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SUPPLY CHAIN PROCESS DESIGN TOOLKIT (SCPDT)

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ABSTRACT

A characteristic that will distinguish successful manufacturing enterprises of the next millennium is *agility:* the ability to respond quickly, proactively, and aggressively to unpredictable change. The use of extended virtual enterprise *Supply Chains (SC)* to achieve agility is becoming increasingly prevalent. A key problem in constructing effective SCs is the lack of methods and tools to support the integration of processes and systems into shared SC processes and systems. This paper describes the architecture and concept of operation of the Supply Chain Process Design Toolkit (SCPDT), an integrated software system that addresses the challenge of seamless and efficient integration. The SCPDT enables the analysis and design of Supply Chain (SC) *processes*. SCPDT facilitates key SC process engineering tasks including 1) AS-IS process base-lining and assessment, 2) collaborative TO-BE process requirements definition, 3) SC process integration and harmonization, 4) TO-BE process design trade-off analysis, and 5) TO-BE process planning and implementation.

1 INTRODUCTION

There is a growing recognition that tomorrow's manufacturing enterprises must be *agile*; that is, these enterprises must be capable of operating profitably in a competitive environment with continually changing customer opportunities. As a consequence, a prominent characteristic that will distinguish successful manufacturing enterprises of the next millennium will be the ability to respond quickly, proactively, and aggressively to unpredictable change. The use of extended virtual enterprise *Supply Chains (SC)* to achieve this goal is becoming increasingly prevalent.

An enterprise is a system whose framework is defined by a collection of processes and information. Because of the rate of unpredictable change and the demand in today's market for high quality products, agility often requires the collaboration of multiple enterprises, each contributing their core competencies to the supply chain. Thus, as an enterprise system itself, the SC will have its *own* processes and information systems, and these processes and systems must also be rapidly defined, designed, constructed, and implemented. In addition, the SC processes and information systems must integrate seamlessly with those of the member organizations. This integration extends from such simple processes as time and attendance recording, to more complex processes such as material ordering and receiving, and to still more complex processes such as Integrated Product and Process Design (IPPD). In short, the central problem in the construction of effective SCs is the lack of methods and tools to support the integration of processes and systems from several organizations into shared SC processes and systems.

This paper describes the architecture and concept of operation of the Supply Chain Process Design Toolkit (SCPDT), an integrated software system that addresses the challenge of seamless and efficient integration. The SCPDT enables the analysis and design of Supply Chain (SC) *processes*. SCPDT facilitates key SC process engineering tasks including 1) AS-IS process base-lining and assessment, 2) collaborative TO-BE process requirements definition, 3) SC process integration and harmonization, 4) TO-BE process design trade-off analysis, and 5) TO-BE process planning and implementation.

2 MOTIVATIONS

As described earlier, planning, designing, and implementing a supply chain in today's world raises many challenges that the SCPDT is intended to address.

1. Members of a SC must *rapidly* design and *agree* upon a common set of core processes, terminology, and organization structure.

2. Traditional process modeling techniques generally lack features required for describing process knowledge and process structures.
3. The distributed negotiation-based nature of the SC core process design requires that process knowledge that is described at different levels of abstraction using domain specific terminology and housed in a heterogeneous collection of tools be shared.
4. SC designers' lack of a common set of template reference models (i.e., a supply chain process handbook) that have a generally accepted validity and well defined criteria for application.
5. Members must integrate their processes and information systems with those of the SC.
6. Engineering analysis must generate performance predictions of the SC processes, the modified member company processes, and the overall integrated processes.
7. Organizational structures and management strategies must be designed for the SC and evolved within the member companies.

Converting businesses, technologies, and the workforce is far from easy. Successful business processes are optimized to support a collection of customer-derived and customer-focused paradigms. These paradigms form the basic operating philosophies and rules that permeate the entire enterprise and define the product/service transformation process. Once established, business philosophies and rules define the behavioral responses and operational capabilities of the organization. Thus, given the diverse nature of the members of a SC team, there are many problems facing the SC engineer. These problems are outlined in the following list.

1. Most organizations do not have up-to-date enterprise models. The rapid design of SC processes that are compatible or at least able to be interfaced with the existing member processes must be preceded with a rapid definition of the member processes. The differences in terminology as well as the differences in process and information systems highlight the critical need for the integration of process and ontology models. In addition, different organizations (and even different groups in the same organization) typically will use different process modeling tools, each with its way of representing process information.
2. In spite of significant progress in knowledge representation techniques in the past two decades, there is a lack of representations for knowledge about *enterprises*. Particularly lacking to date are techniques, languages, and tools to represent knowledge about *processes* at the *enterprise* level. Our observations show that process knowledge modeling has been neglected at the expense of research focused on *product or physical process* knowledge representation.
3. No process is independent of the organization(s) which must execute the process, and no organization is independent of the processes which it must execute. The lack of methods and tools for the design of organizational structures to support process execution makes it difficult to design an agile organization. This situation is even more complicated when designing extended supply chains.
4. Because of the complexity of most SCs, the design of an SC will always require knowledge of processes that are unfamiliar to any SC team member. However, there is no easily accessible library of general process *templates*, a set of reference models, that can be serve as guides to process design.
5. The success of an SC is critically dependent on the quality and correctness of the SC processes. Therefore, engineering analysis tools that can rapidly generate performance predictions of the SC processes, the modified member company processes, and the overall integrated processes are needed.
6. In order for a collection of enterprises to form a SC, they must collaborate in its design. Teams of representatives from each member enterprise must be able to meet (either physically or over the network, either concurrently or asynchronously) and brainstorm, classify, and elaborate/outline ideas and concepts for the SC. They must be able to achieve consensus.

3 THE SCPDT SOLUTION

These issues reveal the need for an integrated product, process, business, and information system development strategy supported by technologies that enable simultaneous *business process* and *information infrastructure* design. We describe a Supply Chain Process Design Toolkit (SCPDT) that addresses these needs. The unique characteristics and challenges of the SC environment motivate the need for Business Reengineering technologies specifically targeted for the development of efficient and evolutionary business processes. Furthermore, agility and rapid responsiveness—key characteristics of the supply chain—can only be made possible with technologies capable of delivering design-level, rather than documentation-level, support. Knowledge-based, model-driven systems definition, design, analysis, and (eventually) generation offer the promise of supplanting the patchwork-fix paradigm and bring agility to SC business processes through their supporting process and information infrastructure.

The SCPDT solution will support the following application scenario. In order to support the definition and design of a supply chain, the participants must perform the following steps.

1. Scope and bound the mission and functions of the SC.
2. Identify the information that must be managed by the SC independent of the members and the information that must be managed by the members to support the SC.
3. Identify the required processes to achieve the functional goals of the SC.
4. Identify the appropriate process descriptions from component SC enterprises.
5. Translate process descriptions into a common representation.
6. Import process descriptions into the integration environment.
7. Stitch together process descriptions from component enterprises to form end-to-end supply chain processes.
8. Tailor the SC-specific processes.
9. Identify roles and responsibilities.
10. Capture and manage terminological and semantic agreements among the SC members.
11. Analyze performance metrics of the SC processes.
12. Analyze cost metrics of the SC processes.
13. Store and manage all models and data associated with the evolving SC design.

3.1 Supply Chain Process Design Toolkit (SCPDT) Architecture

The SCPDT is a collection of COTS and advanced prototypes that have been assembled to provide intelligent support for *supply chain process integration and design* (Figure 1). The SCPDT allows SC *process integration engineers* to design and analyze processes with the *same level of precision* currently provided by CAD, CAE, and CAM tools for *the product engineer*. The key subsystems of the SCPDT are the Process Construction Workbench (PCW), the Process Design Assistant (PDA), the Agenda Manager (AM), the Process Template Library (PTL), and the Process Analysis Workbench (PAW). The SCPDT also includes interoperability mechanisms such as the En-

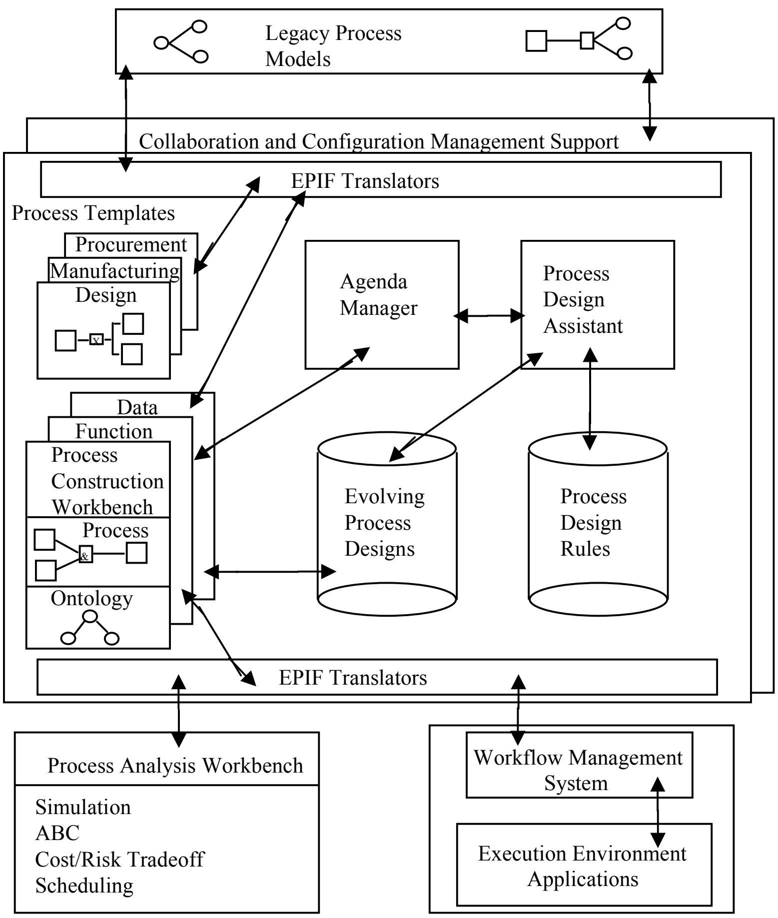

Figure 1: SCPDT Architecture

hanced Process Interchange Format (EPIF) translators and workflow translators.

At the front-end, the SCPDT allows for the import of process descriptions/models from different process modeling tools. The Extended Process Interchange Format (EPIF) translators allow for the delivery of process knowledge originating from multiple, disparate formats in a common, standard form to the process development environment. Using the EPIF as the common intermediary, the process descriptions are converted to a common language that is accessible by the PCW and the PDA. At the back end, the SCPDT generates process scheduling output that can be processed by project management tools such as MS Project™ and workflow specifications that can be processed by workflow management systems such as WorkXpert™.

The PCW facilitates the construction of end-to-end integrated process models from piecewise process models or model fragments. It allows for the "stitching together" of end-to-end enterprise processes from piecewise process segments. It also draws from a repository of re-usable process templates that includes the MIT Process Handbook (Malone et. al 1993). The architecture of the PCW is based on an integrated modeling tool called ModelMosaic (Fillion and Crump 1998). ModelMosaic provides for integrated supply chain modeling and analysis.

The PDA is a knowledge based process diagnosis and advice tool. It is a rule-based system that identifies potential problems in the designed model and offers advice to resolve these problems. The PDA provides intelligent support for process design diagnosis, and qualitative analysis to support process improvement and design trade-offs. The PDA and the PCW are linked to the SCPDT Agenda Manager (AM), which helps manage and control process development efforts.

The AM manages a list of agenda/action items in order to progressively refine and improve the process models. The AM is also used to plan the implementation of the process once the design has been completed. The AM inter-operates with commercial project management tools such as MS Project™.

The PAW provides support for different quantitative process analysis and design trade-off techniques. Process analysis techniques supported include 1) Systems simulation, 2) Activity Based Costing, 3) Life Cycle Costing, and 4) Schedule Analysis.

3.2 Using the SCPDT for Supply Chain Process Design

This section describes how to develop integrated supply chain process designs using the SCPDT. The activities involved in process integration and design and the relationships between these activities are described.

Figure 2 shows an IDEFØ function model of the process integration and design process. The rest of this section describes the main activities depicted in this model in the context of an example application problem situation.

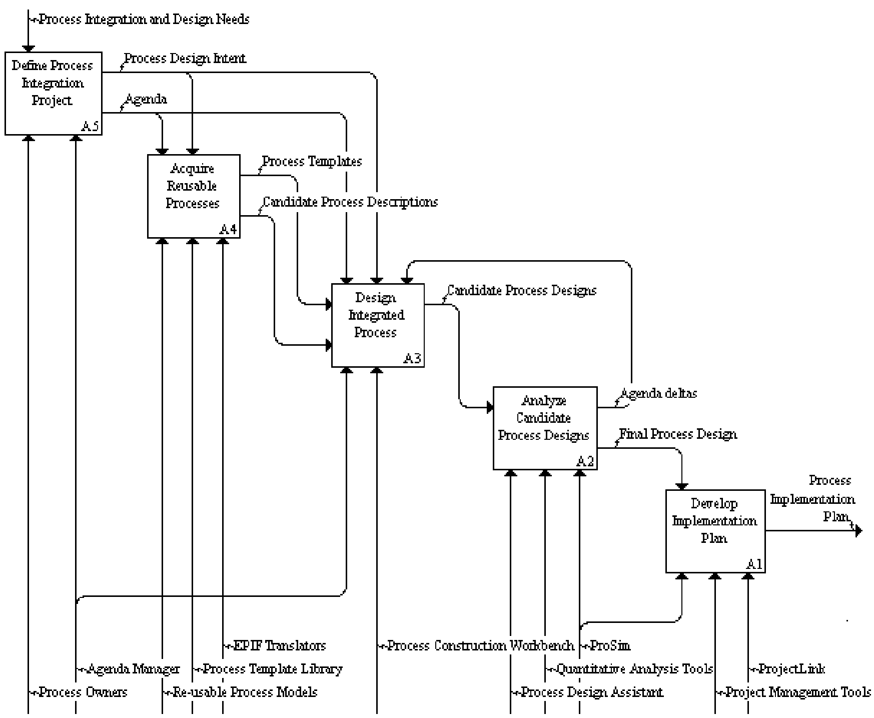

Figure 2: Process Integration and Design Function Model

3.2.1 Example Problem Situation

The following problem situation is used to illustrate how supply chain process design is done using the SCPDT. A manufacturing enterprise (X) currently manufactures two parts and an assembly of those two parts. To reduce labor and materials costs, the enterprise wants to off-load some of its operations to a process planning and manufacturing enterprise (Y) while continuing to design the component parts and the assembly. The CEOs of X and Y decide to team together to form an integrated supply chain (a virtual enterprise) called Z. An initial assessment reveals that the two enterprises (X and Y) already have established Engineering Change Management (ECM) processes in place. Thus, forming the supply chain entails the creation of a new, integrated ECM process by integrating X's and Y's existing processes.

The functional areas that are the target of this process integration effort include

- design of the parts and the assembly,
- process planning for each part,
- manufacture of each part, and
- management and scheduling functions associated with these activities.

3.2.2 Define Process Development Project

The goals, intent, and agenda of the supply chain process integration and design effort need to be defined and an agenda must developed that is specific enough to facilitate the definition of 1) SC process evaluation metrics and 2) products (outputs) of the SC process development project. Z's process development project goal statement is contained in the following paragraph.

Design an Engineering Change Management (ECM) process for SC enterprise Z that will track and manage engineering changes to Z's product.

Process intent includes 1) specification of the process design performance metrics and 2) definition of the products of the process and the customers. Enterprise Z's metrics are 1) Average Process Time <= 20 days, 2) Process Cost <= $100, 000 per month (over the life cycle of the process), and 3) Process Time Variability <= 5%.

3.2.3 Acquire Re-Usable Processes

Once the goals of the SC process integration and design effort have been established, an important initial activity in process design is to select candidate process templates that will provide a "starting solution" for the process integration and design effort.

3.2.4 Select Templates

Early in the process development project, the supply chain process integration engineer will browse the SCPDT library of process templates and copy processes or process fragments that are relevant to the design goals. The MIT Process Handbook is the Process Template Library for the SCPDT (Malone et. al 93). The Process handbook provides support for browsing and navigating through taxonomies of processes to help identify "process ideas" for the process development project. The Process Handbook translates processes that have been selected from the repository to the Enhanced Process Interchange Format (EPIF). The process templates are then read into the SCPDT using the SCPDT EPIF translator.

3.2.5 Import Re-Usable Process Descriptions

The SC process integration engineer would contact the owners of the ECM processes at the member organizations of the supply chain and ask them to submit existing process models. It is assumed that process descriptions exist in electronic form within the member organizations. Suppose that X's ECM process is stored as a ProVision™ model and Y's ECM process is stored as a Visio™ model. The information in these process models is transferred to the SCPDT through EPIF as follows: 1) convert from ProVision to EPIF using a ProVision->EPIF translator, 2) convert from Visio to EPIF using a Visio->EPIF translator, and 3) import the two EPIF files into the SCPDT using the EPIF->SCPDT translator. Note that the value of a well-founded process knowledge representation language (the EPIF) is apparent at this stage; the process knowledge stored in two different enterprises is rapidly transferred to a form that permits shared understanding and re-use for subsequent process design and analysis activities. At this point, Z's SC process integration engineer can look at the process descriptions from A and B in a language/format that the SCPDT user can understand.

3.2.6 Design Integrated Process

Currently, supply chain process design is often thought of more as an art than a science. For this reason, the task of actually designing any organizational process can prove to be quite difficult. In actuality, it may be better to think of process design as an iterative process of refinement. Rather than being a set of clearly defined, sequential steps, the design process may be better represented by a set of successive, though less-precise, stages that eventually lead to an ideal process design for a given scenario. The SC Process Integration Engineer does not follow a list of sequential design steps, but, rather, relies on a set of acquired process design skills that will be employed in any one of a variety of process design scenarios that might be encountered.

Because process design is a design endeavor, it is an inductive, iterative process. Initial designs are developed, these are analyzed/evaluated against design performance criteria, and the analysis results are used to refine the design. This process iterates until an acceptable design is produced. The primitive design activities are sketched in Figure 3.

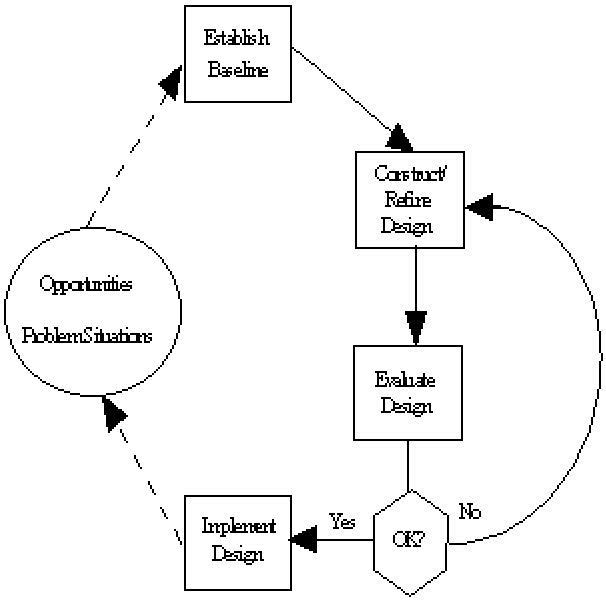

Figure 3: The Design Process

Activities, or modes of thought, supported by the SCPDT include 1) Process construction, 2) Visual analysis and design debugging, 3) Qualitative analyses, and 4) Quantitative analyses.

3.2.7 Analyze Candidate Process Designs

The SCPDT provides different flavors of analysis support. Two major groups of analyses techniques are supported: 1) Qualitative Analysis (QA) and 2) Quantitative Analysis (QNA).

QA techniques are approximate methods used to diagnose candidate process designs based on the information stored within a process design. The QA currently provided by the SCPDT is based on a set of process integration and design heuristics/rules. KBSI has, in fact, evolved a repository of process integration and design rules. These rules are implemented in the Process Design Assistant (PDA), a key subsystem of the SCPDT.

QNA techniques are based on mathematical/logical methods and are typically more rigorous and exact. The SCPDT supports the following QNA techniques: 1) Systems Simulation, 2) Activity Based Costing, 3) Life Cycle Costing, and 4) PERT/CPM Schedule Analysis. The SCPDT contains a set of integrated tools for supporting these QNA techniques. Specifically, PROSIM® and WITNESS® support Systems Simulation, AIØ WIN® and EasyABC® Plus™ support Activity Based Costing, SMARTCOST™ and MSExcel™ support Life Cycle Costing, and PROJECTLINK™ and MSProject™ support Schedule Analysis.

3.2.8 Qualitative Analysis

The Process Design Assistant (PDA) provides knowledge-based support for qualitative supply chain process analysis. The PDA has a rule base which stores heuristics/rules that support: 1) diagnosis of potential problems in the designed process, 2) consistency and completeness checking, and 3) process improvement—advice to move from a current design state to a desired target design state.

3.2.9 Quantitative Analysis

As noted earlier, the SCPDT supports multiple modes of quantitative analysis. The SCPDT PROSIM® tool automatically generated the WITNESS® model. Simulation is typically used to analyze processes to determine performance metrics such as flow time, resource utilization, throughput, work-in-process, waiting time, etc. The analysis results are used to refine the process design or as the basis to compare and perform trade-offs between alternative designs.

Once the quantitative analyses are complete (using one of more of the different analysis techniques listed earlier in this section), the results are used to 1) select a "best" design and/or 2) refine and fine-tune the selected process design for implementation.

3.2.10 Develop Implementation Plan

The designed process needs to be planned and implemented. The SCPDT PROJECTLINK™ tool supports the development of a project plan to implement the completed process design. PROJECTLINK™ automatically generates project plans in MSProject™, a useful tool for project scheduling, schedule analysis, and project management.

4 SCPDT APPLICATIONS AND BENEFITS

There have been several successful applications of the SCPDT that have delivered significant benefits to different end user communities. Two of these SCPDT applications are outlined in the following sections.

4.1 Development of a Reengineered Supply Support Process for a Military Parts Acquisition Supply Chain

4.1.1 The Problem

The goal was to analyze and redesign the U.S. Air Force acquisition supply chain processes for preoperational, interim contractor support of initial and replenishment spares. An Integrated Product Team (IPT) was formed to accomplish this goal. An IPT is formed each time the government purchases a new weapon system and exists during the life cycle of the system. The IPT is thus an extended (virtual) supply chain and includes the Government, Contractors, and Suppliers as participating organizations. The objectives of this IPT were to 1) study the AS-IS acquisition process, 2) design a TO-BE process, and 3) develop a plan to implement the redesigned process.

4.1.2 The Solution

The SCPDT tools were used by to analyze and redesign the Air Force spares acquisition supply chain process.

The SCPDT tools were first used by the IPT members to capture and analyze the AS-IS Supply Support Process. The SCPDT AS-IS modeling activities 1) developed a shared understanding of the process, 2) provided a standard framework for collecting performance data, 3) detailed the key process steps in the Supply Support Process for each phase, and 4) isolated those portions of the process with the most significant payback potential.

The AS-IS process analysis led to several candidate redesign options. Simulation models of the TO-BE supply chain design options were developed using the SCPDT PROSIM® and WITNESS® tools. The overall simulation was built by piecing together multiple process model fragments. Figure 4 shows IDEF3 fragments of the redesigned contractor-operated and the government-operated supply chain process. These IDEF3 process flow model fragments were integrated and converted to an executable simulation model. The WITNESS® model generated from PROSIM® was used to analyze the performance of the redesigned process and to validate the application benefits.

4.1.3 Benefits

The designed supply support process developed was targeted for Air Force-wide implementation. A Cost Benefit Analysis indicated a Worst Case ROI of 14:1 and a Most Probable value of 29:1. The expected cost savings/avoidance is in the range $440M to $668M.

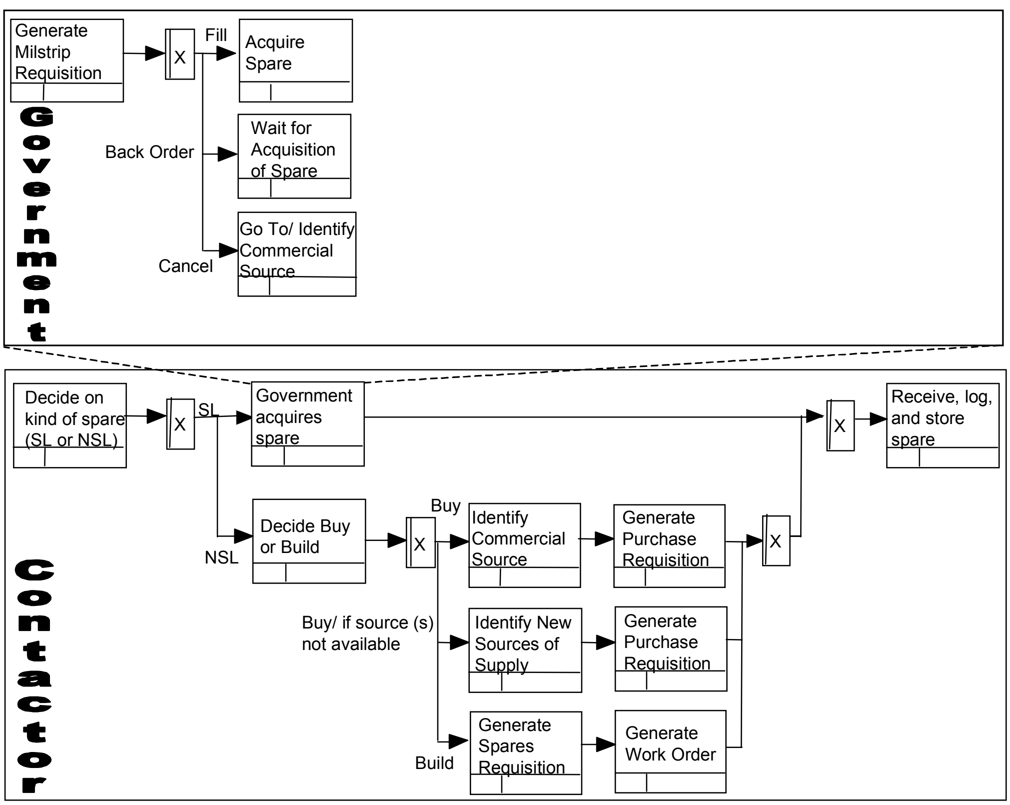

Figure 4: PROSIM Simulation Model Design for the Spares Acquisition Supply Chain Process

4.2 Reengineering the Electronic Design Process for a Multi-Missile Manufacturing Supply Chain

4.2.1 The Problem

The goal was to analyze and redesign the missile production process. The application was performed as part of the DARPA-funded Affordable Multi-Missile Manufacturing (AM3) Program. Specific performance objectives of the AM3 program were to 1) reduce the cost and cycle time of ongoing missile Programs by 25% and 2) reduce the cost and cycle time of new missile programs by 50%.

The SCPDT tools were used by an integrated supply chain team (consisting of several different weapons system contractors) to analyze and redesign the missile production process. Earlier studies had shown that the design of missiles and smart munitions is 10% to 25% of the total life cycle costs. Analysis of the current "As-Is" design process showed much inefficiency that lead to excessive costs and schedules. The objective of the Concept Validation phase of the AM3 Program was to demonstrate how a new missile design methodology would achieve a 50% reduction in design cycle and costs and a 5% to 12% reduction of life cycle costs (LCC) and cycle time for missiles and smart munitions.

4.2.2 The Solution

4.2.2.1 Background

The missile design process is comprised of five main steps as shown in Figure 5. The process steps traverse multiple organizations and several organization units. The process is repeated for each new project and there may be concurrent projects.

The first major task was to develop a model of the As-Is Process so that it could be analyzed using simulation. Since a complete process model did not exist, a strawman process template was first built using the SCPDT IDEF3 process description method implemented in PROSIM. This template was used as the starting point and was then detailed with existing process descriptions and modified based on interviews with domain experts. The model eventually grew to be a fairly complex one with about 200 activities. PROSIM served as a unifying framework for integrating the process maps of the various sub processes.

4.2.2.2 Simulation-Based Analysis of AS-IS Process

With the AS-IS process model completed, the next step was to perform a dynamic analysis of the process. The time and effort needed to develop and use the simulation model was reduced through the automated generation of executable WITNESS simulation models from PROSIM process models. The performance metrics of interest were project cycle time and cost, and process and queuing time. The collection of statistics concerning these metrics, as well as graphs and pie-charts to dynamically display this information during the simulation run, were directly specified within PROSIM.

Simulation results of the As-Is process showed that even the total elimination of the top 10 process and queue times would save only 38% and 14% respectively, which was far short of the goal. The AM3 team reached the conclusion that in order to significantly affect cost and cycle times, new initiatives and tools, which span many processes, were needed. Workflow and data management systems were considered as candidates with the necessary potential.

4.2.2.3 TO-BE Process Design

The simulation analysis of the AS-IS process was used to design a TO-BE Guidance and Control Design process. To clearly see the benefits of the redesigned process, it became necessary to simulate the process at a greater level of detail than that used in the analysis of the AS-IS model. The flow of electronics components such as ASIC, subassembly, FPGA, backplane, etc. that comprised a Project had to be individually traced in order to take into account the "re-entrant flow" resulting from a redesign of the components.

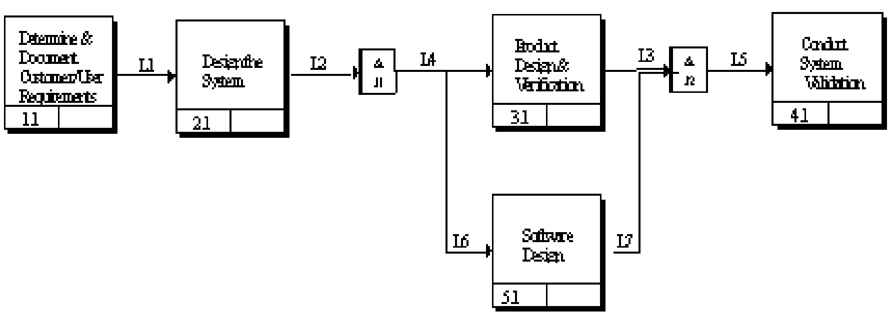

Figure 5. Top Level Diagram of Missile Design Process

4.2.3 Benefits

Results from the simulation runs of the TO-BE Electronics Guidance Design process indicate that a 60% reduction in process cycle-time and 79% savings in costs is possible by implementing all the proposed improvements. The use of the SCPDT tools helped reliably predict the performance implications of the proposed design changes, providing a rational basis for decision making. Also, the process modeling and simulation exercise helped validate the utility of using a workflow management system to achieve the required objectives.

5 SUMMARY

This paper described the architecture and concept of operation of the Supply Chain Process Design Toolkit (SCPDT). The SCPDT is an integrated collection of tools that have been assembled to provide intelligent support for supply chain process integration and design. An example application problem situation was used to illustrate how the SCPDT is used for practical virtual enterprise process design. Finally, two SCPDT application scenarios were described to show the practical benefits of the technology.

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