these departments. Even though project deliverables are tracked on a department basis, the information content required for their completion is often interdisciplinary. None of these groups by themselves can create a tangible end result on the construction site for the customer. The importance of the value stream approach is to break this mental boundary and create a new mental framework for driving project execution and productivity.
- Project Phase Gates were too broad: Like most EPC contractors ABB Lummus also had defined phase gates like the Basic design, Approved for Design (AFD), Engineering (AFE), construction (AFC) etc to breakdown projects into multiple phases. However the scope of these phases were too big that we could not use tools like DSM or other VSM tools to analyze them as a single value stream. We needed a way to drill down further.

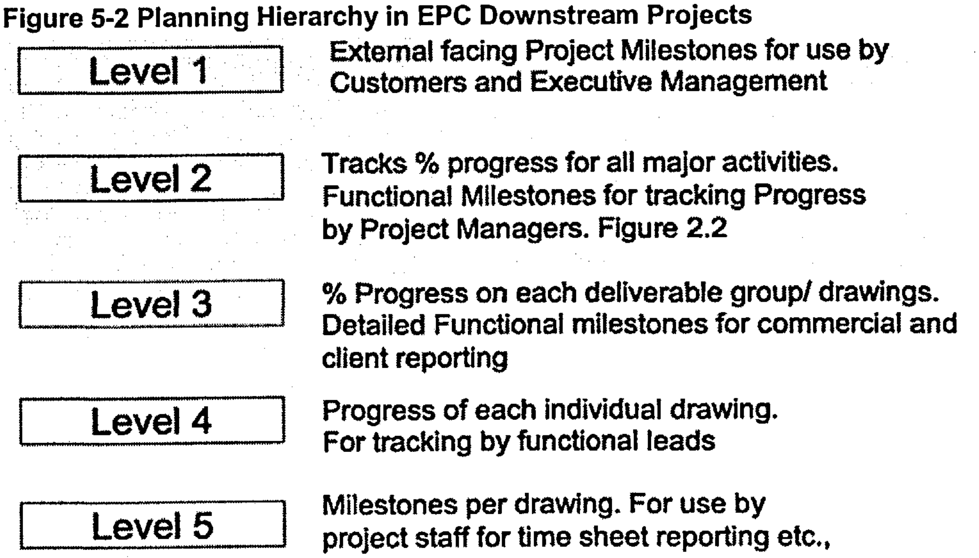
- **Shared PD and manufacturing nature of EPC Projects:** Unlike product development EPC projects involve both innovation and volume manufacturing aspects, thus making them more difficult to analyze using PD techniques. The E, P and C aspects of these projects can be thought as an intertwined mix of design, supply chain and manufacturing environments. Even within engineering there are multiple aspects. Let us for instance consider an engineering drawing like the Process and Instrumentation Diagram (P&ID). There is definitely an iterative design aspect to P&IDs, but it also a production process in that an EPC project typically involves 1000's of P&ID diagrams. This creates more complexity in decomposing project plans as we discuss in next point.

- **Project Plans not consistent and hence not useful:** Project Schedules, in the form of a standard Gantt chart schedule, is a natural choice to understand the sequence, schedule and dependency between tasks and hence understand value streams. In fact the level 2 schedules shown in Figure 2.2 was an important starting point to identify the value streams. However given the scale and complexity of EPC projects central planning was more used as broad milestones to report progress and to set high level deadlines. The detailed project activities were driven my multiple, often not easily reconcilable plans. EPC industry uses Level 1 to 5 to describe details of planning. Broadly they can be thought of as shown below.

  However these levels are broad indicators and interpretations differ widely. Even within ABB Lummus the approach across different offices were not entirely consistent. Also there was no master template of all project activities that was used to derive project plans. Typically a previous project that closely resembles current work is used to prepare a baseline. It took a multi-month team effort just to standardize on what would be the key deliverables in a project so as to start grouping them into different value streams. One of the key outputs of this value streams work is to create a schedule template for each value streams that can be consistently used in project planning.

Finally the projects are too big to do brute force analysis to find value streams: One of the initial attempts to find value streams involved mapping all major engineering deliverables in a large DSM. The idea was to see the natural iterative blocks emerge and use them as the boundaries for defining value streams. However even after several abstractions and simplifications the DSM involved more than 250 elements. The resultant DSM pattern was a one big iterative block that covered more than 70% of all activities!

Figure 5-2 Planning Hierarchy in EPC Downstream Projects



5.2 *Methodology adopted for defining the Value streams*

Given the problems described above, we had to resort to first principles to define an approach for identifying value streams in EPC projects. Using this as a guideline we went about un-layering an EPC project into a manageable number of distinct value streams. As Backhouse and Brookes (1996) point out we first needed to set a new mindset to manage and organize the process. The following concepts were used as a guide to sort through the large complexity and define cross-functional value streams for EPC downstream projects.

1. <u>Defining the end customer:</u> Construction teams were identified as the internal customer and all home office activities of an EPC Project should work to enable on-site construction. The construction work-front (materials and information needed to enable on-site construction) is considered the final product of value streams.
2. <u>Defining the product / work piece flow:</u> We had to decide on the fundamental unit of information / material flow in the value streams. Individual documents or drawings are too small to considered a workable unit for often they only contain partial information. Again using construction as the customer, it was decided that the construction work package[5] should the unit of flow in analyzing value streams.
3. <u>Value Stream characteristics</u>
    a. Value Streams are the string of tasks that is needed to develop a tangible part of the project from concept to delivery
    b. One Value Stream is to have one project purpose or value.
    c. Value Streams are relatively independent from each other, minimum interaction.

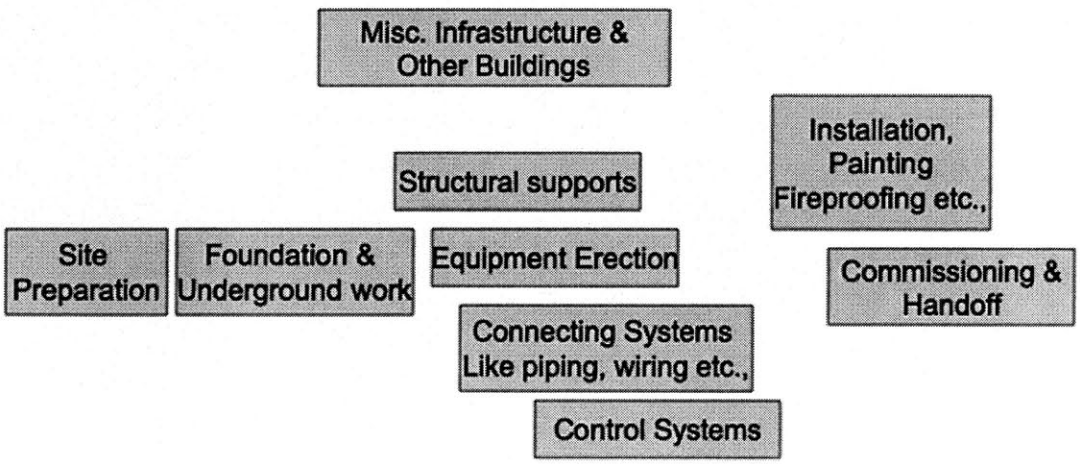
Equipped with these high level definitions the ABB Lummus team identified the value streams described in next section. Some of the value streams fitted well into the typical way some project mangers and construction managers viewed the projects. This was to be expected as we defined the value streams with construction in mind as the end consumer. Three of the value streams (isometrics, equipments, and out of ground) mapped neatly with the four critical paths identified in figure 2.2. This as we will see later played well into integrating value streams based organization with Theory of Constraints implementation.

5.3 *Value streams in EPC downstream projects*

[5] In EPC the construction site is divided into large areas which can be thought of as functionally independent parts of the plant. Each area is then divided into multiple sections and each section into multiple work packages. A work package forms the basis of measuring progress of work on the site.

Based on the series of discussions, inter-disciplinary meetings and individual interviews with various functional managers and senior experts nine value streams were identified. They are outlined in figure 5.3 below. The entire process was highly iterative and spanned over couple of months. The value stream definitions in effect followed the construction sequence on site. A typical construction sequence is as follows:

Figure 5-3 EPC Construction Sequence



The value streams identified below closely followed this sequence and working backwards from the key construction deliverables we were able to trace all the engineering and procurement activities that were part of each value stream. In this exercise documents called as fact-sheets[6] became very invaluable.

Handling overlaps between value streams: The exercise gave us the full list of activities for each value stream but it also created duplicates as some of the major activities appeared in more than one value stream. However for both TOC planning standpoint and also from value stream organizational management aspect a task had to belong to only one value stream. To achieve mutual independence the overlapped activities had to be broken down into their constituent information elements (using contents information in fact-sheets). In cases where finer levels of granularity did not break the overlap the activities were put as part of the main value stream where they belong and listed as constraint `to other secondary value stream(s). Also we found that there are many common design deliverables that are common across multiple value streams. For example as discussed in 6.2 the isometrics value stream had a common design definition phase that included P&IDs and Plot plans for generating isometric drawings. However these two drawings also formed the basis for many other value streams like the nozzle availability. This led to the creation of new value stream called the Planning & definition phase (Figure 5.4).

[6] Fact-sheets were internal documents created by ABB Lummus engineering groups to document the finish start requirements of key engineering deliverables

However there remained questions as to what part of the initial definition should be common across all value streams as opposed to being specifically under he span of isometrics value stream. This resolving of overlaps is a key issue and this exercise is currently ongoing at ABB Lummus as part of the exercise to plan EPC projects along the line of value streams (section 8.5). Potentially an intra value stream DSM could help visualize and better handle such value stream dependencies and is considered a worthwhile exercise in the future.

The entire effort was fairly involved and required standardizing of tasks and deliverables across offices. The end goal of this effort is to arrive at a network plan per value stream that would serve as TOC planning templates for future projects. There were also big organizational ramifications for switching to a value stream based approach as we discuss in chapter 8. The difficult issue is to get management buy-in for such a change and the DSM mapping exercise described in next section was an important first step in facilitating the mental shift.

Figure 5-4 Value Streams in Downstream EPC Projects

Planning and Definition (1): The set of heavily inter-related tasks that is needed to provide a fixed and common basis for effective execution of the project. End consumer: All other value streams.
Core Deliverables: Project plans, execution philosophy, common conceptual design, drawings common across value streams, construction site prep activities like paving, access roads etc.,

Out of ground (2): The chain of inter-related and consecutive tasks that is subjected to the purpose of timely finishing all underground works, to provide construction with free accessible working areas.
Core Deliverables: Under ground design and conceptual layout, U/g Pipes and wiring 3D model production, related vendor information, Connection point's information, U/G materials supply and installation. Covers Temporary Facilities, Excavation Works, Piles, Foundations & Pits, U/G Process Equipment, U/G (Pressurized) Piping, Sewers (Un-pressurized Piping), Cable Trenches, and Conduits for foundations and paving. U/G Wiring E &, U/G Grounding, Culverts, Paving, Warehouse Equipment and UG Piping materials.

Above ground piping systems (3): The chain of tasks whose purpose is to provide construction with sufficient work front for installation of above ground piping systems (rack & process piping). This is also called the isometrics value stream and is described in detail in chapter 6.

Core Deliverables Includes piping studies, isometrics, related P&ID activities, bulk buys, vendor information for piping and instrumentation. Hardware includes Tracing, Insulation, Field Instruments, Lighting Fixtures, Paint, Rack Piping, Spool Piping, Pipe Rack Structures, Sleeper ways, Piping and instrument Commodities, Pipe Supports, Inline Instruments, Piping Specials & Sample Systems, Fireproofing etc.,

Nozzle availability (4): Alternatively called as the equipments value stream, this covers the chain of tasks that provide construction with sufficient work front to install pipe spools from equipment to the rack(s). Often the final information that holds this stream back is the availability of exact location of nozzles in equipments that has to come from the vendor engineers. Hence this value stream is termed as nozzle availability.

Core Deliverables: Includes Equipment Definition & Specification, Purchasing & Supply, Vendor Information & Connection Point Info, Foundations & Structures & 3D Model Production and Pre-dressing & Erection. Covers all In House and vendor designed process and static equipment, Concrete, jacket & steel Structures, Platforms, Cathodic protection, Installation aids, Hydraulic wellhead control panels, Instrument local panels, Analyzers systems integrators, Automatic sampling units etc.,

Packages (5): The set of tasks that provide all involved construction parties and sub-contractors with the work front to install packages on site. These are vendor-designed equipments that are purchased as is, and involves only minimal interface specifications from internal engineers. This is a long lead-time process and because of lack of internal control, this often tends to be a critical issue at later stages in the project.

Core Deliverables: Includes Package Definition & Specification, Purchasing, Vendor Info Collection & Connection Point Info, Peripherals Specification & Purchasing, and Package Supply & Installation. Covers Process Packages, Analyzer Houses, F&G Equipment, Variable Speed Drive Systems etc.,

Above Ground Electrical & Instrument Wiring Systems & Termination Points (6): The chain of tasks that provide construction with sufficient work front for installation and connecting of above ground electrical & instrument cabling.

Core Deliverables: Includes A/G E&I Wiring Definitions & Conceptual Layout, E&I Equipment Specification, Wiring Design & 3D Model, Materials Supply, Equipment & Termination Point Info, E&I equipment & wiring Installation. Covers Substations, MCC, HV Switchboards, Junction Boxes Electrical Motors, Cable Trays & Conduits, all Cables and accessories, Transformers, Cathodic Protection, Communication Systems, all switchgear / MCC / busduct, all power systems incl. UPSs, Capacitor Banks, distribution panels, automation equipment, RCU and Safety Switches, Junction boxes, Outlets and plugs, junction boxes, lighting fixtures, Conduit and fitting material, Instrument consumables

Control and Safeguarding Systems (7): The chain of activities that is required to for timely installing the control and safeguarding systems. These are high value, equipments that involve integration with equipments, AGP etc., and are critical in most projects.
Core Deliverables: Includes C&S Systems Definition, Specification & Purchasing & Supply, Vendor Info Collection, and Installation. Covers ESD and F&G Systems, Main Automation Contractor (MAC), all control systems incl. DCS, MMS etc, Safeguarding system, Programmer logic controller (PLC), Road / rail car loading system, MIS, Advanced process control, Operator / dynamic training simulator, Blending system, Weighing system, Scada systems, Surge Control System, Annunciator System, Access Control System, Weather station, CCTV, Telephone / PABX, Radio communication systems, F&G systems integrator, Pushbuttons / switches / lamps, cabinets, Panel instrumentation

Architectural buildings & Roads & Miscellaneous Infrastructure (8): The chain of tasks required for timely constructing buildings under architecture (no prefab) and miscellaneous infrastructure. This is essentially a catchall stream that captures supporting infrastructure at the plant. The actual content and magnitude of work varies greatly across projects.
Core Deliverables: Includes Buildings & Roads Definition, Specification & Purchasing, Vendor Info Collection and Installation. Covers Architectural Buildings, Prefab Buildings, Shelters, Roads, railway, Fences, Laboratory Equipment, Architectural Buildings, HVAC, MCT Blocks

Finishing Services (9): The set of tasks that is needed to turn over and close out the project. Though this is supposed to be a wrap up exercise it can make or break a project It often take long time to close all open issues and if the previous engineering and procurement phases were not implemented well, they all blow up at this phase. In some projects this phase has stretched for a year or more and led to costly litigations with the clients and other contractors.
Core Deliverables: Includes Pre-Commissioning, Commissioning & Testing, Turn-over, Close out, Training Plant Personnel, Start-up, Operation and Troubleshooting, Test Run and Plant Acceptance. Covers all as-built deliverables, Commissioning Materials, Maintenance & Operating Spares, Commissioning Spares, and Training Materials

6 DSM Analysis of Isometrics Value stream

Early in the value stream (VS) identification process it became clear that isometrics and in-line instruments would be an important stream of activities to study and understand. This part of the project was considered the most prone to rework. We decided to do a value stream analysis on this to 1) understand the causes of rework 2) work out a value stream analysis methodology for use in analyzing other areas and 3) show application of DSM to an actual EPC problem. In this chapter we discuss the methodology and results of isometrics value stream analysis. The resultant findings of this analysis were an important factor in getting management buy-in to adopt value stream thinking in planning and organizing a large scale EPC Project.

6.1 Preparing a Value Stream for DSM analysis

Isometrics typically refer to 3D representation drawings that show the routing of pipes and the location of piping component instruments and supports in a plant. The internal team however used this term to refer to all the activities from piping and instrumentation department that are related to producing the information required for these diagrams and implementing them on-site. Later in the VS definition process this was called the Above Ground Piping Systems (Figure 5.4). We will use the terms isometrics to refer to this value stream in this section. Isometric preparation is an intensive activity that marks an important milestone in EPC projects as it creates work front for the site subcontractor - with isometrics and materials available, the piping subcontractor can build in all the pipes in line with the plant design. Isometrics are the basis not only for construction but also allow procurement to finalize on the bulk buys, a highly problematic area for materials control (chapter 2.3). Basically the Value Stream is intended to generate and maintain work-front for piping sub-contractor at the site.

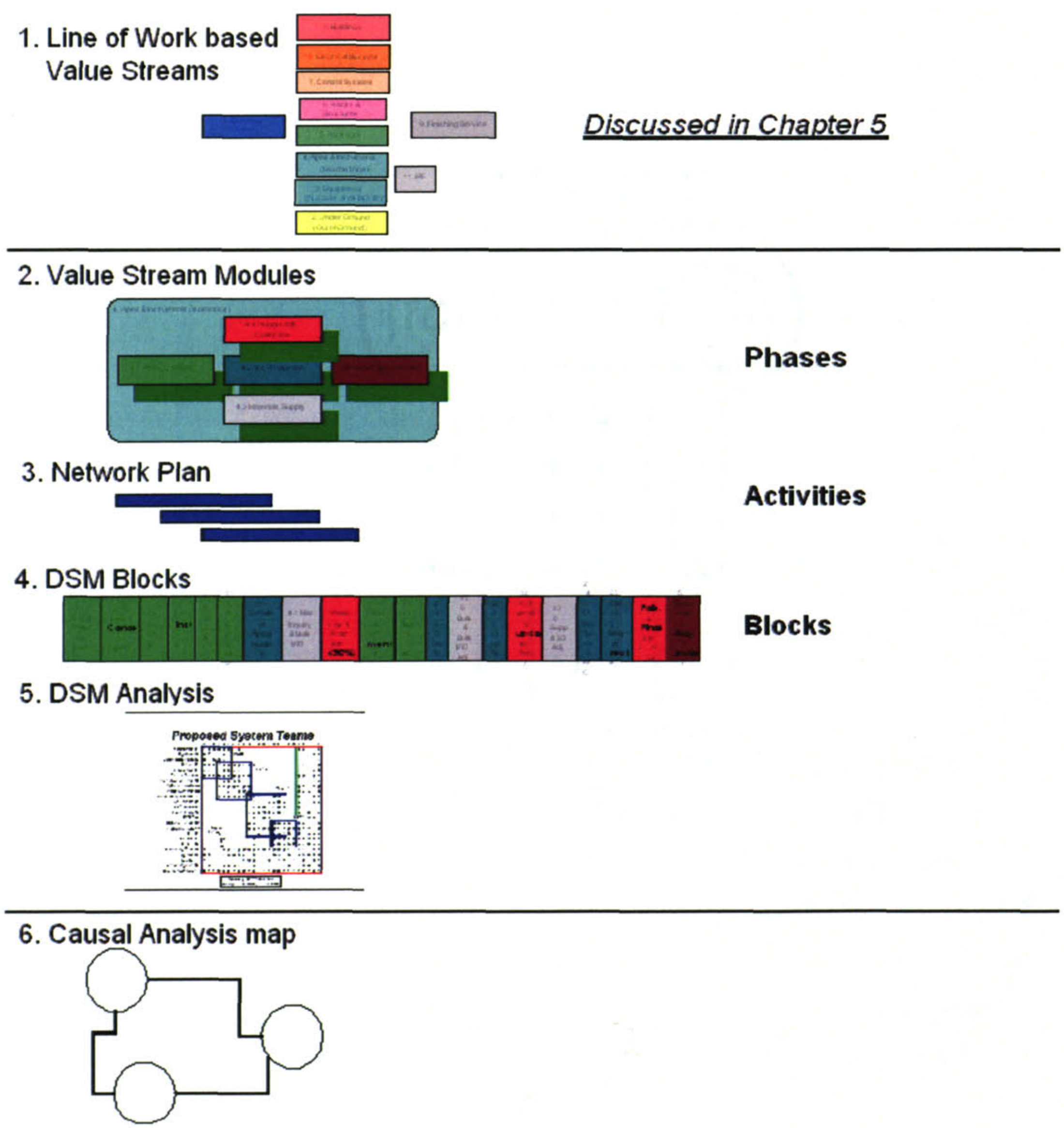
EPC Projects during the home office design and procurement phase mainly involves coordination of information. The major patterns of information flow include

- Back and forth Information exchange between engineering departments to generate detailed drawings
- Information flow between engineers, procurement and vendors to design and procure equipments and materials
- Information and material flow from engineering and procurement at right sequence to construction sub-contractors at the site.

In this knowledge intensive white-collar environment, traditional value stream mapping tools are not very effective. We decided to use DSM as our mapping tool as it has proven very effective in tracking information flow in concurrent engineering value streams (Millard 2001).

DSM Methodology: The information for creating isometrics DSM for isometrics was obtained mainly through a series of interviews that included 3-4 sittings with 10-12 engineering managers over a month long period. The results were then validated with the department heads in both The Hague and Houston office. Formulating a DSM for value stream turned out to be a 4-step process as shown in Figure 6.1.

Figure 6-1 Steps in Isometrics Value Stream Mapping



1. Break down the value stream into conceptual phases to identify the major areas of work involved in creating construction work front. This step was helpful to identify tasks that belong to the isometrics VS from among the hundreds of interconnected activities in EPC projects.
2. Create a network plan to capture all level 3 or 4 activities as appropriate. There were total of 95 generic tasks identified as part of the isometrics value stream. This network plan was an important step as discussed below.
3. Group the activities appropriately into DSM blocks. This necessity for this step was realized during the DSM process. The first pass effort mapped all the activities in a DSM as shown in figure 6.3. The resultant matrix, while it captured all the interactions, was unusable to do any analysis and draw inferences. The blocks were used to achieve right level of abstraction that was not too deep but had enough detail to do meaningful analysis.
4. Use the blocks so identified to do a DSM analysis. Summarize the findings in a causal analysis diagram.

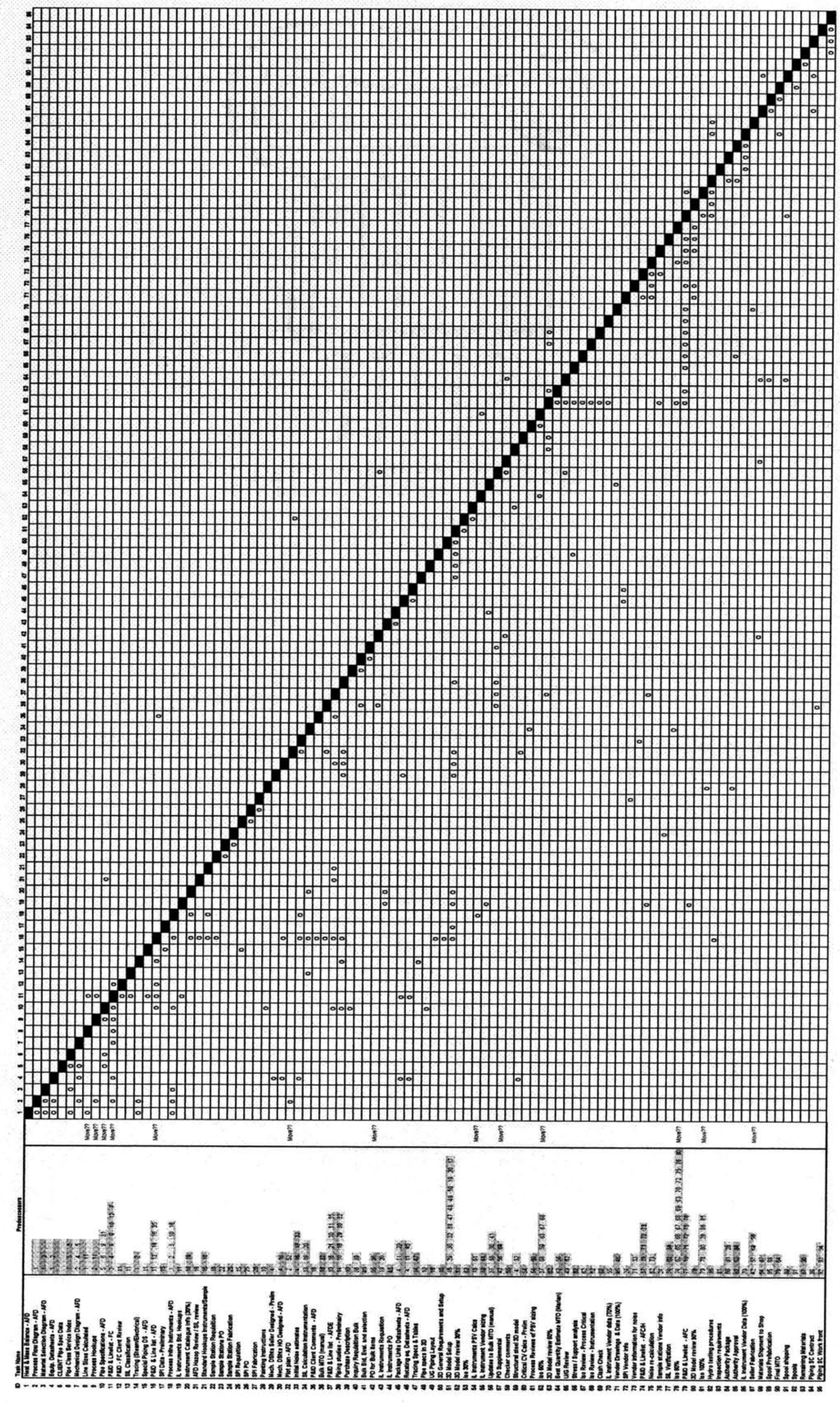
The step to create detailed network plan was important, as many of the blocks used in DSM were not standard terminologies. Network plan was useful in following ways:

- It provided assurance that all activities are covered. A common issue faced during the internship is that the analysis oversimplifies the complex reality of EPC projects. The network plan helped address such issues, by providing an ability to drill down from the DSM blocks to the detailed tasks and activities and so demonstrate that the list is comprehensive.
- It also helped understand the boundaries of each block and so was useful while drawing the DSM interactions.
- Finally once the process was complete the network plan formed the basis for creating TOC templates for each value stream (discussed in chapter 7)

Following were the key challenges faced during the DSM construction process

- The biggest problem in the analysis is to determine the actual scope of activities that should be included in this value stream. In a typical project isometrics related activities consume about 20% of the project engineering hours (covering most of the piping and bulk of instrumentation engineering efforts) and goes on for about 2/3 of the project duration.
- As discussed in 8.4 the team had to overcome the strong skepticism of value streams approach and lean. A key challenge was to get over the mindset of functional deliverables and start working backwards from construction requirements.

Figure 6-2 Isometrics DSM without Blocks



Another important issue was the need to achieve a consistent level of abstraction for the analysis. Most often during the interviews there was a tendency to get too detailed to be analyzed to loose the system view or to create a broad abstraction that did not capture all the relevant information flow patterns. We found that the visual layering from phases to blocks to tasks as shown in Figure 6.1 was very useful in guiding the discussions.

- Many of the engineering deliverables were more like reports that aggregated information produced by a department(s) and so were used for multiple downstream activities. We had to focus on the information content that is relevant for the deliverables in isometrics value stream.
- Though the steps in EPC projects are fairly standard, the actual information flow varied depending on specific project complexities and also to a big extent on the nature of management practices. We had to use multiple sources and validation rounds to construct reliable information patterns. In some cases we had to use a probabilistic number to show that such interactions occurred only in a fraction of the projects as shown in Figure 6.4

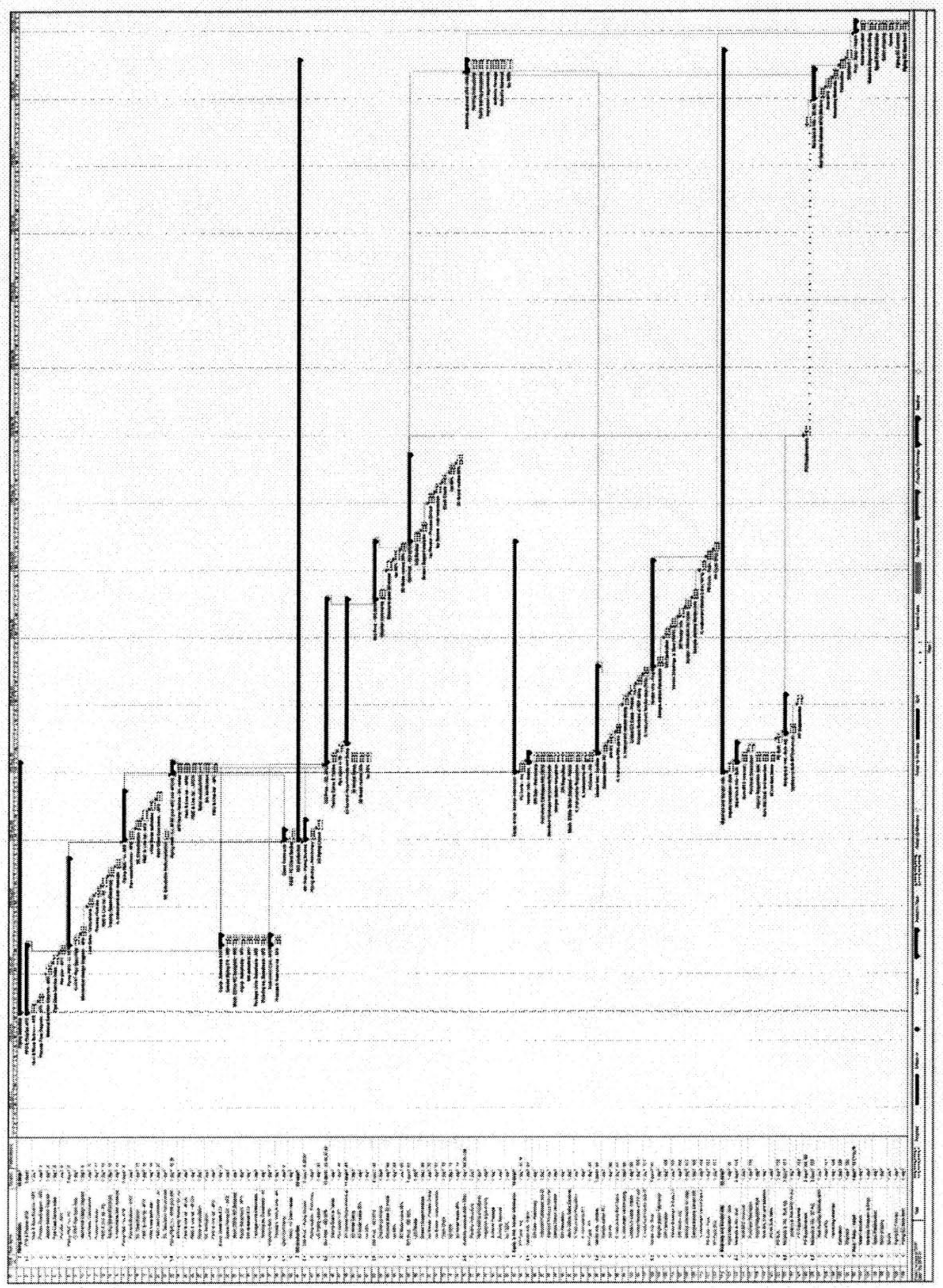
6.2 Key components of Isometrics DSM

To make sense of the complex web of activities in the isometrics generation process, we first identified key phases (streams of work) needed to create construction work front. The brainstorming exercises led to identification of five high level blocks: initial definition, isometrics production, vendor information, materials procurement and finally on-site installation.

Definition phase: This is the basic design process that generates information required for starting on isometrics drawings. This included Process flow diagrams from Process, the mechanical and instrumentation data sheets, area plot plans and preliminary piping studies from Plant design and the completion of Process and Instrumentation Diagrams (P&IDs). These activities enabled not just the isometrics production but also many other value streams components as discussed in section 5.3. Activities whose information content cannot be isolated for isometrics generation later got moved to a separate value stream called Planning and Definition.

Three streams of activities were initiated once basic design is complete - the detailed engineering to produce isometrics drawings, sending RFI to vendors for buying key equipments and the procurement process to buy the required materials.

Figure 6-3 Isometrics Network Plan

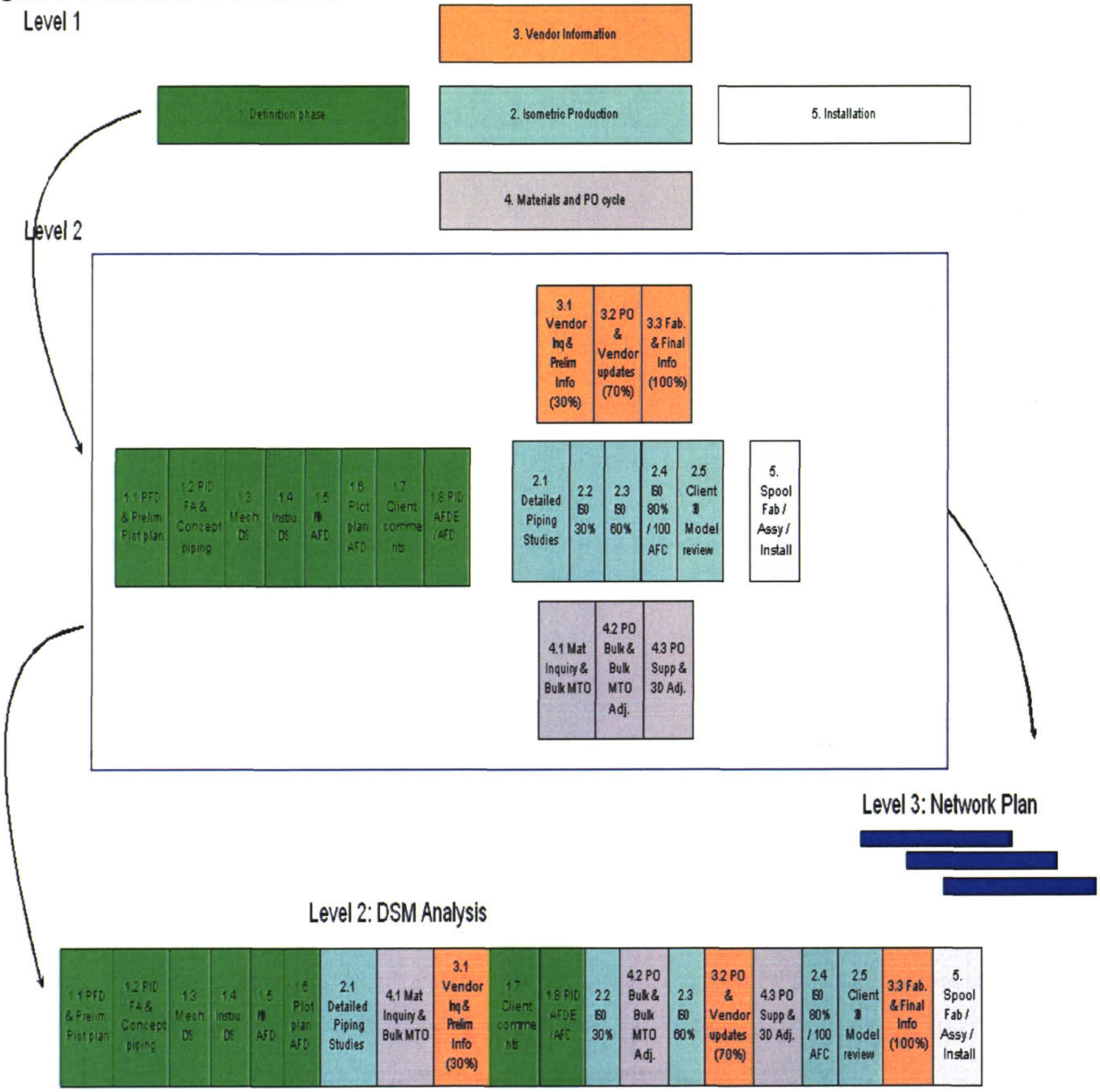


Isometric Production: The detailed engineering translated the design requirements to detailed specifications that can be used by on-site teams to lay the pipes and fit all instrumentation. It involves building upon the basic design by filling in the details for pipe dimensions, supports, locations, painting and fireproofing instructions etc., The piping activities includes detailed piping layout, stress support calculations etc., The in-line instruments covers areas like control valves, safety valve etc., instruments that controlled the flow through the pipes.

Vendor information: This stream covered the RFI, RFQ, technical evaluation, contract awards and actual delivery of key equipments. Much of this process belongs to the nozzle availability value stream. However the information from vendor on their internal engineering determines many of the details in the isometrics production drawings Information on In-line instruments 3D dimensions is important since this will influence the design of the pipe it's in and the adjacent pipes. This should ideally match with initial datasheets and P&ID specs, but in some cases deviations occur for cost, availability or some internal design constraints. In these situations the new information from vendor has to be reflected in the engineering diagrams. The actual equipment fabrication takes months of lead-time so the information is passed on from vendors in 3 stages: 30% (initial information based on vendor's standard datasheets), 70% (almost complete design info) and 100% (the final equipment configuration information).

Materials procurement: As noted in 5.2, creating construction work-front requires both engineering drawings and materials. The materials block is about ordering the pipes and inline instruments required to realize the drawings on site. The items purchased are mostly off-the-shelf, low value, high volume commodities and this category is called the bulk buys. The procurement process starts by calculating the quantities for each type of valve or pipe by counting the requirements across all drawings. This process is called the material take-off (MTO). There are two broad ways to procure these materials. The preferred method is to source directly from the manufacturers of these materials. This is a long lead-time process but it is very cost effective. Part warehouses, which are intermediary dealers carry inventory for most of part types, offer short lead-times but charge a premium over the manufacturer's price. Since the quantities involved in bulk buys are fairly high, a small premiums can make a big difference in the end. So in practice 80-90% of the requirements are determined through initial designs. Thus bulk of the materials ordered from vendors and final minor changes are accommodated through ad-hoc high cost purchases from warehouses. So the MTOs are done in 3 stages bulk MTO, Bulk Adjustments and 3D adjustments. There is a fine act of balance between ordering early to save costs and managing the waste if information changes later on.

Figure 6-4 Isometrics DSM Blocks



The final installation included home office construction work like sub-contract awards and activities to get the construction work-front like spool fabrication and shipping.

6.3 DSM planned and unplanned iterations

Figure 6.5 shows the interactions between these blocks represented in a DSM. As each DSM block is an aggregation of multiple activities in the network plan, each interaction shown in the DSM is a consolidation of information flow between the component activities. In some cases where the interaction does not happen in all projects used probability[7] in the cells (for instance 0.1 indicates that this feedback occurs 1 out of every 10 projects). The blocks are each identified by a phase number (1 through 5) and each sub stage in a block also has a number sequence. The sequence gives an idea of relative flow of time and also `helps understand easily which conceptual phase each of the DSM block belongs to. It is important to understand that the DSM blocks vary in time and effort. To give an idea the phase 1 takes 5 months, phase 2 takes about 1.8 years, phase 3 takes10 months and phases 4 and 5 are about a yearlong. However since the stream is expected to take between 2 – 3 years the phases are highly overlapping.

The sequence is based on the actual timeframe in which they happen in projects and is different from the planning sequence. The project plans portray an ideal scenario and while the actual project reality is often different. Also in EPC projects since a document is released in multiple phases like ISO 30% or 60% this tends to mask feedback iterations. For instance the when a new vendor information changes an information in ISO 30% drawing, it is shown as being incorporated in ISO 60% drawing which comes later in the sequence. This will make the information flow appear as a normal below the diagonal interaction. However in reality the information content that should have been finalized in ISO 30% (a predecessor task) gets changed. We had to determine the exact information content that is affected and accordingly place the DSM interactions to reflect a true picture of rework.

As expected, most of the interactions fell below the line. But there are quite a few that are above the diagonal. These feedback loops provided basis for rich analysis. We found some common patterns in the iterations and we have color-coded them accordingly. There were 2 main types of unplanned iterations and a planned iteration. The patterns are discussed below. In this section we discuss the problems identified by DSM and suggest some possible solutions in section 6.4

[7] based on best guess estimates from past experience

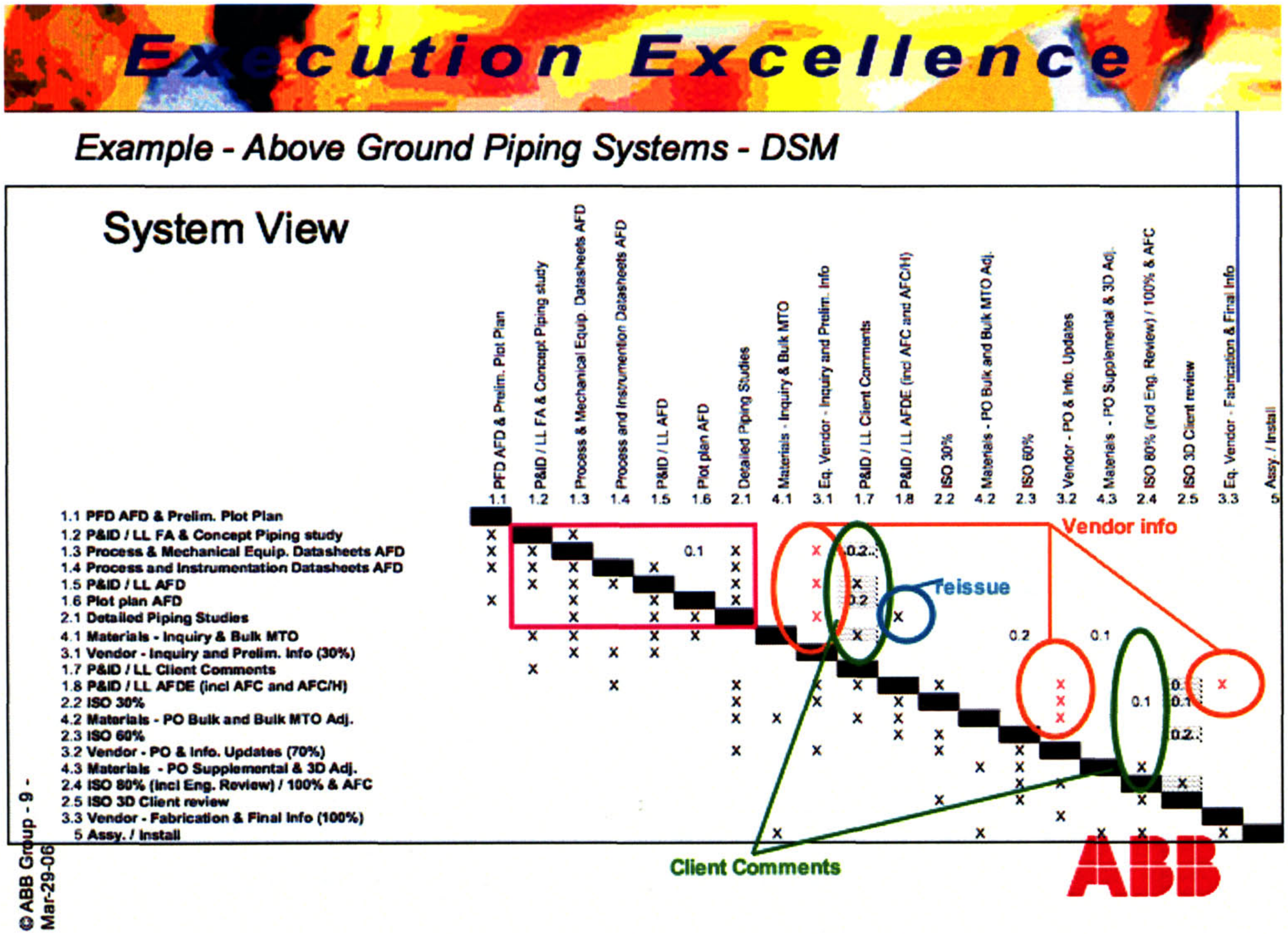


Figure 6-5 DSM for Isometrics Value Stream

Planned iteration block: The process of datasheets generation and P&ID creation is highly iterative as shown in the block in red, spanning activities 1.3 to 2.1. However this was widely understood by project teams and the engineers often interacted closely with other teams to smooth out information flow. For example Process Flow Diagrams are input for plot plan studies and equipment design in parallel. However plot plan study might cause the equipment design to be changed, due to space, safety or constructability considerations. This then may lead to an alternative Process Flow Diagram, creating an iteration loop. So in this stage documents are kept open in evolving stage to allow for modifications that are inevitable. This sort of iteration was also less harmful in that this represented the early stage of the design process and so iterations are fairly fast and information flow is often between small groups of design engineers who often work in one office. This is reflected in the crosses being so close to the diagonal and the time elapsed from 1.2 to 2.3 is usually 6-8 weeks. There are standard DSM techniques that can be employed to reduce the duration of each iteration cycle and average number of iterations. However for ABB Lummus the duration per se is not an issue. The biggest benefit was to identify this sequence explicitly as a planned iteration and manage it accordingly.

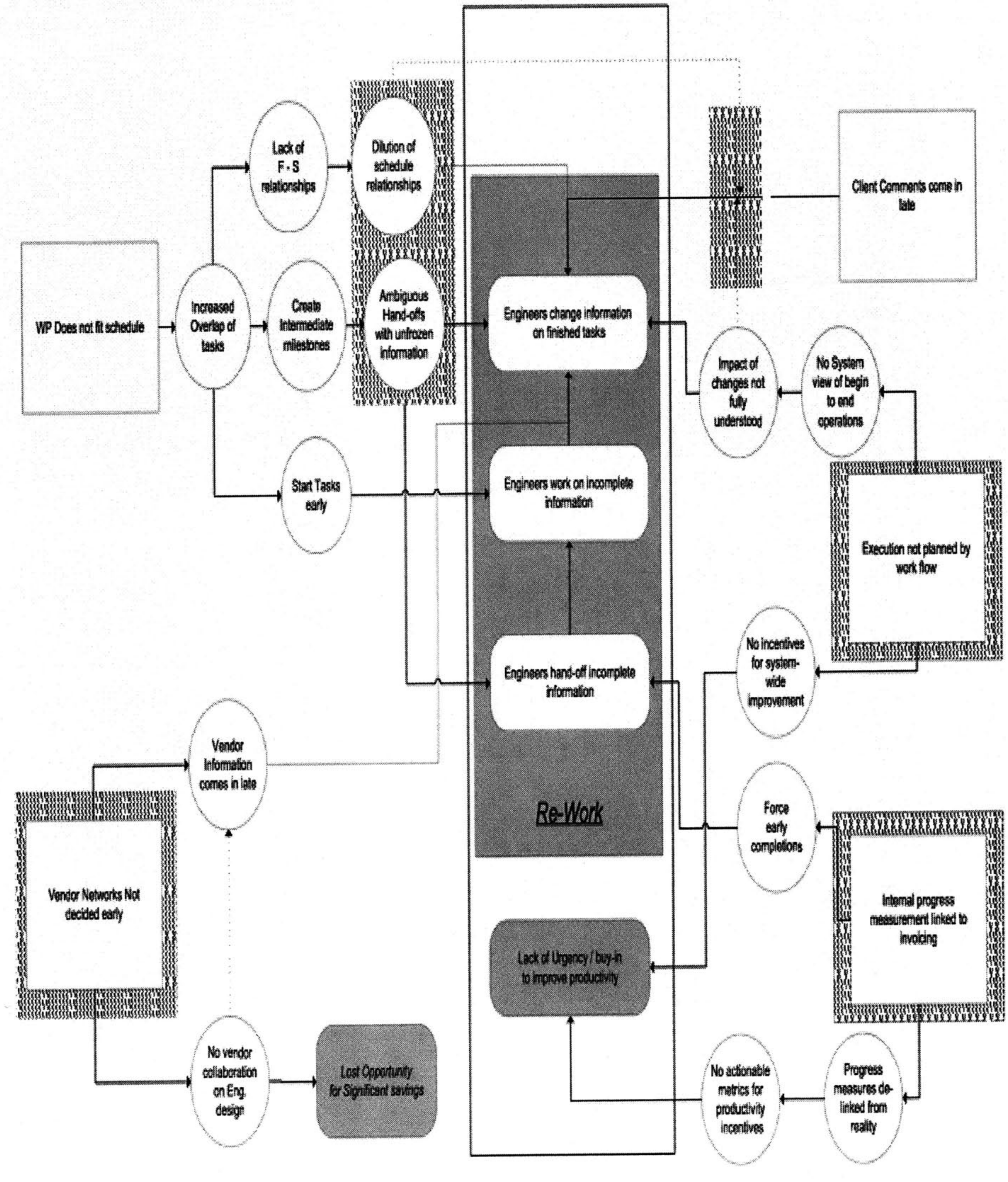
Vendor information coming in late: As described in section 6.4 delays in vendor selection can lead to required engineering information coming in late. Sometime procurement in their drive to keep costs down can lead to schedule and information delays from vendors. Due to lack of direct accountability, engineers might not be prompt in their responses to vendor enquiries or not follow up diligently with vendors to obtain key information. All these leads to vendor information coming in after a document have been released.

The DSM analysis also uncovered the fact that some of the changes caused by delayed vendor information were not really necessary to completion of isometrics drawings. Some information, like testing procedures and paint codes might be available only towards the end of the delivery process. The isometrics might not need this information for completing its engineering calculations. However the released isometrics are changed to reflect new information so as to provide complete information in one document to the field. But once engineers reopen a closed document they also tend to change other areas leading to rework. Clearly there is a need to separate the engineering revisions from documentation updates. A proposal was made to have a separate documentation team (at a low cost centre) update the drawings towards the end after all vendor information is completely available. This would free up the engineers from reopening their released work, thus both increasing engineering productivity and also reducing scope for further changes that create rework.

Delayed Client feedback: Often the required client feedback does not come on time during the review cycles. In most projects, client teams have a natural tendency to put off reviews and then raise design issues before phase gate signoffs. In some cases the client team composition does not involve operational team who will take over the plant. So even though client approved the designs initially, during later stages they might find reasons to deviate again. For instance, take a case where the client team sign-off on an area of plant after design review. Review of a subsequent area might identify some issues that require some design changes for that area. However the client might want to make all areas consistent reopen the reviewed designs for previous areas. The tendency to request ad-hoc changes have become worse with increasing client power. However such issues are outside projects control and are tracked by change orders and negotiated at senior levels. The worst problem is the small creeping changes that client engineers make over time. The EPC contractor's internal engineers tend to accommodate that change since they know that they will be making other changes to the document anyway. This breakdown of schedule discipline is identified as the major cause for rework as discussed in 6.4.

Impact of changes on materials procurement: Another iteration pattern worth mentioning is the impact of unplanned iteration on materials bulk buys process. If we look at horizontal rows for 4.1, 4.2 and 4.3 we see that they get affected by interactions that are close but above the diagonal. The elapsed time for these events can be in months and can have big cost implications. The unplanned iterations here can be a serious issue and often a problem in projects. As discussed in 6.2 in order to save costs, procurement orders bulk of the materials during takeoffs calculated during early engineering drawings. However in some cases, as the engineering process moves along the quantities might change drastically. This often occurs in packages, where the detailed information comes available only late in the project. Hence there is a higher risk for misestimate in the bulk buys. Even planned events like for instance safety review, a downstream activity after design is complete, might surface the need to change a design seriously. A minor innocuous change in safety requirement for higher say a large pipe width requirement might lead to changing specs from requiring 50 x' valves to 50 y' valves. If bulk buy has ordered say 40 x' valves in their 80% order, the entire order has to be revoked leading to cancellation fee and even full write-offs if they have been manufactured already. There are additional procurement costs as the 50y' valves has to express ordered and drop shipped to avoid construction delays. While most cases involve smaller write-offs in extreme situation it can wipe off a project margin. For instance a project in Russia that had miscommunications on detailed engineering takeoff from a offshore vendor led to 2M in bulk buy write-offs which more than wiped off any cost savings from outsourcing!

Figure 6-6 Isometrics Causal Analysis Map



6.4 Analyzing the results and creating Causal map

Based on the results from DSM and drawing from anecdotal observations during the interviews, we identified many common underlying issues that seemed interrelated. To bring out this picture a causal map served as a powerful representation tool. Issues like vendor / client information delays or overlap issues came out of DSM. Other issues like inadequate metrics and lack of system perspective repeatedly came up during discussions with senior functional experts. The causal map shown in figure 6.6 brought them all together and tied it to the three common tendencies that led to rework:

1. Pressure to show progress forces handover before information is fully mature
2. Tendency to force early start of activities before the required information is fully evolved
3. Increasing tendency for engineers to change information on released documents.

The root causes that led to these behaviors are highlighted in grey and briefly discussed below:

- **Breakdown of schedule discipline:** With increasing overlap of tasks, the information handoff between tasks has become increasingly ambiguous leading to an escalation in the frequency of post release document changes. The net impact of such frequent changes creates a behavioral pattern that leads to a negative spiral. Engineers tend to become careless in information they handover as they know it will change later anyway. And whenever an engineer reopens a document they tend to make few other modifications while they are at it. For instance making a change in one system may reveal a calculation flaw, which (once known) needs fixing, or lead to a consistency problem with other areas. Such inclusion of desired but not required changes leads to over-engineering at the expense of schedule and cost overruns.

  A related issue is the nature of ambiguous hand-offs between overlapped tasks. In many cases like P&IDs or isometrics the information transfer happens in multiple stages and these documents are released with multiple release states. This is a preferred technique to fit long lead-time tasks into shorter schedules. For example, vendor information on in-line instrument dimensions is handed of in three stages with the information maturity during each handoff reflected by a percentage like 30, 70 or 100%. However the percentages have a different significance than one would expect. 30% does not mean that 30% of the information is complete. Rather it meant that the information in the document is expected to be stable with a 30% confidence level. Treating information maturity on a probabilistic basis created fertile ground for rework. All it achieves is to give leeway room for the releasing department to make future changes (a 70% data still leaves open a 30% chance to change any information). A preferred approach would be to break the deliverables by information content and release a subset of information that is fully mature. This was one of the key recommendations from the study and is being actively considered.

- **Lack of system view of internal workflow:** The excessive functional focus leads to lack of appreciation for the overall system. This leads to behaviors that make decisions based on local functional priorities that affect other functions adversely. An engineer might accept a change from a client, as it seems like a half hour effort for him to incorporate the change, however leading to major consequences for downstream functions. In one of the projects discussed during DSM analysis, a process engineer reviewed the nozzle size of a pump and found out it was 3", while the line. The process engineer decided to change the size of the 400m long lines to 3" (a non existing size), after the isometrics were issued and the materials were purchased in final quantities. This would have triggered a whole circuit of changes and waste materials. However by adding an extra reducer the change was reverted by project team containing the damage. While this is an extreme example, very often there is more than one way to solve an engineering problem. Without a system view, people might not identify the workarounds that would result in overall cost and effort savings.

  Another way this lack of system view manifests itself is in out of schedule progress. In order to meet monthly progress targets, a mechanical engineering lead might ask his engineers to work on deliverables that can be finished easily. For example pressure and temperature indicating hardware are typically needed late but can be specified soon. So often, in order to show project progress (in an earned value system) engineering leads start this process earlier than required. However when the hardware is bought early there is a higher chance of reorder or order modifications due to changes in underlying design. This leads to additional effort and cost and also distracts the engineers from being fully involved in the early design / datasheets review cycle. While the review efforts are not counted to progress it can avoid costly rework cycles later on.

- **Vendor finalization takes time:** Most EPC procurement almost happens like public contracts. In order to achieve lowest procurement costs and also to show the client that all good faith efforts are taken, it is handed in an arms-length fashion with formal tenders. This process is very time consuming and the vendors will not commit to prices till all specs are clearly laid out. The vendor information as a result comes in late and creates many engineering documents to be changed after their release. Ideally one would want the vendors to be involved early in the design process where they can come in and share knowledge with internal engineers to achieve overall reduction in costs. This is precisely the type of changes that lean enterprise pushes forward and many product development efforts in auto industry and others have followed Toyota's lead in this constructive supplier engagement. *However given the razor thin margins in EPC industry and the uncertain such trust based, constructive, long-term business relationships this is not the norm in EPC industry.*

- **Misaligned metrics:** Chapter 3.2 discusses the sub-optimizing tendencies that arise due to focusing on the wrong metrics – the engineering man-hours. However in some cases the metric themselves might be inaccurate or misleading. The metrics used to measure internal performance is also coupled to external commercial reporting, as clients often tie their payments to progress with respect to milestones. However this means that the metrics are not designed to handle rework. For instance the monthly productivity figures were calculated on incremental progress achieved and the effort spent that month. When rework happens the progress is not rolled back, as that would mean reporting negative progress to clients! Ideally to reflect true performance, previous milestones should roll back whenever there is rework. The end result is productivity measures become inaccurate when rework increases. The metrics show an alarmingly declining trend when in fact the teams might be working hard to resolve issues and so have higher period productivity. For instance in almost all projects it seems to take forever (almost 30-50% of project duration in extreme cases) to do the last 5% of the job. Such wrong feedbacks lead teams to ignore many of the metrics halfway through the project and rely on informal feel for the project. This highlights the importance of alignment of metrics and other supporting systems so as to drive the desired behavioral change.

6.5 Conclusions from ISO DSM causal analysis

The DSM and causal analysis brought together various internal data and presented them in a visually compelling manner. The causal diagram was a very powerful persuasion tool. It presented in a clear and concise fashion how existing issues were real and most importantly showed that there is a reinforcing pattern. It also led to exercise for creating network plan and DSM for all value streams that is currently underway. Also it led to series of discussions on the implications of VS based organization discussed in detail chapter 8.

The biggest realization was that there is a reinforcing pattern and so a system wide approach rework is needed to break the rework cycle. This increased gave strong impetus to the value stream approach. The causal analysis also made clear the need for a planning methodology that can handle the excessive overlaps / rework and bring back schedule discipline and reduce tendency to change. The DSM and VS enabled TOC plans described in next chapter addressed this issue.

The DSM exercise also helped identify specific process improvements like tracking progress by information content rather than on a probabilistic basis, separating engineering change from documentation updates or creating internal progress metrics that accommodate rework. These process improvement exercises are precisely the type of insights and improvement we wanted to create by taking a value stream impact view and applying lean principles. However we did not explore these improvement options fully and a manager for isometrics value stream was appointed to explore implementation of these recommendations. The internship's focus was to establish a system that will enable project teams to identify and act on such issues on a continuous improvement basis. This is discussed in chapter 8.

7 Facilitating TOC implementation Using Value streams and DSM

In this chapter we take brief look at learning's within ABB Lummus Global from implementing Theory of constraints (TOC) in small EPC projects. We then explore ways how value streams and DSM approach can facilitate TOC implementation in large-scale Lump-sum turnkey (LSTK) projects.

7.1 TOC Implementation in a small scale EPC project

The EPC business of ABB adopted TOC after seeing its success in the manufacturing business. Prior to adopting TOC at Lummus, a team was sent to study and adopt the success from a switchgear manufacturing plant in Europe. Following are the key observations from that report.

- <u>Required conditions</u>: A firm and sustained commitment from top leadership is essential in overcoming the hurdles of pilot rollouts and manage resistance to change. It is important to get buy-in of the people even if its takes a long period of time (over 1-2 years for the plant). Also implementation team should involve full participation of every department.
- <u>Results:</u> After a year of TOC implementation, the plant realized on an average 50% through put improvement, delivery times were reduced by 25% and fewer resources were spent on a project.
- <u>Differences:</u> While the behavioral problems addressed by TOC are also present in EPC projects the scale was very different. The ABB manufacturing unit considered each major order a project and there are 60 projects running at same time. A network consisted of about 100 individual activities all finished to start, and average cycle time was between 30-45 days. In fact this was an issue during Lummus assimilation into the main ABB, as the concept of a project in manufacturing setup is very different in scale and complexity from an EPC industry project.
- <u>Implementation issues:</u> Concerto works with durations and not man-hours. This leads to task/resource managers making durations longer to make sure they get enough man-hours. People needed to be repeatedly educated on the intention and benefits of TOC. Gaming on task duration estimates is a common problem encountered in TOC projects, as people have big resistance to cutting task durations significantly. Also managers needed to be educated not to treat buffer time as excess slack time that can be cut, but as necessary schedule component to handle variations.

In the EPC business TOC was implemented on a small heater design project. The project was carefully selected to be a low risk implementation. The project was chosen, as it was a repeat business that replicated a recent successful project with many of the original team members. It was executed in one office and was small in scope about one tenth the size of a typical EPC turnkey project. It had 300 major activities and a team of 15 engineers as compared to 3000 major activities and 250 engineers for a typical EPC LSTK project.

The project was a first in implementing TOC in EPC industry. The TOC tools had to be scaled and adapted to fit the pilot project (even though it was small by EPC standards). Following are the key steps in preparing for TOC implementation.

- Typically planners use previous project templates to work out a project schedule and it is then briefly reviewed by the project teams. In this project all key project team members and the TOC team joined for a week to develop a project network based on the previous project schedule
- TOC plans have to be detailed enough so that resource allocations can be done based on the network plan. This and the requirement that all tasks be F-S meant that the plans have to be much more detailed at a level 3 or 4 (figure 5.2).
- A 'fishbone' structure was developed with a total of 300 activities with planned durations. All tasks were interconnected with 'Finish-Start' relations only.
- All engineering durations were reduced by 40% to meet client requirements. Individual task durations to be reduced by another 33% to create various buffers.
- Initially daily and later weekly follow-up meetings were held to check on TOC implementation progress.

The team adopted a new planning and schedule-monitoring tool Concerto[8] in place of Primavera the standard industry tool for EPC project schedules. The project plans was maintained in Concerto and the system was used to update schedule progress and for planning resource allocations. Though concerto could do other functions like time sheet and efforts measurement those systems were left unaffected and only planning component of the software was used. This led to many duplicate data capture issues as Concerto added additional overhead to existing information gathering requirements. But such resistance issues were overcome with management commitment.

7.2 Lessons learned from the pilot

There was strong skepticism about TOC among many quarters and the program needed sustained management commitment to get the implementation going. Familiarity with the concepts and tool in the

[8] Concerto is a software-planning tool that handles TOC planning methodology. Goldratt consultants, the firm founded by author who propagated TOC concepts, advocated it for adoption by ABB Lummus.

pilot project helped in getting broader receptivity to the tool. Following were the key results / observations of the initial TOC pilot.

- The Project spent most of time in the Red zone. The buffer was consumed more than 75% even before 25% of project progress. Subsequent analysis showed this was due to unrealistic commitments to the client. As discussed in 3.1 the project started with a perennial deficit. This to some extent made the buffers ineffective as early indicators as they stayed red all the time. Some of the buffers were utilized rapidly as unplanned iterations lead to excessive task variations much more than what is allowed for by TOC methodology.
- The project network changed constantly as the teams had to fix the network logic to fix initial network errors. This highlighted that project plans cannot be easily retrofitted into a TOC plan. There was a need for a methodical approach to converting existing project planning methodology to create TOC networks.
- The team did not change the nature of tasks. So the rework caused by concurrent engineering was never addressed. So tasks were split to introduce nebulous "ongoing" open-ended tasks so as to enable succeeding tasks to start earlier. For example Placement of piping PO's was split in two tasks - placement of critical piping PO's and "ongoing" piping activities. The latter task was just a placeholder for rework and iterations. This made it clear that certain groups of activities needed to planned as a single block and allow for iterations to happen within the block.

However concerto did create the sense of higher awareness of schedules and created a sense of flow. Managers felt the pull from successor tasks as they became more aware of the days left for predecessors to complete so as to meet end dates. Also gave focus on critical issues and highlighted the bottleneck issues more readily. The construction teams and other sub-contractors were also better informed. They let the project team know of their priorities creating similar type of pull that were intended by value streams.

In the end, the project did complete on time without overruns. But it did not avoid the ad-hoc resource mobilization pattern and needed more management attention than regular projects. This highlighted the need for a better approach to creating TOC network plans for larger projects.

7.3 DSM and VS role in implementing TOC

In this section we discuss how DSM and VS approach could have mitigated many of the problems encountered in TOC implementation in EPC projects.

- **Logistics of creating a F-S network:** TOC requires F-S relationships and network plans that has enough details to allow resource planning. If the tasks have to be finish to start but also fit into the current schedule requirements then we need to organize and arrange activities differently. Relying on traditional heuristics by brainstorming with few managers does not work given the scale of the EPC project network. We need a way to

a) Break down the problem into smaller networks and
b) Systemically analyze the interactions to determine a feasible schedule structure

Value Streams provided convenient way to break down the problem and DSM provides a way to analyze the interactions of tasks within each value stream to form a viable network.

- **To be stable, plans have to reflect reality:** As seen in our isometrics DSM analysis, project plans are idealistic and often don't reflect actual information flow might be different. TOC F-S planning does not allow for a finished activity to subsequent change due to rework requirements. TOC might even make the problem worse with its aggressive task deadline and rigid resource planning algorithms. It can lead to 90% syndrome (section 3.1) creating false sense of progress in beginning. This will then manifest itself as rapid consumption of buffers at later stages of project and nullify the benefit of using early indicators, as was the case with the pilot project. DSM allows us to capture true interactions across activities in a project and so can help form more realistic networks.

- **Stable network plan need to handles rework:** If planned and unplanned iterations are not clearly understood and provided for then the plans will go through continuous change, as seen in the pilot project. Traditional project plans do not allow for such iterations. Perhaps realizing that schedules will constantly change, project planners have always stayed at level 2 or 3 reporting for the project and left the detailed plans to respective departments. The pilots handled the issue by introducing new, open-ended tasks, however this not an effective solution. This in effect reintroduces the resource and schedule buffers at task level, the very issue that TOC is very much trying to avoid.

  DSM can help build a detailed but stable plan by identifying planned iterations and aggregating them into blocks that can be used in TOC network. The task duration for the blocks can allow for a certain number of iterations. This way we handle the iterations within the block without affecting rest of the network. Left to themselves the individual functional leads planning the TOC schedule on their own will never come up with this solution.

- **Breaking down overlapped tasks:** DSM also helps understand information flow problems by identifying unplanned iterations. The planning exercises for TOC revealed that some tasks are too big and needed to be broken down into their information elements. Also as the DSM study pointed out in chapter 6, release phases of documents need to be structured around information maturity and not on probabilistic estimates. However breaking all documents by information elements will make EPC projects run into tens of thousands of activities.[9] So we need to be selective on areas that need to be broken down, DSM can help identify the overlaps and also interactions that need to be teared. Using frameworks like the one developed by Krishnan et al (1997) we can select appropriate strategies for managing overlaps.

- **Cross-functional buffer management:** In the pilot project the Project Manager had to get closely involved with the schedule and allocated the buffers across the teams. However for larger projects this approach is not scalable. We need managers who can span across engineering disciplines and effectively manage buffer management and resource allocation. The focus of TOC buffer management is on critical paths and network branches that span department boundaries. VS organization (chapter 8) provides for the chain focus vs. task focus, allows cross-functional management of schedule and resource buffers. Each TOC critical path or network branch can be thought as a value stream.

7.4 Steps in preparing TOC networks

Since EPC projects are too big we need a logical structure to break down the network. Functional departments are not the best way to do this as they conceal issues like rework and concurrent engineering issues. As discussed in 5.1 value streams provide a better way to group projects into mutually independent networks. VS and DSM help TOC network by breaking down the problem and analyzing them in detail to find new ways of organization that will create a stable F-S network.

A TOC planning methodology leveraging value streams and DSM tools will involve the following steps.

1. Break down EPC project into value streams based on construction sequence.
2. Prepare comprehensive list of all tasks in a value stream (by working backwards from construction hardware / deliverables per value stream). Create concurrent engineering network plan for each VS.
3. Create a DSM matrix for each value stream tasks, using blocks approach (6.2) if needed. Use DSM to capture both the network dependencies (planning logic) and also the real patterns of information flow in projects.
4. Translate planning logic in DSM to a value stream network plan. Use the DSM real information flows to readjust the network plan to avoid feedback iterations.

[9] A upstream business acquired by Lummus actually tracked project schedules based on information data elements rather than activities. It had around 30,000 tasks and 20 project controls personnel per project. By contract downstream projects that are 3-4 times bigger in scope 10,000 tasks and 2 project controls personnel per project.

   a. Aggregate interdependent tasks (planned iterations) into a cross functional module that can be used as a F-S block in TOC.
   b. Reduce unplanned iterations (tendency for rework and change) by re-sequencing the network plan using DSM, changing the workflow to break down tasks or introducing review stages.
5. Use these standardized, reengineered value stream network plan for building a TOC network (by blowing up the network for project details like equipments, construction areas etc.,)

Thus DSM, VS and TOC interlinked. Value Streams break down EPC projects into manageable mini-projects. Within each value stream, DSM capture reality of concurrent engineering and find ways to improve by re-sequencing tasks, tearing down certain tasks and aggregating planned iterations. Once we form a workable F-S for each VS we can put the VS network plans to form a viable, overall project TOC project schedule.

8 Value streams based EPC project Organization

From our discussions it is clear that the main challenge in EPC projects is managing the information flow. We saw that DSM analysis and other anecdotal evidence repeatedly reinforce the need for taking a full system view of operations. To achieve these goals effectively, based on lean literature and internal discussions, the following value streams based organizational structure was proposed for EPC projects. Adopting a Value streams approach meant a widespread impact on the EPC project management structure. During the internship this was studied in detail. In this chapter we outline the value stream based organization proposal, its rationale, its impact on EPC project organization and preparatory steps needed to facilitate implementation. We summarize the results of results of a task force of cross-functional mangers formed to study the implications of value streams. Value streams approach needed redrawing of mental map of EPC projects and hence reorienting the project organization structure, realign of incentives and change supporting processes.

8.1 Value Stream Organization proposal

The essence of the approach is to break an EPC project into mini projects along the line of value streams. The goal of this exercise is to enable decentralized operational decision-making, foster cross-functional innovation, create a system flow and align incentives to end customer priorities. This un-bundling of projects is a common practice in upstream EPC business where the projects themselves are very modular. This is also the norm in on-site construction where a project is divided into independent areas. This method has been found very effective and gives operational clarity and focus to achieve high productivity. Value streams organization allows us to move this approach further up and bring it to design, engineering, and procurement phases. One of the main reasons that this was not done before is that the home office work was difficult to separate in any other way other than the functional disciplines. However value streams effort initiated in this thesis provided a basis for cross-functional unbundling of the work. The TOC approach provides a way to stage these changes gradually and helps us avoid drastic cold turkey changes, which are difficult to work in this conservative industry.

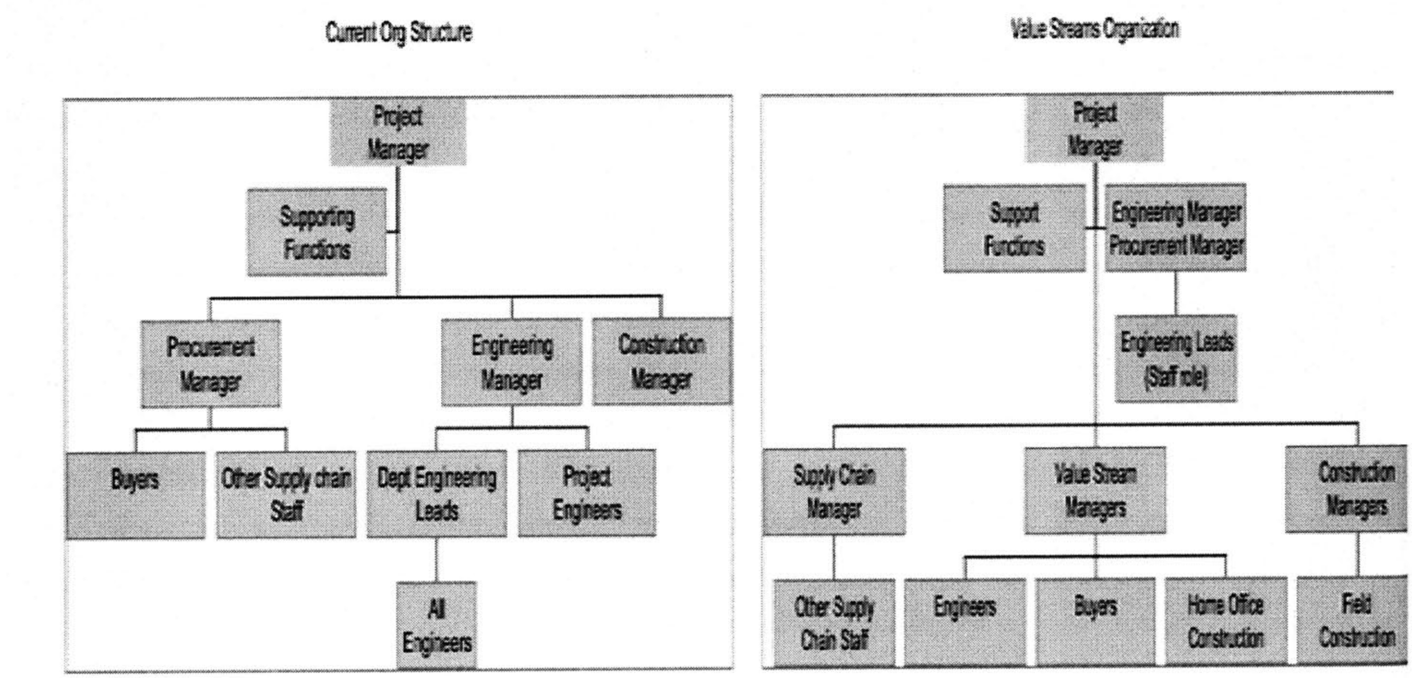
Proposed Organizational structure:

- Project is managed as a series of mini projects, each with its own manpower and procurement budgets. The end product of each value stream is to provide construction work front (incl. Materials and drawings) in timely manner.

- Each value stream will have direct control over a cross functional team of engineers and senior buyers. Home office construction personnel will be dotted line reporting into one or more value streams[10].
- Managers specifically trained to manage cross-functional teams will run each value stream. A manager can manage multiple value streams as these are staggered in time (figure 5.3).
- A Supply chain management team will oversee procurement and materials logistics for entire project and will contain all supply chain staff like expeditors, inspectors, materials coordinators etc. The senior buyers from each of the system teams will be dotted into this group.
- Outside of projects there will be a value stream champion for each stream of work in the organization. This is usually a senior manager who will take on the responsibility of institutionalizing cross-functional work process improvements using DSM, overlap analysis, lean principles etc.

Mapping to current Org structure: Figure 8.1 compares the proposed and existing project organizational structure. The key changes are as follows,

Figure 8-1 Proposed and Existing Project Organization Structure



- Currently functional departments have direct line control while coordinating roles like project engineers are staff roles. The proposal is to switch these roles. The rationale being that the checks and

[10] At ABB Lummus construction is heavily outsourced and there are typically only 1-2 home office construction staffs per project.

balances can be effectively provided even in a staff function whereas active coordination in a complex distributed concurrent engineering setup needs to be a line role in projects.

- The existing functional roles like engineering leads will become staff roles responsible for ensuring technical quality and adherence to standard procedures. The budget and delivery responsibility, which are difficult to manage effectively at a functional level, is transferred to the value stream managers.
- As part of the project executive team, the engineering and procurement managers will delegate operational responsibility to the value streams. They will focus on managing interfaces with clients and external contractors and provide necessary oversight.
- The home office organization, outside of projects, is unchanged and will continue to be along functional lines. This helps keep the benefits of a functional office organization like expertise building, best functional practices and personal development etc.

8.2 *Impact of the change on tools and supporting processes*

Many other supporting structures in EPC projects needed to be adopted to facilitate the change to new organization structure. We briefly discuss the impacted systems below,

- **Planning:** This is the most affected. However the value stream approach mapped well into TOC planning so the two efforts merged into one as discussed in chapter 7. The methodology and thinking of project planners needed to be adapted to incorporate value streams in project plans. Instead of using previous projects as templates, planners were to use rigorously developed, value streams based network templates as basis for project plan. Schedule hierarchies are created in a way so they can be rolled up both functionally as well as per value stream.

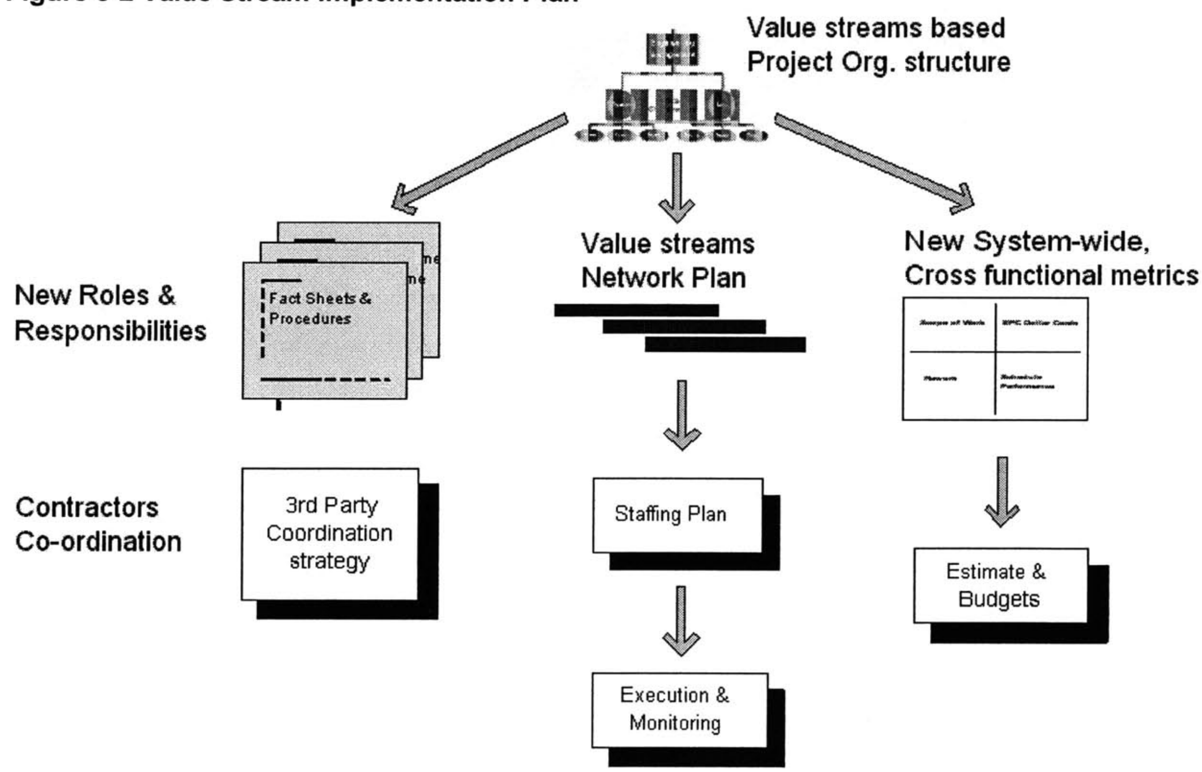
- **Metrics:** Measurement drives behavior and so the metrics and management reports needed be aligned along the value streams. The timesheet system for home office staff should be adapted to capture information on a value stream basis. This involves additional classification of task codes and also minor modifications to reporting hierarchy of existing IT systems. Project control systems had to be adapted so as to aggregate information (man-hours, procurement spends and schedule progress) both on functional and value stream basis.

  Also new metrics will need to be devised to substitute focus on man-hours with overall cost measure that reflects manpower utilization, procurement spend and cost of on-site construction delays. Also with TOC implementation individuals cannot be measured based on task durations, so new team level metrics that track performance and progress with respect to final construction work front needs to be devised.

- **Budgeting and Estimation:** To create accountability on value stream basis the project budgets needed to be allocated per value stream. This meant the project cost estimation, done during the bid phase of contracts, should also be realigned. This was however considered a second level task and could be derived from the efforts to convert project plans and metrics.
- **Redefinition of roles and functional procedures:** Extensive documented processes and procedures drive EPC industry operations. To start with the documents outlining the roles and responsibilities should be modified to reflect new authority and control structure. Also as process innovations happen in value streams, new mechanisms have to be created to update this into the formal procedures of multiple functions. The value stream champion role envisaged in the organization was expected to play this role.
- **IT Systems:** There were also other minor but nevertheless indispensable changes that were to be done on the way the document management tools and other communications systems are setup. Many other tools like the staffing allocation sheets needed to also change to adapt with the value streams approach.

Figure 8.2 shows the various steps involved in preparing the supporting systems required for VS based organization.

Figure 8-2 Value Stream Implementation Plan



8.3 Rationale for new Organization

The first step in enabling lean and productivity improvements in EPC projects was to start with effective team organization. Teams are natural units for information flow. More importantly mental models and hence behavior are shaped by organizational structure. The right management structure also empowers teams with full control and responsibility to create end customer value. It allows us to set incentives and measures that drive right behavior to meet project goals. If the value streams meet their goal, the project goals are automatically met. This is not the case with current functional organization.

The value stream approach solves many of the problems by creating appropriate organizational structure that matches actual workflow in projects. As we see below it fixes the two common issues found in the DSM analysis (chapter 6), is in line with TOC approach (chapter 7), solves many of the project issues (chapter 3) and those raised by the causal analysis (chapter 7) and also enables lean.

- **Enable faster information flow with Vendors:** By combining manpower and procurement budget together under one manager we enable better cross-functional tradeoffs. For instance procurement decisions can be more holistic to include delivery schedule and overall landed cost in its purchasing decisions. Creating cross-functional teams also has significant impact on behavioral patterns. For instance engineers will respond faster and follow-up more diligently with vendors, as they will be measured on final delivery to construction. Buyers will expedite certain orders to ensure schedule goals are met rather than wait for batching orders to achieve administrative efficiency. Such close interactions between procurement and engineering could theoretically also be achieved in a traditional functional structure. However current organizational structure and metrics do not drive such behavior.

- **Better handle client changes:** The value stream manager can see the impact the impact of delayed decisions on overall system flow and has direct incentives to manage the review process right. Currently engineering leads measure client changes in terms of incremental efforts for their department and do not base their decisions in terms of cost to other downstream functions. Project / engineering mangers cannot be present at all client technical meetings and so system-based, operational decision-making has to be pushed down in projects. Currently project engineers facilitate such decisions but this is done on an ad-hoc basis. Value streams create a mental map that facilitates system view. They also help create a visibly clear the total system cost of changes and so help provide concrete basis to push back client changes.

- **Complement TOC structure:** TOC eliminates task level buffers and creates chain buffers. Managing the chain buffers requires a cross functional view of entire workflow. In large projects it is not feasible for a project manager to manage all chain buffers. Since value streams map to critical paths of TOC and VS networks formed the basis for TOC planning (Chapter 7.3), value stream managers are natural choices for managing chain schedule and resource buffers. Also with TOC, engineers cannot be evaluated on their individual task times. Evaluating operational performance needs to take full chain view and this again can be done well by a cross-functional workflow manager – the value stream manager.

- **Effectively address common project problems:** Value stream organization addresses many of the common project issues that were discussed in chapter 3 and 6.4 (DSM causal analysis). It avoids sub-optimization, avoids focus on man-hours, enables taking a system view, creates appropriate metrics, avoids out of sequence work, reduces matrix conflicts and enables closer procurement and engineering coordination. *Perhaps the most important benefit is that it creates a right mental picture both internally and externally on the end goal in EPC projects.* It makes people realize that EPC is not about getting engineering done in lowest man-hours or getting lowest procurement costs. It rightly reorients the focus to delivering a cost efficient and time effective end solution on the site.

- **Facilitates Lean:** Most importantly value streams enable closer and continuous cross functional interactions which combined with better accountability can lead to innovations for meeting tighter schedule & budgets. By pushing down operational decision-making, it creates the environment for continuous improvement. It enables lean by creating a system view of information flow and creates an environment of pull from end consumers. VS also create standardized modular approach to projects which enables new cross-functional procedures, data / information handoffs, benchmarking etc., leading to across the board productivity improvement.

In summary value streams organization improves operational efficiency by *facilitating better information and workflow, creating better accountability and enabling cross-functional innovation.* It creates operational teams that are self sufficient in terms of information flow, work dependencies and skill requirements. Since teams are aligned towards project goals, they can and should be given more execution autonomy thus enabling more proactive & informed decision making at operational level in projects.

8.4 Issues in moving to new organizational structure

The proposal for changing the project organization raised many issues, some real and others perceived, in a very traditional and slow moving industry. Following are the key concerns that came up during the study,

Issues with breaking functional engineering boundaries: Each engineering group has its own strong internal identity and stereotypes about other functions. While they are used to working together in task forces, a formal project organization structure that brings them together is considered a big change. Even bigger issue was combining engineering and procurement functions together. However such cross-functional team structures are the key benefit of the new approach. Ideally EPC projects should be a predominantly commercial driven activity with focus on managing profit margins. The new structure breaks the perceived superiority of individual groups, brings down the walls and creates a balanced scorecard that combines engineering and procurement priorities. Achieving this mental transition however still remains a big challenge.

Issues with Delegating Authority: Projects are typically run by few seasoned hands who call all the shots. This often creates a bottleneck for decision-making and leads to reactive firefighting. However it is often difficult for project mangers and engineering managers to delegate authority and control to lower levels. This requires investment in training to prepare next rung of managers who can handle such responsibility. But it also requires maturity on the senior managers to be comfortable in delegating authority and manage by exception. It was critical to communicate the need for expanding decision-making capacity and improve the pace of decisions to cope with dynamic complexity of concurrent engineering and distributed execution. Lean is about gaining control on process by decentralizing operational decision-making. The transition to this counter intuitive approach is easier in manufacturing where there is faster feedback as productivity improvements are quickly reflected in process parameters. This is difficult in EPC projects where the work is knowledge based information flow and the process involved take months and years to complete.

Difficulty in communicating with external interfaces: EPC industry as shown in figure 2.1 is a highly integrated activity. Making this sort of a change in an industry where the clients and other contractors work in traditional way is a big challenge. This problem is even more complicated with the outsourcing of detailed engineering activities to low cost development centers. These third party agencies deal with multiple EPC contractors and will resist adapting to a new project organization for ABB Lummus. This is a typical challenge for most lean, systems-thinking rollouts. Lean enterprise advocates the management of entire supply chain through interventions at the level CEO and industry trade groups. Some of the operational issues were mitigated with the ability to translate between functions and value streams in systems like metrics, management reports etc.

The biggest issue was inertia to change and persistent questions as to whether this is the 'right structure. Preparing an organization to even consider such a change was a significant challenge and formed the bulk of the efforts of the internship. In 8.6 we discuss some of these leadership challenges involved in making the case for change.

8.5 Current status and Future steps

Given the results from DSM analysis and the alignment with TOC, ABB Lummus has started adopting some of the recommendations given in this chapter. A dedicated effort has been created to adapt value streams and a big EPC project (> 1 Bn Euros) is being currently planned along value streams basis. There is an active debate within the project team on implementing metrics changes that will measure performance along the line of value streams. The role of a value stream manager is bound to solidify as TOC implementation enforces a cross functional management of resource and schedule buffers. Depending on the early success of the TOC and value stream implementation in this project, other changes like formal role redefinitions, budgeting and estimation will follow.

The value streams based organization is seen as the first of a three-step process to improve project productivity using lean principles. The program outlined below has committed budgets and staffing and is expected to complete by 2007.

1. **Value Stream (System) Based Project Management:** Implement new cross-functional project organization that focus on stream of activities that create end customer value. Create network plans for each value stream and incorporate that into the TOC implementation in projects. Create metrics that drive productivity in value streams.
2. **Individual Value Stream (System) Improvements:** For individual value streams apply DSM analysis and lean approaches to improve operational efficiency. Create flow in the value stream through pull from end customer.
3. **Task content improvements:** Focus on bottleneck tasks in the value stream and improve them by identifying and eliminating waste. Create an environment for continuous improvement.

8.6 Leadership challenges - Making a case for change

Enabling change by shifting mindsets in a very conservative industry was a constant challenge and took most of the efforts during the internship. Here we briefly discuss some of the strategies that were effective in getting acceptance for value streams.

- **Positioning the idea right:** Though the value streams proposal had been successful in other industries, it has not been tried in EPC industry but had some parallels too previous initiatives at Lummus. The concept was difficult to position in an organization that had a tendency to dismiss previously explored ideas as failures and dismiss new concepts as unworkable in EPC industry. Through a series of informal one-on-one discussions, brainstorming team sessions and repeated management meetings we were able to get buy-in for the idea. We had to show that value streams concepts were built on ideas similar to successful internal concepts while at the same time it offered some new insights that will ensure sustained implementation success. Here the role of internal champions was extremely important.

- **Importance of internal champions:** EPC projects typically span over 2-3 years and new projects takes years to materialize. Given the internship timeframe and also the involved nature of EPC processes, a key success factor in the internship was in identifying strong internal champions at each of the offices of ABB Lummus. While this meant that things moved slowly at first, it also ensured longevity and integration with internal goals. The championing of the ideas by internal champions, as opposed to a student intern, helped add tremendous organizational credibility to the approach.

- **Build broader support:** In internships the natural tendency is to quickly jump into some analysis to show progress. However due to the project circumstances and the need to identify internal champion, much of the internship time was spent in convincing multiple layers of management. At one stage there were intense discussions with over 15 managers at Houston office for close to two months. However in retrospect this was a very productive phase of the project that helped get broader support for the program. These sessions were crucial to help identify, in a non-confrontational environment, key reasons that made feel people threatened or uneasy with the change. This was helpful in building a clear rationale for change and presenting potential new opportunities to the affected groups. In addition, the continued exposure to the concept created familiarity and helped reduce resistance. Also the word of mouth informal opinions that circulated proved effective in building organizational support.

- **Leverage the political momentum:** Despite its strategic rationale, the program did not take off till we found a way to tap into existing momentum of TOC project. Even though TOC and lean has many complementary benefits, the two programs had different internal champions and were seen as separate efforts. The key turning point for value streams program happened when The Hague management got convinced value streams and concurrent-engineering tools enabled TOC implementation. Also the reception to the idea was much more immediate at Houston office which however had limited resources for implementation. However by leveraging the momentum in Houston, we were able to launch a cross-office standardization effort around value streams and get commitment and funding from The Hague office.

The slow but steady approach in getting systemic organizational buy-in was key to the longevity of the ideas discussed in this thesis at ABB Lummus. During the course of the internship the chief executive who sponsored the internship left the firm. A key internal champion at Houston quit the company and a project in Houston that was to be the first pilot for the effort got scrapped. The Hague pilot project got delayed by nine months. Any of this would have broken the internship and shelved the ideas, if it were not for the success in recruiting key internal champions and the time spent in building broader acceptance.

9 Conclusion

Changing external environment in EPC industry has forced the projects to adopt concurrent engineering and distributed global execution. The current mental models in the industry that drive organization, incentive structure and behavior are all still geared to a sequential execution mode leading to major productivity issues. The thesis uses a combination of concepts from value streams and DSM to recommend a structure that can solve many of these problems and provide a basis for implementing lean continuous improvement.

The approach of unbundling large projects into smaller, independent modules has been very effective in upstream EPC projects and on-site construction work. Value streams bring this concept to design and engineering phase of downstream projects. In this thesis we identified value streams based on first principles, which un-bundle a downstream EPC project into nine independent mini-projects. We show that value streams provide a better alternative to functional boundaries in creating appropriate mental modules for executing EPC projects.

We then analyzed a key value chain, isometrics analysis, using Design Structure Matrix (DSM). To deal with the size and complexity of EPC value streams we evolved a four-step approach for DSM analysis. This included breaking down the value stream into conceptual phases, creating a detailed network plan, grouping activities into DSM blocks and mapping the interactions between the blocks. We used a causal analysis map to summarize the analysis and showed that there is a reinforcing pattern of root causes that lead to rework. The causal analysis map and DSM analysis were powerful visual presentations and made a strong case for system-based approach to break the rework cycle.

To better handle the intense coordination challenges of distributed concurrent engineering we suggested a value stream based project organization as opposed to functional organization structure. Value streams breaks down EPC downstream project into a series a mini-projects that can be managed independently to achieve maximum operational inefficiency. We showed how this approach facilitates orderly information and workflow, creates better accountability and enables cross-functional innovation. By aligning the incentives and objectives of teams with projects, value stream organization pushed down operational decision making setting the stage for continuous work process improvement.

Finally to gain internal momentum for the proposal we tied the value stream implementation to Theory of Constrains implementation. We showed how a combination of VS and DSM approach could help overcome the issues faced in TOC EPC pilot project.

The internship effort and ideas presented in this thesis helped get management buy-in at both offices of ABB Lummus for a value streams based approach to EPC projects. As a result a dedicated effort was created and a big EPC project (> 1 Bn Euros) is being planned along value streams basis.

In this thesis we extend the envelope for value stream application from manufacturing and product development domain and apply it to large-scale EPC projects. Building on the work of Millard (2001), we demonstrate that DSM can be an effective tool for value stream analysis in information centric domains like EPC projects. We finally show that VS organization and DSM analysis could be powerful complementary to TOC approach to project management. Most importantly we put forth a case for value stream based project organization to transform operational productivity in EPC industry.

Appendix I Framework for Risk Evaluation in EPC Projects

Rationale:

There is a broad consensus within EPC industry that projects vary considerably in their risk. The external factors determined during the bid / contract of project determines the outer envelop of eventual success / failure for projects. This approach formalizes that internal experience and intuition into a quantifiable risk rating scheme that gives a concrete feel for project risk and predicts expected loss / profitability of projects based on past history.

Approach:

- Internal discussions have identified 7 macro factors as being critical to determining eventual success probability for projects.
- Each factor has a score from 0 to 2 depending on the specified criteria to measure their risk. The scores across the factors are additive and their overall sum gives the project risk score.
- Some of the factors by themselves may not be bad if there are other mitigating conditions. The additive nature of the factors in this rating takes care of that interdependency.
- Overall project score of above 5 indicates an above average risk project. The expected loss for each project with a given score is inferred from a lookup table. The table is obtained by maps past history of projects within Lummus.
- The scale is expected to be non-linear with losses increasing rapidly as we approach the higher end of the spectrum.

Rating Methodology:

1. **Customer** (scale of 0 to 1)

- Give a score of 1 if any of the following conditions are true
  - 3 out 5 past projects for client of similar contract type went bad for contractor
  - There is reason to believe that client has clear intent to skim contractor margins
  - The project is not bid by any of the tier 1 firms and other top contractors have walked away from the client.

2. **Country** (scale of 0 to 1)

- Give a score of 1 if all of the conditions below are true
  - Lummus has no prior experience managing projects in the country / region

- None of our partner firms has experience dealing with the country / region
- The level of construction activity competing for similar resources is high

3. **Partner** (scale of 0 to 1)

- Give a score of 1 if all of the conditions below are true
  - We have no prior experience working with the partner
  - We have LSTK responsibility and we do not control full EPC scope

4. **Team** (scale of 0 to 2)

- Give a score of 1 if
  - The 3 of the top 5 key managers in the project have no prior experience with a project of comparable size or complexity (one way to judge complexity is to use the overall score in this risk rating methodology)
  - Subjective evaluation of quality, experience of team does not meet comfort levels
- Additional score of 1 if
  - The work is done in a HVEC center that we have no prior experience
  - The HVEC capacity utilization is above 80%, thus stretching its key resources

5. **Value at Risk** (scale of 0 to 2)

- Give a score of 1 if the contract is LSTK
- Additional score of 1 if the contract value at risk is > 200M

6. **Quality of Bid/ Contract** (scale of 0 to 2)

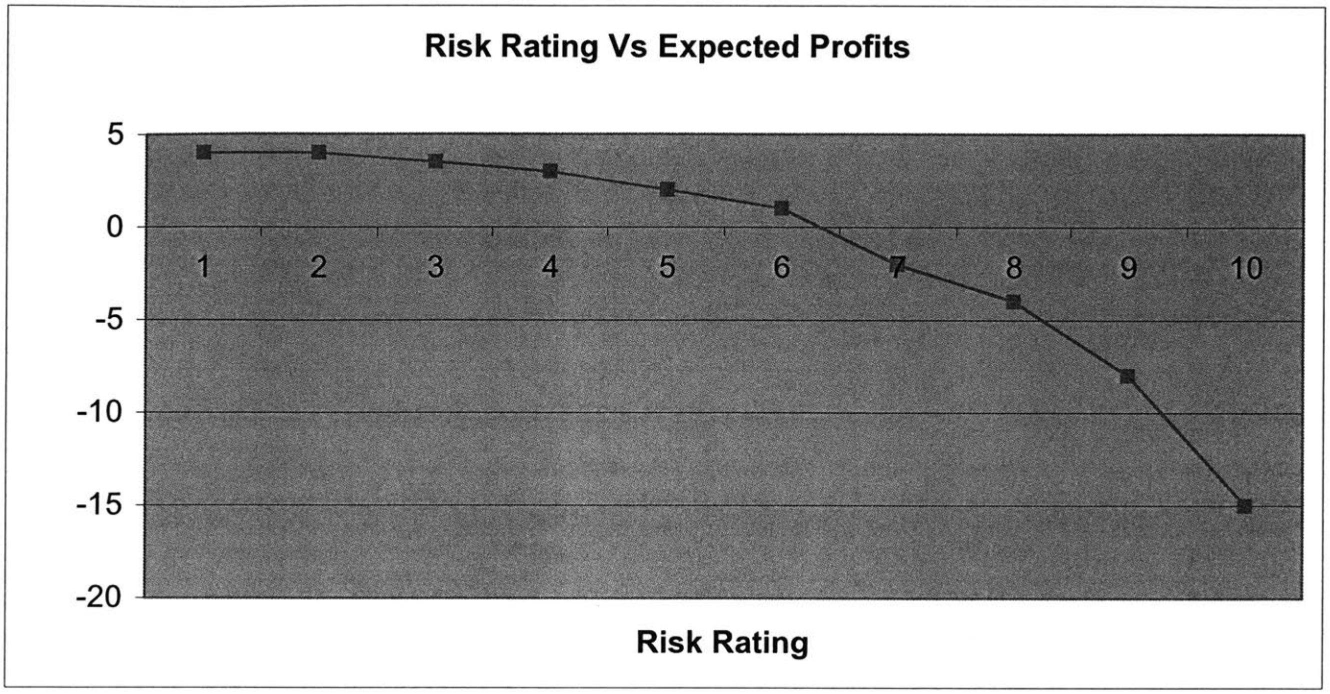
- Give a score of 1 if the actual contract budget is 20% below internal estimates
- Additional score of 1 if the Contract / Bid preparation team has a past history of bad projects

7. **Supply Environment** (scale of 0 to 1)

- Give a score of 1 if any of the conditions is true
  - Our 80% of our suppliers for key equipments and parts are projected to be near full capacity during peak purchase period of the project
  - Our target buyout ratio for the project is above 8%

<u>Expected Profitability Chart</u>

Since the factors in this rating methodology are macro factors it should be easy to go back and calculate risk factors of Lummus projects in the past 5 – 7 years. We can then plot a curve of a project's estimated risk rating (on X axis) against actual realized profit / loss (as percentage of overall contract value on Y axis). The resulting curve should look similar to the graph shown below and can be used to predict expected loss / success of future projects based on their risk rating.



References

1. Backhouse, C.J and Brookes, N.J (1996). Concurrent Engineering, What's Working Where, Gower, Brookfield, VT: The Design Council.
2. Eppinger S.D, Innovation at the speed of Information, Harvard Business Review January 2001.
3. Eppinger (1997), A Planning Method for Integration Of Large-Scale Engineering Systems, ICED 97 Tampere, August 19-21, 1997.
4. Eppinger, S., Whitney, D., Smith, R. and Gebala, D. "A Model-Based Method for Organizing Tasks in Product Development" Research in Engineering Design, Vol.6, 1-13,1994.
5. Ford D,N and Sterman J.D, The Liar's Club: Concealing Rework in Concurrent Development, Concurrent Engineering: Research and Applications, September 2003
6. Ford D.N and Sterman J.D, Overcoming the 90% syndrome: Iteration management in concurrent development projects, Concurrent Engineering: Research and Development, September 2003
7. Krishnan, V., Eppinger, S. and Whitney, D. "A Model Based Framework too Overlap Product Development Activities", *Management Science Vo 43, No.4, Aril 1997.*
8. McManus, H.L, and Millard, R.L, "Value Stream Analysis and Mapping for Product Development" *The International Council of the Aeronautical Sciences, 2002.*
9. Millard, R. "Value stream analysis and mapping for product development" *MIT Master's thesis, June 2001.*
10. Petakis S.T and Pultar M, Modeling detailed information flows in building design with the parameter based design structure matrix, Elsevier Ltd 2005.
11. Repenning N.P and Sterman J.D, Nobody Ever Gets Credit For Fixing Problems That Never Happened, California Management Review Summer 2001.
12. Repenning N.P, Goncalves Paulo and Black L.J, Past the Tipping Point: The Persistence of Firefighting in Product Development, California Management Review Summer 2001.
13. Rother, M., and Shook, J., "Learning To See: Value Stream Mapping to Add Value and Eliminate Muda" *Lean Enterprise Institute, 1999.*
14. Sterman, J., "Business Dynamics: Systems Thinking and Modeling for a Complex World" *Irwin/ McGraw-Hill, 2000.*
15. Sterman, J.D (1994) Learning in and about complex systems, Systems Dynamics Review, 10 (2-3): 291-330
16. Browning, T "Modeling and analyzing cost, schedule, and performance in complex system product development" *MIT Ph.D. thesis, 1998.*