Development of a Process Reference Model and Performance Measures For Use in a Synchronized Supply Chain

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1 INTRODUCTION

Development of effective performance measures is a necessary prerequisite to building a process reference model. The performance measures are used for evaluation of the system and the reference architecture by which a model is built must center around these. Prior to development of the synchronized supply chain (SCC), a proper reference model and associated performance measures must be determined. For a full supply chain to be modeled, measures need to be determined for both internal and intra-organization and company relationships [14]. On the facility level, each supply chain member should have its own measures by which it is evaluated. These parameters should be based upon crucial issues facing supply chains and the areas which most critically impact overall performance. The ability to respond and effectively meet the parameters are, in a large part, due to the effectiveness of the flexibility of a company. The measures of the enterprise level represent performance of the system in its entirety. This research combines inter-firm interaction with coordination and control. Thus the measures must be able to accurately quantify the effects of that control and global, enterprise level measures are also needed. The issue becomes one of defining the proper measures to maintain suitable control over the system.

When defining the performance measures of a supply chain system at the enterprise level, an aggregation of the facility level measures is desired. This, however, leads to a few issues. Each member of the supply chain does not contribute equally to the output. The contribution of each member differs in volume, value and profit contribution. Inputs to the aggregate measure are also dependent upon each other. Consider two performance measures: flexibility and lead time. The flexibility of one supplier directly effects the lead time its downstream member can quote. By becoming more efficient and adaptive, a supplier can actually increase the performance of the subsequent downstream members in various measures. It is well known that supply chain members are inter-dependent [23]. Scannell, et al [23] illustrate this by examining the relationships of three automakers and their suppliers. Due to the non-equivalent contributions, the measures must also be weighted or ranked prior to aggregation. A simple weighting based on something like the profit contribution is not sufficient due to the dependence issue. One of the ways to overcome this problem is to adopt a total systems view with the objective of understanding and measuring the system performance as a whole, as well as in relation to the constituent parts of the system [12].

The remainder of this paper is as follows. Section 2 provide a review of some of the relevant literature on supply chain process reference models and performance measures and Section 2.3 gives various methods of weighting and aggregating. Finally, Section 3 defines the selected model and measures to be used in this research.

2 LITERATURE REVIEW

2.1 Process Reference Models

2.1.1 ISO9001

The ISO 9000 family of standards [13] is known universally and provides a uniform system for quality management systems. In brief, it is organized in Table 1. These standards are helpful

Table 1: ISO 9000 Overview

Standard	Type of Document	Description
ISO 9000-1	Quality Management and Assurance Standards	roadmap for ISO 9000
ISO 9000-2	Quality Management Assurance Standards	general guidelines for ISO 9001, 9002, 9003
ISO 9000-3	Quality Management Assurance Standards	guidelines for ISO 9001 for computer software
ISO 9000-4	Quality Management Assurance Standards	guidelines for project management
ISO 9001	Quality System	guidelines for design, development, production, installation and service
ISO 9002	Quality System	guidelines for production, installation and service
ISO 9003	Quality System	guidelines for final inspection and testing
ISO 9004-1	Quality Management and Quality Systems	general guidelines for ISO 9004
ISO 9004-2	Quality Management and Quality Systems	guidelines for services
ISO 9004-3	Quality Management and Quality Systems	general guidelines for processed materials
ISO 9004-4	Quality Management and Quality Systems	guidelines for quality improvement

in defining the metrics for the facility level and in particular, ISO 9001 is used here (ISO 9002 and 9003 are also contained within 9001). The performance metrics given in these standards are not as explicit as in most of the frameworks seen in the literature review. Rather, the ISO standards are meant to give general guidelines for continuous quality improvement. For this present research the guidelines developed in 1994 were used.

ISO 9001 encompasses initial design of product through final installation and customer service. In the contract review section, the requirements stipulate that all items needed for order processing are contained within the order and that the internal system is verified for its capabilities. Design review ensures that a new design meets the customer specifications. Purchasing requires that all subcontractors are evaluated for performance, although no specific measures are given related to that performance. Process control requires that process parameters are monitored. This can be translated into measures which describe the efficiency, flexibility and overall performance of the manufacturing process. Inspection and testing covers the measures associated with incoming, in-process and final inspection. The incoming inspection also relates back to the subcontractor performance. In-process and final inspection testing measures are further classified, in the control of nonconforming product, into rework or scrap.

One goal of ISO is to provide a standard framework by which organizations can produce a quality product or service. The aforementioned requirements detail areas which should be addressed when defining a company striving for continuous quality improvement. At

Table 2: FEA Consolidated Reference Model

Measurement Area	Categories
Customer Results	customer benefit, service coverage, timeliness and responsiveness, service quality and service accessibility
Processes and Activities	financial, productivity and efficiency, cycle time and timeliness, quality, security and privacy, management and innovation
Technology	financial, quality, efficiency, information and data, reliability and availability, effectiveness

a minimum, the areas for measurement should include contract review (incoming order receipt), subcontractor evaluation, internal monitoring of the production process and final product quality.

2.1.2 FEA Consolidated Reference Model Document Version 2.0

The Federal Enterprise Architecture (FEA) [18], comprises 5 sub-models used to create a consistent method of collecting data, inputs and outputs across government agencies. The sub-models include Performance Reference Model (PRM), Business Reference Model (BRM), Service Component Reference Model (SRM), Technical Reference Model (TRM) and Data Reference Model (DRM). The five models will be discussed here for their relevance to performance measures.

The PRM framework describes classifications of measurement. Hierarchically, these classifications are named: *areas, categories, groupings and indicators.* In general the *areas* which are measured include the Mission and Business Area, Customer Results Area, Process Activities Area, Technology Area, Human Capital Area, and Other Fixed Assets Area. The *groupings* and *indicators* are specific to the government and not applicable here. For instance, the energy *category* includes the groupings of energy supply, conservation and preparedness, resource management and production and its *indicators* are specific to each of the functions of those *groupings.* However, the *areas* (and their respective *categories*) which are generic enough to be applied to any organization include Customer Results Area, Process Activities Area, Technology Area, Human Capital Area, and Other Fixed Assets Area.

The Customer Results Area measures how well the organization is serving its customers. The Processes and Activities area captures outputs related to processes supported by information technology (IT). The Technology Area measures effectiveness of any initiative which requires IT support. The Human Capital and Other Fixed Assets Area are not yet developed and are anticipated to be completed in 2008. Table 2 details the above areas and their respective categories which are measured. Although some areas are repeated from ISO 9001, the FEA uses overall customer service, efficiency of production activities, product quality and efficiency of information transfer to determine performance.

2.1.3 SCOR Model

The Supply Chain Council (SCC or SCOR) developed a process reference model which creates a framework for the processes, measures and practices to be followed by a complex organization [9]. The latest version, Version 8.0 [25], is quite comprehensive and is used

here. In this model, the processes of PLAN, SOURCE, MAKE, DELIVER and RETURN are each decomposed and carry their individual measures. In the proposed research, the measures of each of the facilities, (stages), in the supply chain will be consistent with this. The processes and metrics are detailed in Appendix I.

The SCOR Process-model encompasses three levels of hierarchical detail: Level I-process types, Level II-process categories (configuration level) and Level III-process elements (decomposition of processes). The hierarchy can be seen in the $IDEF_0$ model in Appendix 6. The measures used to gauge performance of each level are detailed and strive to cover the attributes of reliability, responsiveness, flexibility, costs and assets. For each Level I process type, the Level II process categories are listed with their associated performance measures in Tables 13 through 16 in Appendix I. Each of process categories (Level II) is further decomposed into the associated process elements (Level III) in Tables 17 through 20 in Appendix I. The exception is the RETURN process type. It is not included here as the return process will not be considered in this research.

2.2 Performance Measures

Many articles dealing with performance measures in a supply chain have emerged recently. Performance measures provide the necessary feedback for management which assist in business decisions [6]. Consider the supply chain architecture in Figure 1. This multi-echelon

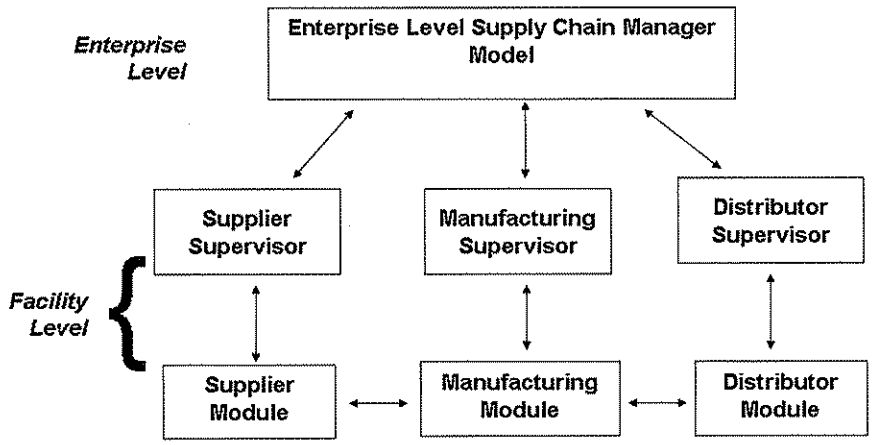

Figure 1: Supply Chain Architecture

supply chain incorporates the use of a supply chain manager (SCM). SCMs have been implemented to assist in the survival of companies in the face of global competition [6]. A supply chain overseen by a Supply Chain Manager (SCM) who coordinates activities between and within agents, will produce goods at a much lower cost [3].

The measures to be used in this model are twofold. One set is needed for the facility level and another for the enterprise level. Although this dual measure set is rarely seen in literature, Swaminathan et al., [26], utilize local and global measures. For a full supply chain to be modeled, measures need to be determined for both internal and intra-organization and

company relationships [14]. The first step in creating global measures is to identify the measures of the individual facilities. In the past, performance measures were mainly financial and result-oriented. In order to support continuous improvement, the shift has been to measures which are more process-oriented [6]. Allwood and Lee [2] utilize agents to explore the dynamics of a supply chain and incorporate only quantitative measures. Melnyk, Stewart and Swink [17], define the measures as having three levels: balanced scorecard, individual and metrics set, with the last two being defined for an individual organization. In a similar manner, Gunasekaran et al., [12] cites the measures as strategic, tactical and operational incorporating both quantitative and qualitative factors. These measures are grouped according to process category (plan, source, make deliver). In a later paper, Gunasekaran et al. [11], justify these measures with results from an analysis of various companies. Park and Kim [20] include measures for both single organizations and collaborative partnerships. Although Swaminathan et al. [26] describe both quantitative and qualitative measures, only the former are used in their modeling.

Beamon [3] [4] defines both quantitative and qualitative factors, however, the author's process model [3] uses only the former. In Beamon's survey of 24 articles of supply chain models [3], the performance measures addressed were cost (used by 75%), customer responsiveness or backorders (46%), activity time (4.2%) and flexibility (4.2%). It is the opinion of the author that the reason for the low use of flexibility is the difficulty in quantification. The result of a series of benchmarking studies, Stewart [24] reports four key areas to be measured: delivery performance, flexibility and responsiveness, logistics cost and asset management. Van Hoek [27] suggests that different measures are needed for different strategies. Cost effectiveness, customer service and integration are the three inputs to the overall benchmark of overall competitiveness. In van Hoek's paper, the inputs are only applied at particular strategies. The strategies the author suggests are cost saver, market penetration and market creation. Otto and Kotzab [19] distinguish performance measures based upon the field of study: System Dynamics, Operations Research/Information Technology, Logistics, Marketing, Organization and Strategy. Chan and Qi [7] use the 5 processes from the Global Supply Chain Forum (supply, inbound logistics, manufacturing, outbound logistics, marketing and sales) to classify their performance measures. Li et al., [16] identified five dimensions of supply chain performance (flexibility, integration, supplier performance, responsiveness and partnership quality) and conducted a survey of almost 200 manager-level personnel to identify factors related to each. Table 3 lists an overview of this literature.

However, it is the partnerships created by the supply chain which can directly effect performance. A strong partnership emphasizes direct, long-term association, encouraging mutual planning and problem solving efforts [12]. The measures describing the system as a single entity tend either to be inadequate, defined mainly by cost [4], or loosely defined, with measures such as overall flexibility not being quantified. The issue is how best to aggregate them to the enterprise level.

2.3 Global Performance Measures

As mentioned earlier, the global measures are to be an aggregation of the facility level measures. However, the inter-dependency between the supply chain members necessitates some form of weighting technique but the unknown relationship between them makes this

Table 3: Performance Metrics

Author	Year	Measures
Allwood [2] and Lee	2005	finished goods inventory, raw material inventory, work in process, unfulfilled orders, planned production, forecasted and actual demand, forecasted and actual raw material lead time
Stewart [24]	1995	Delivery performance, flexibility and responsiveness, logistics cost (including order mgmt, material purchasing cost, holding cost and finance, planning and MIS cost
Beamon [4]	1998	Qualitative: customer satisfaction, flexibility, information and material flow, risk mgmt, supplier performance. Quantitative: cost and inventory, minimization, sales, profit, fill rate and ROI maximization, lateness, response time, lead time, business function minimization
Chan, Qi [6]	2003	Cost, time, capacity, productivity, utilization, effectiveness, reliability, availability and flexibility
Chan, Qi [7]	2003	Supply: Delivery cost, reliability and flexibility; Inbound Logistics: Transport cost, productivity and flexibility, facility utilization; Manufacturing: Quality, operating cost, efficiency, flexibility and productivity; Outbound Logistics: Warehouse cost, inventory flow and accuracy, stock capacity, utilization; Marketing and Sales: response time, order fill rate, flexibility and reliability
Gunasarekan et al. [11]	2004	strategic, tactical, operational
Li et al [16]	2002	Flexibility, integration, responsiveness, supplier performance and partnership quality
Melnyk et al. [17]	2004	balanced scorecard individual set, metrics set
Otto and Kotzab [19]	2003	Systems Dynamics: capacity utilization, inventory level stock-outs, time lags, time to adapt Operations Research: logistics costs, service level, delivery time
Swaminathan [26]	1998	Qualitative: customer satisfaction,integration of information and material flow, effective risk management.
van Hoek [27]	1998	cost effectiveness, customer service, integration

process difficult. This issue has been studied for many decades; Gold [10] discusses the need for developing input-output ratios and argues that most changes in outputs are passive results from changes at lower levels.

The analytic hierarchy process (AHP), developed by Saaty [21] is one method which can be used to deal with multiple-criteria decision making. Chan [8] utilized this method to aggregate quantitative and qualitative performance measures for the purpose of selecting an optimal chain. Chan and Qi [7] amend this by utilizing a triangular fuzzy number scale to determine the relative ratios and ratios and then combining it into a fuzzy measurement scale to finally obtain a performance grade of the measurement results. By utilizing fuzzy set theory, the inclusion of multiple human evaluators is allowed.

Lambert and Pohlen [15] capture supplier-customer dynamics by aggregating the measures through a combined profit and loss statement. Beamon [5] extended earlier work [4] of production flexibility definition by defining for a range of product mixes and aggregating. Further work by Beamon and Chen [5] develop regression models for five different performance measures (average periodic inventory level, average transport cost, stock-out fraction, backorder fraction and volume flexibility) in a 4-echelon SC. The factors incorporated into the models are stockout risk, supplier lead-time, demand distribution, transport time and processing time. This it the first identifiable attempt to quantify relationships within a supply chain.

Cross-impact analysis and influence diagrams both help to explain the relationship between events and elements. Since, the effect of one occurrence alters other structurally related events [22], they could be used to determine the effect one supply chain member from an adjoining member. However, in order to utilize these techniques, the probability of occurrence of events must be known. A thorough data analysis could yield these probabilities.

3 DETERMINATION OF THE PROCESS MODEL AND PERFORMANCE MEASURES FOR RESEARCH CONSIDERATION

3.1 Reducing the SCOR Model for Research Considerations

The process types to be considered are PLAN, SOURCE, MAKE and DELIVER. The associated decomposition for each of these into the Level II and Level III categories and elements must be sufficient to ensure that both necessary strategic and operational decisions are made. Each of the SCOR process types has been reduced to incorporate these processes. Sections 3.1.1 through 3.1.4 detail the justification for these.

3.1.1 Plan

The PLAN process type includes process categories: Plan Supply Chain, Plan Source, Plan Make and Plan Deliver. Each of these will need to be considered in the model. Of the Level II metrics given in Table 13 in Appendix II, the following will be considered:

- cost to plan supply chain

Table 4: Research PLAN Process Categories and Measures

Category (Level II)	Metrics
Plan Supply Chain	1. cost to plan supply chain 2. order fulfillment cycle time 3. plan cycle time
Plan Source	1. cost to plan source 2. order fulfillment cycle time 3. plan cycle time
Plan Make	1. order fulfillment cycle time 2. return on supply chain fixed assets 3. return on working capital
Plan Deliver	1. cash-to-cash cycle time 2. cost to plan deliver 3. order fulfillment cycle time 4. return on supply chain fixed assets 5. return on working capital 6. total deliver costs

- order fulfillment cycle time
- plan cycle time

The reduced PLAN categories, elements and measures are given in Tables 4 and 5. Note that these do not change from the original SCOR model.

3.1.2 Source

The SOURCE process type consists of three categories as seen in Table 14. The metrics are identical to each category with the exception of Source Make-to-Order Product which includes the perfect order fulfillment metric. Of the metrics listed in Table 14, the following will be considered: cost to source, order fulfillment cycle time, perfect order fulfillment product acquisition costs and source cycle time. Similarly, the Level III elements for each Level II category (Table 18) are alike with the exception of selecting suppliers and negotiating seen in Source Engineer-to-Order Product. These elements will become important, in this research, in the event a disruption causes the supply chain to choose an alternate supplier(s) and new relationships must be formed. Thus, for the purposes of the model to be used here, the Source Stocked Product category will be used with the addition of two Level III elements from Source Engineer-to-Order Product: identify sources of supply and select final suppliers and negotiate. The members of the supply chain to be studied will hold inventory, both raw materials and finished goods and not customize orders. Thus the category will be labeled Source Stocked Product, however, the above two elements will be included. See Tables 6 and 7 for the reduced SOURCE categories, elements and measures.

Table 5: Research PLAN Process Elements

Category (Level II)	Elements (Level III)
Plan Supply Chain	1. identify, prioritize and aggregate supply chain requirements 2. identify, assess and aggregate supply chain resources 3. balance supply chain resources with requirements 4. establish supply chain plans
Plan Source	1. identify, prioritize and aggregate production requirements 2. identify, assess and aggregate product resources 3. balance product resources with requirements 4. establish sourcing plans
Plan Make	1. identify, prioritize and aggregate production requirements 2. identify, assess and aggregate production resources 3. balance production resources with requirements 4. establish production plans
Plan Deliver	1. identify, prioritize and aggregate delivery requirements 2. identify, assess and aggregate delivery resources and capabilities 3. balance delivery resources and capabilities with requirements 4. establish delivery plans

Table 6: Research SOURCE Process Categories and Measures

Category (Level II)	Metrics
Source Stocked Product	1. cost to source 2. order fulfillment cycle time 3. product acquisition costs 4. source cycle time

Table 7: Research SOURCE Process Elements

Category (Level II)	Elements (Level III)
Source Stocked Product	1. *identify sources of supply* 2. *select final suppliers and negotiate* 3. schedule product deliveries 4. receive product 5. verify product 6. transfer product 7. authorize supplier payment

Note: the elements identified in italics are to be used only when a disruption occurs.

Table 8: Research MAKE Process Categories and Measures

Category (Level II)	Metrics
Make-to-Stock	1. cost of goods sold 2. cost to make 3. downside make adaptability 4. make cycle time 5. order fulfillment cycle time 6. perfect order fulfillment 7. inventory days of supply (WIP) 8. upside make adaptability 9. upside make flexibility 10. yield

Table 9: Research MAKE Process Elements

Category (Level II)	Elements (Level III)
Make-to-Stock	1. *finalize production engineering* 2. schedule production activities 3. issue sourced/in-process product 4. produce and test 5. package 6. stage product 7. release product to deliver

Note: the elements identified in italics are to be used only when a disruption occurs.

3.1.3 Make

There are three process categories in the MAKE process type as seen in Table 15. The metrics considered are identical in each category with the addition of inventory days of supply (WIP) seen in the Make-to-Order and Engineer-to-Order categories. Of those listed, the following will be considered in this research: cost of goods sold, cost to make, make adaptability, inventory days of supply (WIP), make cycle time, order fulfillment cycle time, perfect order fulfillment, upside make adaptability, upside make flexibility and yield.

Again, the process elements for each of the three categories are also similar. The exception is that Make-to-Stock does not include the "issue sourced/in-process product" element and only the Engineer-to-Order category includes the element "finalize production engineering". It is evident that the remaining elements are crucial to the proper functioning of any organization. The element "issue sourced/in-process product" element will be critical to this research as its function will allow proper inventory of raw materials (sourced) and WIP (in-process) product to be kept. Additionally, it is assumed that the order received consists of an existing product and engineering a new product will not be necessary. However, a disruption can cause a change to the order if, for instance, a part is no longer available and the replacement causes some engineering changes. Thus, the engineering changes to the

Table 10: Research DELIVER Process Categories and Metrics

Category (Level II)	Metrics
Deliver Stocked Product	1. cost to deliver 2. deliver cycle time 3. downside deliver adaptability 4. finished goods inventory days of supply 5. order fulfillment cycle time 6. perfect order fulfillment 7. upside deliver adaptability 8. upside deliver flexibility

order which may need to take place will only occur in the event of a disruption. See Tables 8 and 9 for the reduced SCOR categories and measures.

3.1.4 Deliver

Again, the three process categories for Deliver are similar in both metrics and process elements. The category of Deliver Make-to-Order and Engineer-to-Order includes elements of negotiation and the latter incorporates the Request for Proposal/Quote (RFP/RFQ) process element. All three categories define steps to optimize route shipments. This research is concerned with disruption recovery, therefore, the steps of creating a more effective supply chain by route optimization is a topic of a separate nature and will not be included here. Since the research considered here assumes that carriers are already selected for a particular order, the elements of RFP/RFQ and negotiation will be included only for possible use under a disruption situation. Tables 10 and 11 contain the DELIVER categories and measures to be used from SCOR.

Table 11: Research DELIVER Process Elements

Category (Level II)	Elements (Level III)
Deliver Stocked Product	1. *obtain and respond to RFP/RFQ* 2. *select carriers and rate shipments* 3. *negotiate and receive contract* 4. enter and validate order 5. pick product 6. pack product 7. load product and generate ship documents 8. ship product 9. receive and verify product by customer 10. invoice

Note: the elements identified in italics are to be used only when a disruption occurs.

Table 12: Final Research Performance Measures

	RELIABILITY	
Category	Level I Measures	Level II Measures
Delivery performance	1. overall % on-time and in-full shipments	1. %supplier on-time and in-full 2. manufacturer schedule attainment 3. % warehouse on-time and in-full 4. % transporter on-time and in-full
Perfect order fulfillment (quality of shipments)	1. overall % on-time/ in-full/perfect	1.% supplier on-time/in-full/perfect 2. % retailer on-time/in-full/perfect
Fill rates	1. % ship from stock within 24 hours	forecast accuracy
	RESPONSIVENESS	
Category	Level I Measures	Level II Measures
Order fulfillment lead time	1.no. days from order receipt to delivery	1. no. days order receipt to order entry 2. no days order entry to shipment 3. no. days order shipment to order receipt 4. backorder duration
	FLEXIBILITY	
Category	Level I Measures	Level II Measures
SC response time (adaptability)	1.no. days to respond to unplanned 'significant' change in demand without cost penalty	1. Source lead time 2. Order fulfillment lead time
Production flexibility	1. no. days to achieve unplanned 20% change in orders without cost penalty	1.no. days to increase or decrease labor, material and capital
	SUPPLY CHAIN COST	
Category	Level I Measures	Level II Measures
Cost of Goods	1. direct cost of material and labor	material cost 2. direct and indirect production cost
Inventory Days of Supply	1. no. inventory days of supply	2. no. days raw material inventory 3. no. days WIP inventory 4. no. days finished goods inventory
	PROFITABILITY	
Category	Level I Measures	Level II Measures
Income After Cost	1. Gross Margin	1. revenue 2. cost of goods

3.2 Performance Measures of the Facility Level for this Research

As in the SCOR model, the attributes to be considered in this research will include reliability, responsiveness, flexibility and cost/profitability. Combining and comparing the chosen measures from Tables 4, 6, 8 and 10 with the measures identified in Section 2, the final measures to be used in this research are grouped according to their attributes and shown in Table 12. For each attribute, the category of measure is listed with the decomposed Level I and Level II measures. These will be the final measures used at the facility level in this research. Measures for the enterprise level are discussed next.

3.3 Performance Measures of the Enterprise Level for this Research

In order to determine effectiveness of creating a synchronized supply chain, there needs to be a way to measure performance of the supply chain as one entity. As seen in the literature review, there are plenty of metrics at the plant or individual corporation level but the aggregation of them proves difficult since the output measures of each company are, to some extent, dependent upon the output of the other members. This dependency should increases down the SC. Therefore, the performance measures from each company need to be weighted somehow to account for this inter-dependency when aggregating them. The methods discussed in Section 2.3 will be analyzed for potential use and a case study may also prove beneficial.

4 IDEF MODELING

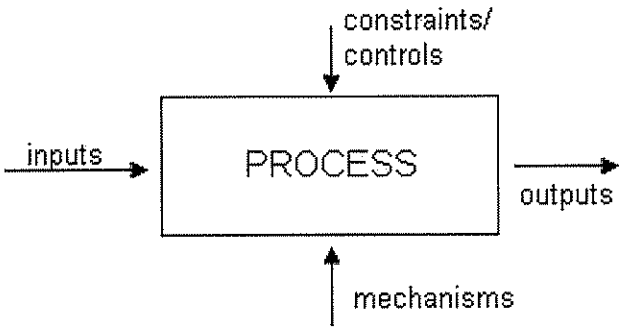

Figure 2: ICOM Representation

$IDEF_0$ models are useful tools for developing functional models, and are composed of ICOM boxes(input, control, output, mechanism), developed under US Air Force funding as part of the Integrated Computer Aided Manufacturer (ICAM) program [1]. They are static

models used to represent processes of a dynamic system. $IDEF_3$ models [28] are an are an improvement on the $IDEF_0$ model in that it was designed to capture the sequence of events.

The nature of an ICOM box can be seen in Figure 2. Each box is numbered, typically corresponding with the tree diagram, and contains a verb-based name describing the process or activity and its associated inputs, outputs, controls and mechanisms. The $IDEF_0$ model containing the node trees and ICOMs for the research reduced-SCOR model detailed in the previous sections is shown in Appendix II. Appendix III contains the $IDEF_3$ models, showing the relationship between events and the necessary inputs, outputs and constraints. Note that no IDEF models for the Plan process are shown. The Plan process deals with issues faced on the supply chain manager or enterprise level. At present, the measures to be used and the exact role of this level is not known. When this issue is resolved, the IDEF modeling will be performed.

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5 APPENDIX I-SCOR Processes and Measures

Table 13: The **PLAN** Process Categories and Measures

Category (Level II)	Metrics
Plan Supply Chain	cash-to-cash cycle time cost to plan supply chain order fulfillment cycle time plan cycle time return on supply chain fixed assets return on working capital
Plan Source	cash-to-cash cycle time cost to plan source order fulfillment cycle time plan cycle time return on supply chain fixed assets return on working capital
Plan Make	order fulfillment cycle time
Plan Deliver	cost to plan deliver order fulfillment cycle time total deliver costs

Table 14: The **SOURCE** Process Categories and Measures

Category (Level II)	Metrics
Source Stocked Product	cost to source order fulfillment cycle time product acquisition costs return on supply chain fixed assets return on working capital source cycle time
Source Make-to-Order Product	cost to source order fulfillment cycle time perfect order fulfillment product acquisition costs return on supply chain fixed assets return on working capital source cycle time
Source Engineer-to-Order Product	cost to source order fulfillment cycle time product acquisition costs return on supply chain fixed assets return on working capital source cycle time

Table 15: The **MAKE** Process Categories and Measures

Category (Level II)	Metrics
Make-to-Stock	cash-to-cash cycle time
	cost of goods sold
	cost to make
	downside make adaptability
	make cycle time
	order fulfillment cycle time
	return on supply chain fixed assets
	return on working capital
	upside make adaptability
	upside make flexibility
	yield
Make-to-Order	cash-to-cash cycle time
	cost of goods sold
	cost to make
	downside make adaptability
	inventory days of supply (WIP)
	make cycle time
	order fulfillment cycle time
	perfect order fulfillment
	return on supply chain fixed assets
	return on working capital
	upside make adaptability
	upside make flexibility
	yield
Engineer-to-Order	cash-to-cash cycle time
	cost of goods sold
	cost to make
	downside make adaptability
	inventory days of supply (WIP)
	make cycle time
	order fulfillment cycle time
	return on supply chain fixed assets
	return on working capital
	upside make adaptability
	upside make flexibility
	yield

Table 16: The **DELIVER** Process Categories and Measures

Category (Level II)	Metrics
Deliver Stocked Product	cash-to-cash cycle time return on working capital cost to deliver deliver cycle time downside deliver adaptability finished goods inventory days of supply order fulfillment cycle time order management costs perfect order fulfillment return on supply chain fixed assets upside deliver adaptability upside deliver flexibility
Deliver Make-to-Order Product	cash-to-cash cycle time cost to deliver deliver cycle time downside deliver adaptability finished goods inventory days of supply order fulfillment cycle time perfect order fulfillment return on supply chain fixed assets return on working capital upside deliver adaptability upside deliver flexibility
Deliver Engineer-to-Order Product	cash-to-cash cycle time return on working capital cost to deliver deliver cycle time downside deliver adaptability finished goods inventory days of supply order fulfillment cycle time order management costs perfect order fulfillment return on supply chain fixed assets upside deliver adaptability upside deliver flexibility

Table 17: The **PLAN** Process Elements

Category (Level II)	Elements (Level III)
Plan Supply Chain	1. identify, prioritize and aggregate supply chain requirements 2. identify, assess and aggregate supply chain resources 3. balance supply chain resources with requirements 4. establish supply chain plans
Plan Source	1. identify, prioritize and aggregate production requirements 2. identify, assess and aggregate product resources 3. balance product resources with requirements 4. establish sourcing plans
Plan Make	1. identify, prioritize and aggregate production requirements 2. identify, assess and aggregate production resources 3. balance production resources with requirements 4. establish production plans
Plan Deliver	1. identify, prioritize and aggregate delivery requirements 2. identify, assess and aggregate delivery resources and capabilities 3. balance delivery resources and capabilities with requirements 4. establish delivery plans

Table 18: The **SOURCE** Process Elements

Category (Level II)	Elements (Level III)
Source Stocked Product	1. schedule product deliveries 2. receive product 3. verify product 4. transfer product 5. authorize supplier payment
Source Make-to-Order Product	1. schedule product deliveries 2. receive product 3. verify product 4. transfer product 5. authorize supplier payment
Source Engineer-to-Order Product	1. identify sources of supply 2. select final suppliers and negotiate 3. schedule product deliveries 4. receive product 5. verify product 6. transfer product 7. authorize supplier payment

Table 19: The **MAKE** Process Elements

Category (Level II)	Elements (Level III)
Make-to-Stock	schedule production activities 1. issue material 2. produce and test 3. package 4. stage product 5. release product to deliver
Make-to-Order	1. schedule production activities 2. issue sourced/in-process product 3. produce and test 4. package 5. stage finished product 6. release finished product to deliver
Engineer-to-Order	1. finalize production engineering schedule production activities issue sourced/in-process product produce and test package stage finished product release finished product to deliver

Table 20: The **DELIVER** Process Elements

Category (Level II)	Elements (Level III)
Deliver Stocked Product	process inquiry and quote receive, enter and validate order reserve inventory and determine delivery date consolidate orders build loads route shipments select carriers and rate shipments receive product from source or make pick product pack product load vehicle and generate shipping documentation ship product receive and verify product by customer install product invoice
Deliver Make-to-Order Product	process inquiry and quote receive, configure, enter and validate order reserve inventory and determine delivery date consolidate orders build loads route shipments select carriers and rate shipments receive product from source or make pick product pack product load vehicle and generate shipping documentation ship product receive and verify product by customer install product invoice
Deliver Engineer-to-Order Product	obtain and respond to RFP/RFQ negotiate and receive contract enter order, commit resources and launch program schedule installation build loads route shipments select carriers and rate shipments pick product pack product load product and generate ship documents ship product receive and verify product by customer install product invoice

6 APPENDIX II-IDEF$_0$ Modeling

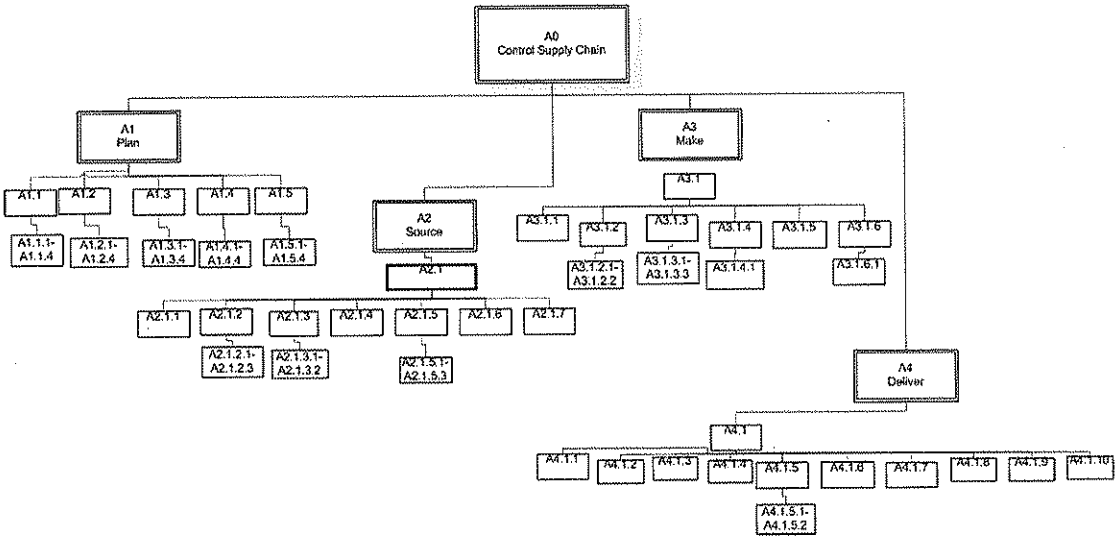
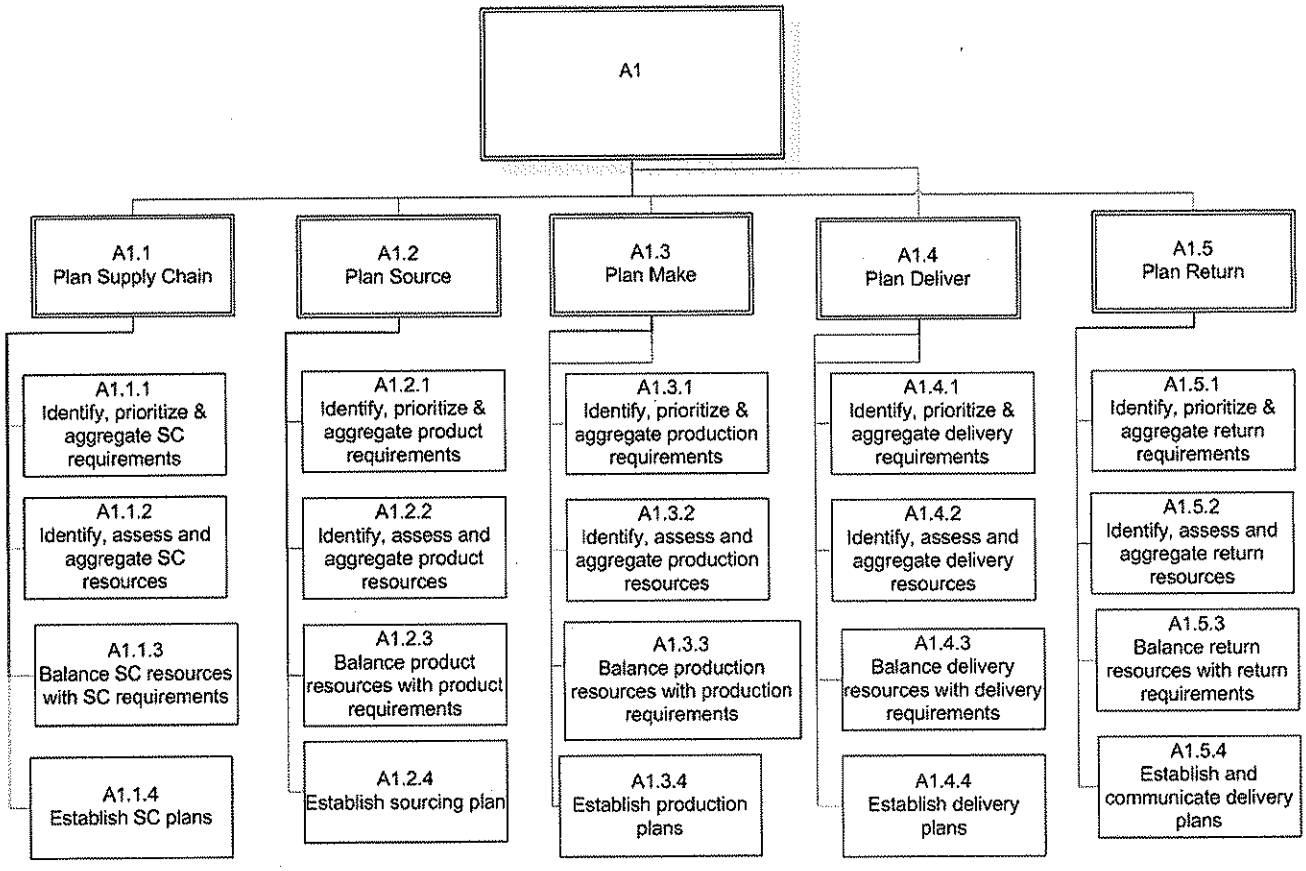
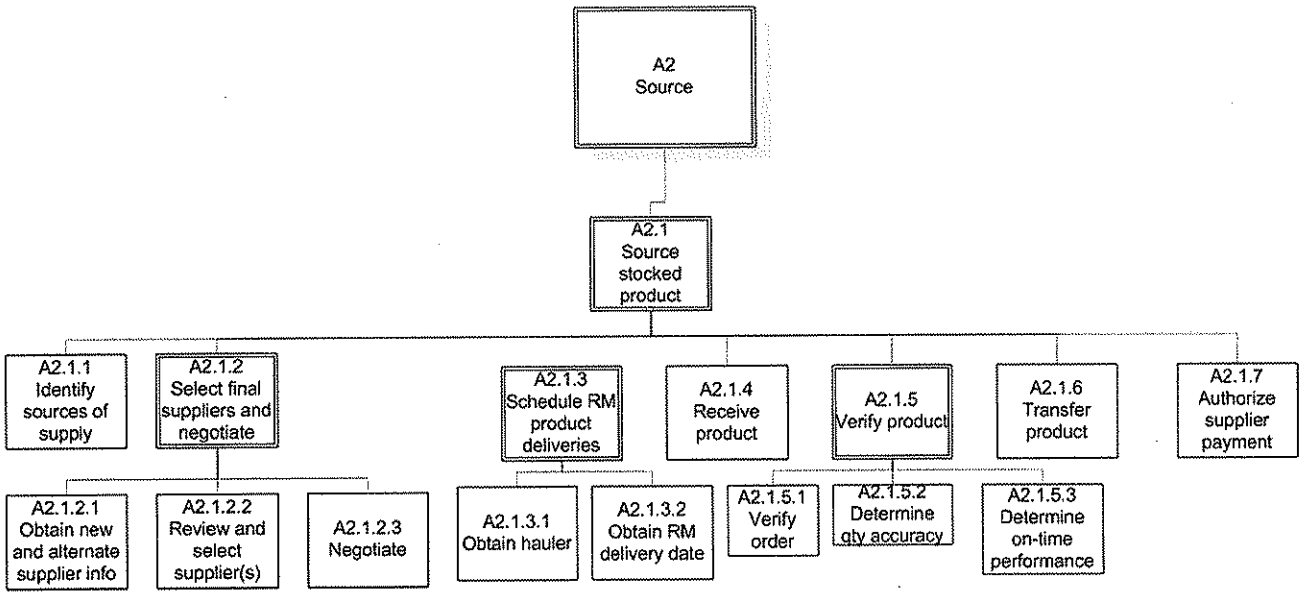
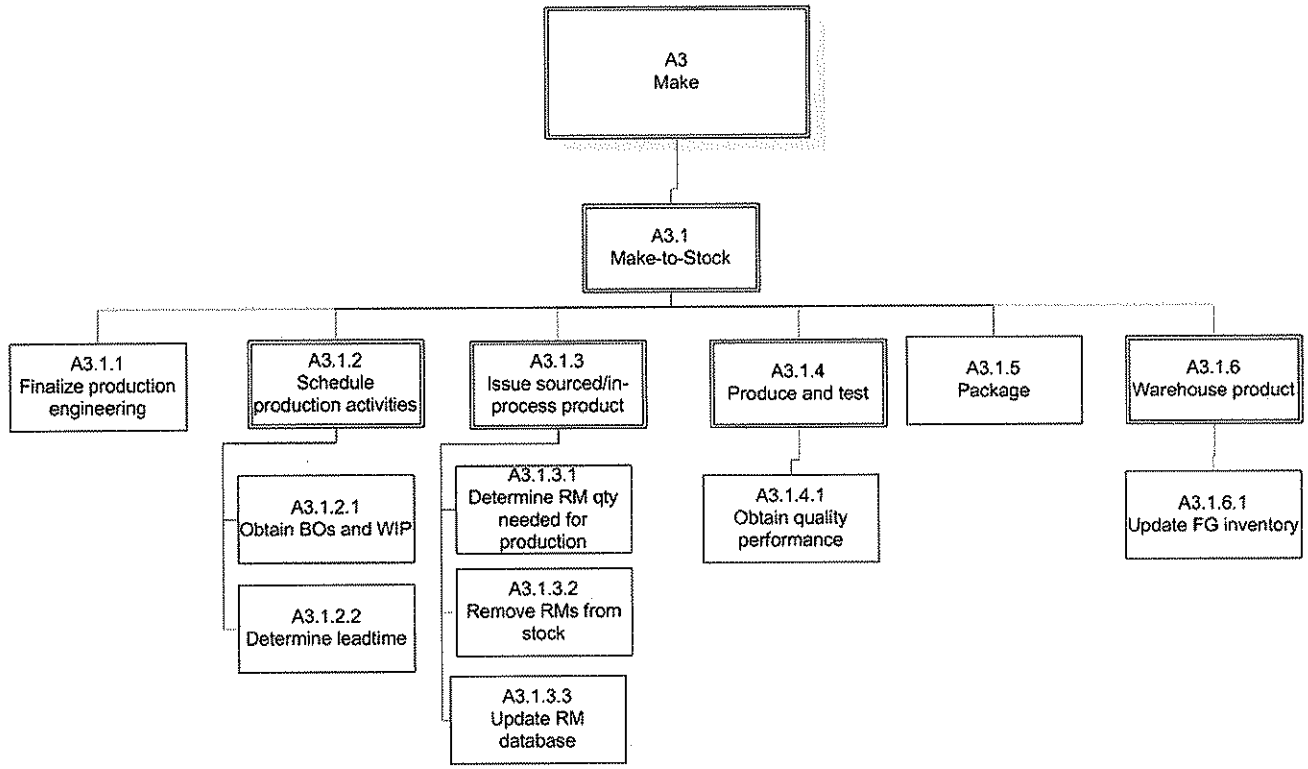


Figure 3: The SCOR Process-model IDEF_0




A2
Source
A2.1
Source stocked product
A2.1.1 Identify sources of supply
A2.1.2 Select final suppliers and negotiate
A2.1.3 Schedule RM product deliveries
A2.1.4 Receive product
A2.1.5 Verify product
A2.1.6 Transfer product
A2.1.7 Authorize supplier payment
A2.1.2.1 Obtain new and alternate supplier info
A2.1.2.2 Review and select supplier(s)
A2.1.2.3 Negotiate
A2.1.3.1 Obtain hauler
A2.1.3.2 Obtain RM delivery date
A2.1.5.1 Verify order
A2.1.5.2 Determine qty accuracy
A2.1.5.3 Determine on-time performance


A3
Make
A3.1
Make-to-Stock
A3.1.1 Finalize production engineering
A3.1.2 Schedule production activities
A3.1.3 Issue sourced/in-process product
A3.1.4 Produce and test
A3.1.5 Package
A3.1.6 Warehouse product
A3.1.2.1 Obtain BOs and WIP
A3.1.2.2 Determine leadtime
A3.1.3.1 Determine RM qty needed for production
A3.1.3.2 Remove RMs from stock
A3.1.3.3 Update RM database
A3.1.4.1 Obtain quality performance
A3.1.6.1 Update FG inventory

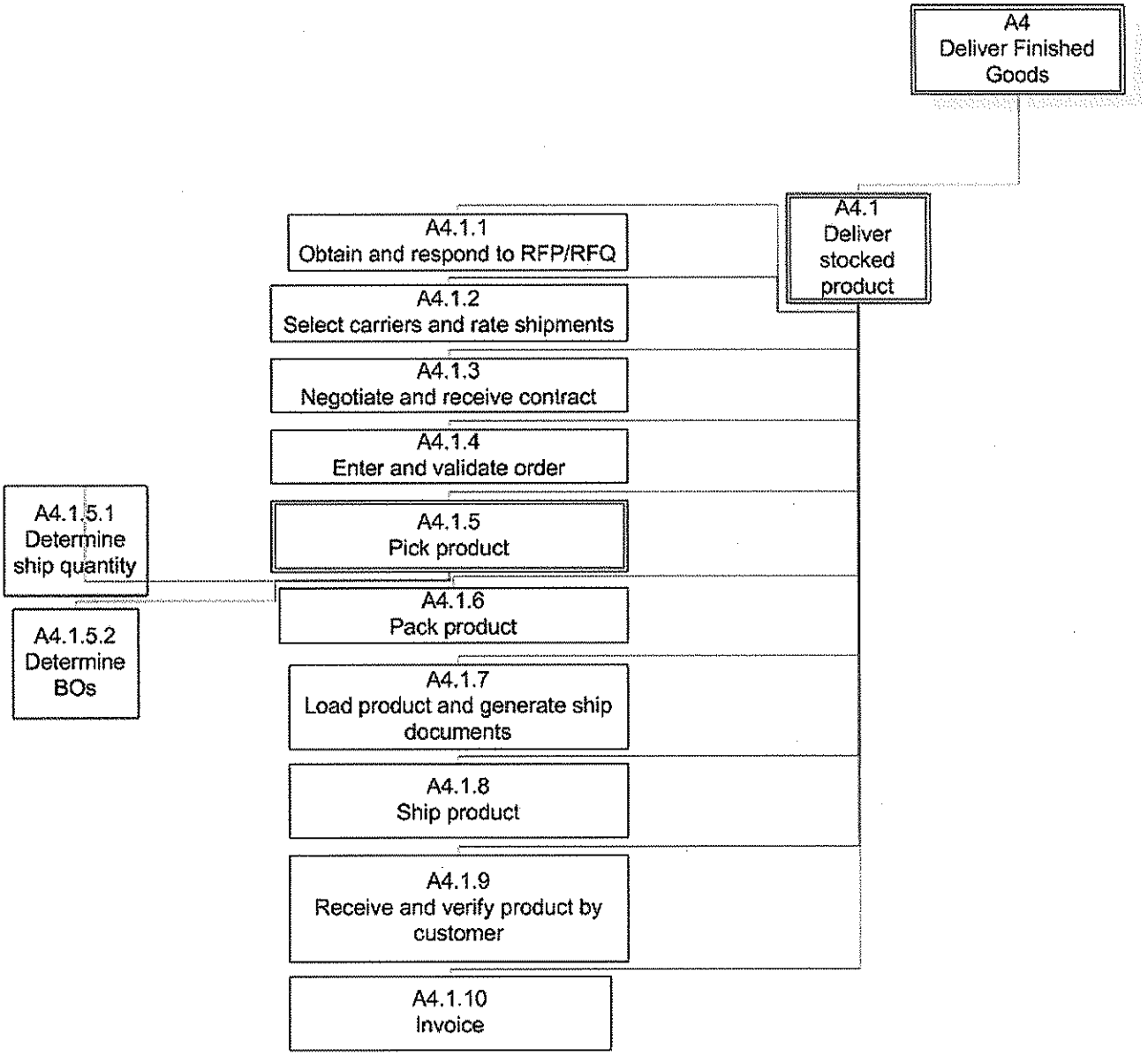

A4
Deliver Finished Goods
A4.1
Deliver stocked product
A4.1.1
Obtain and respond to RFP/RFQ
A4.1.2
Select carriers and rate shipments
A4.1.3
Negotiate and receive contract
A4.1.4
Enter and validate order
A4.1.5
Pick product
A4.1.5.1
Determine ship quantity
A4.1.5.2
Determine BOs
A4.1.6
Pack product
A4.1.7
Load product and generate ship documents
A4.1.8
Ship product
A4.1.9
Receive and verify product by customer
A4.1.10
Invoice

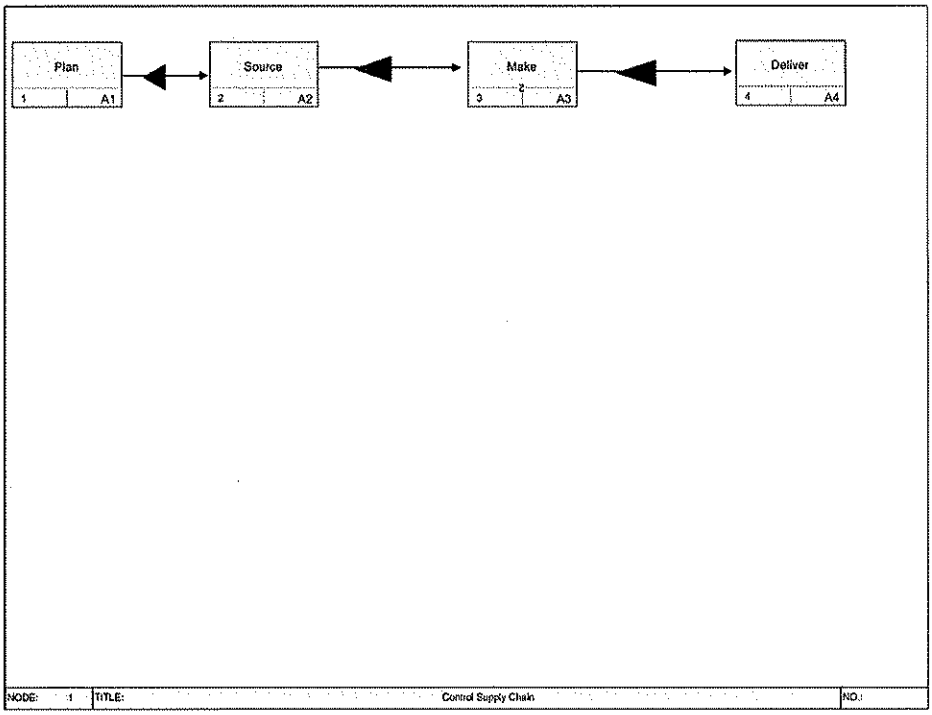
Table 21: $IDEF_0$ ICOM Inputs and Constraints

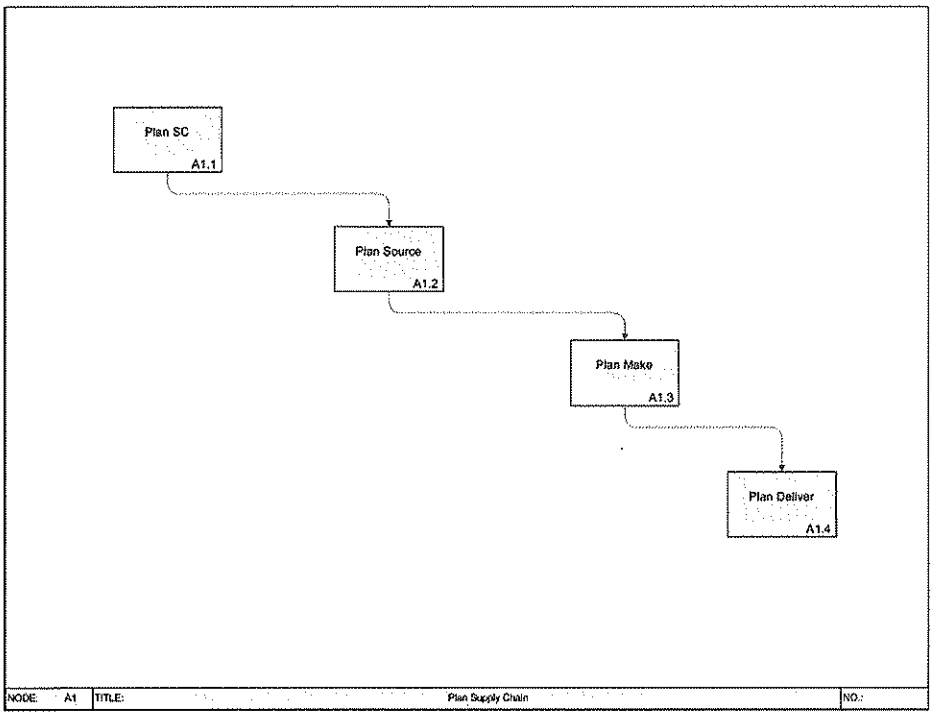
		Inputs	Constraints
		Source Stocked Product	
1.	Identify Sources of Supply	approved supplier list	source availability cost delivery time
2.	Select Final Supplier and Negotiate	potential supplier(s) approved supplier list	min profit
3.	Schedule Product Deliveries	selected supplier negotiated order	truck availability natural delays
4.	Receive Product	negotiated order received product	available labor
5.	Verify Product	received product	available labor
6.	Transfer Product	verified product	available labor
7.	Authorize Supplier Payment	verified product	available cash
		Make-to-Stock	
1.	Finalize Production Engineering	approved customer design	design review
2.	Schedule Production Activities	customer order	available raw materials available labor
3.	Issue Sourced/In-process Product	customer order production schedule	available raw materials
4.	Produce and Test	production schedule	available labor machine breakdowns
5.	Package	FGs customer order	available materials
6.	Stage Product	customer order filled order	
7.	Release Product to Deliver	customer order logistics provider	available truck
		Deliver	
4.	Enter and Validate Order	customer order	FGI
5.	Pick Product	validated order	FGI
6.	Pack Product	validated order	
7.	Load Product and Generate Ship Documents	packed order logistics arrival	
8.	Ship Product	shipped order	
9.	Receive and Verify Product by Customer	received order verified received order	QA check
10.	Invoice	verified received order	

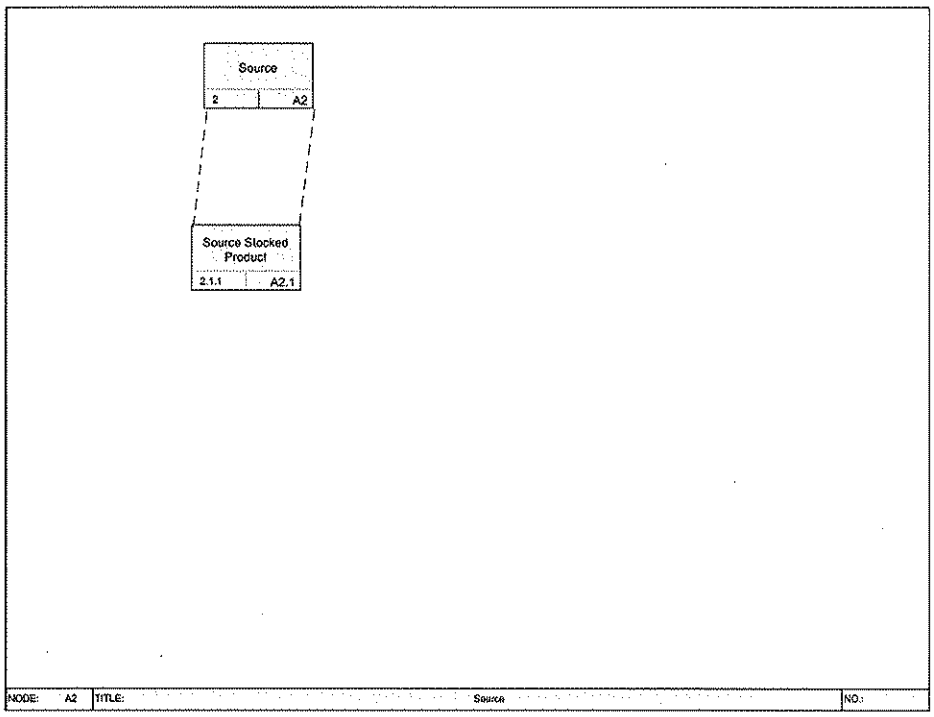
Table 22: $IDEF_0$ ICOM Outputs and Mechanisms

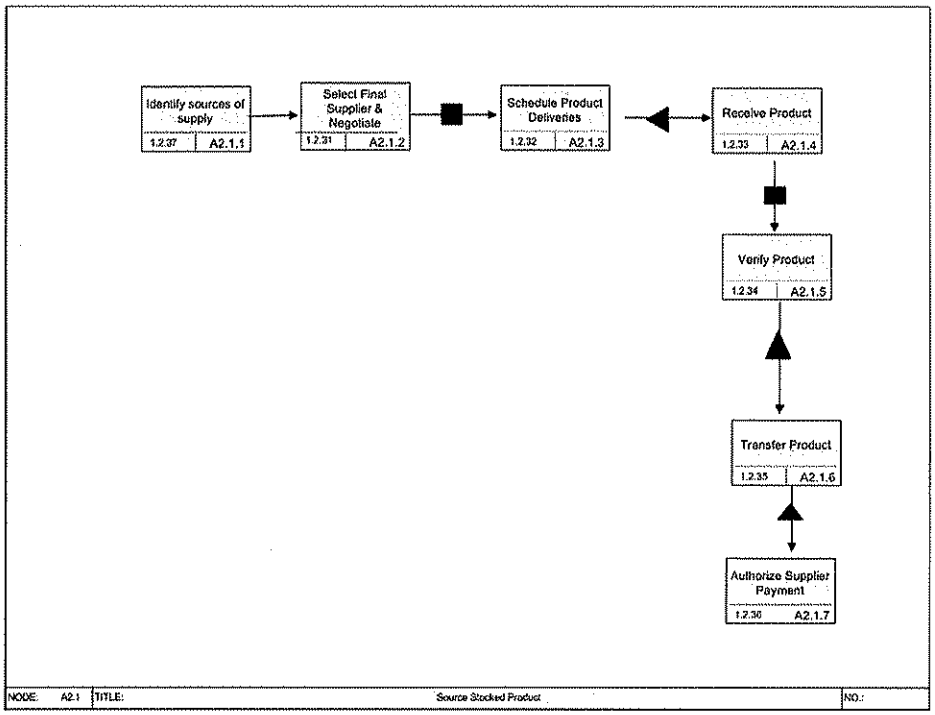
		Outputs	Mechanisms
	Source		
1.	Identify Sources of Supply	potential supplier(s)	database purchasing personnel
2.	Select Final Supplier and Negotiate	selected supplier negotiated order	negotiating/contracting mechanism(s)
3.	Schedule Product Deliveries	delivery date selected carrier	logistics supplier
4.	Receive Product	received product	warehouse personnel
5.	Verify Product	verified product	database
6.	Transfer Product	updated inventory	warehouse personnel
7.	Authorize Supplier Payment	supplier payment	supplier invoice finance personnel
	Make-to-Stock		
1.	Finalize Production Engineering		
2.	Schedule Production Activities	production schedule	scheduling s/w
3.	Issue Sourced/In-process Product	updated RMI	warehouse personnel
4.	Produce and Test	WIP FG % rejects updated FGI	production labor production facility QA labor
5.	Package	updated FGI filled order	warehouse personnel
6.	Stage Product	filled order	warehouse personnel
7.	Release Product to Deliver	shipped product	warehouse personnel logistics provider
	Deliver		
4.	Enter and Validate Order	validated order	database
5.	Pick Product	picked order updated FGI	warehouse personnel
6.	Pack Product	packed order	warehouse personnel
7.	Load Product and Generate Ship Documents	ship docs shipped order	warehouse personnel
8.	Ship Product	order in transit	logistics provider
9.	Receive and Verify Product by Customer	verified received order	database
10.	Invoice	invoice	A/R personnel

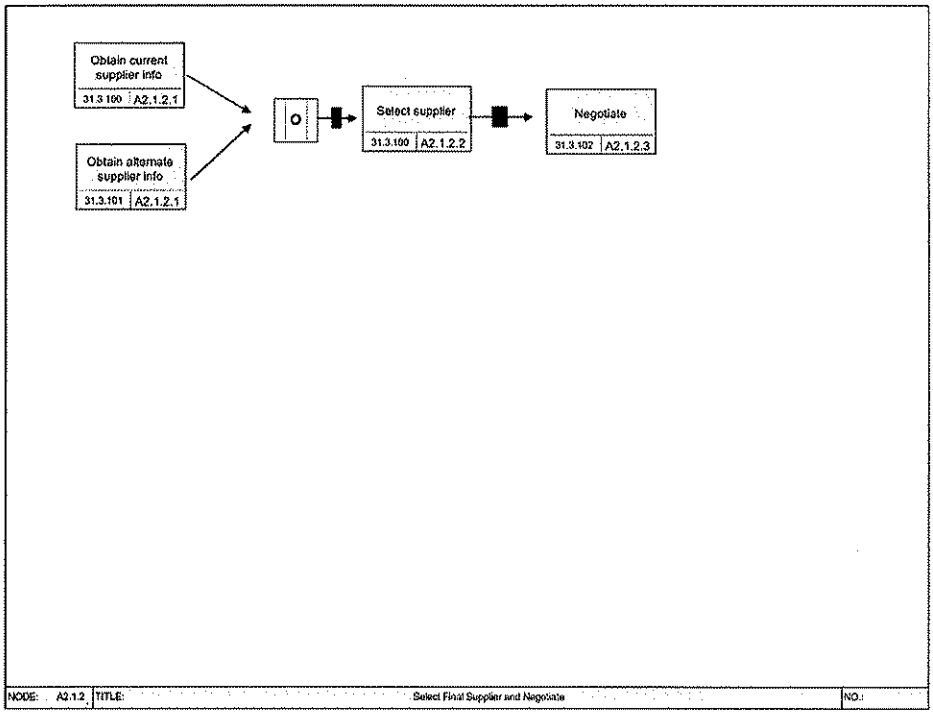
7 APPENDIX III-IDEF$_3$ Modeling

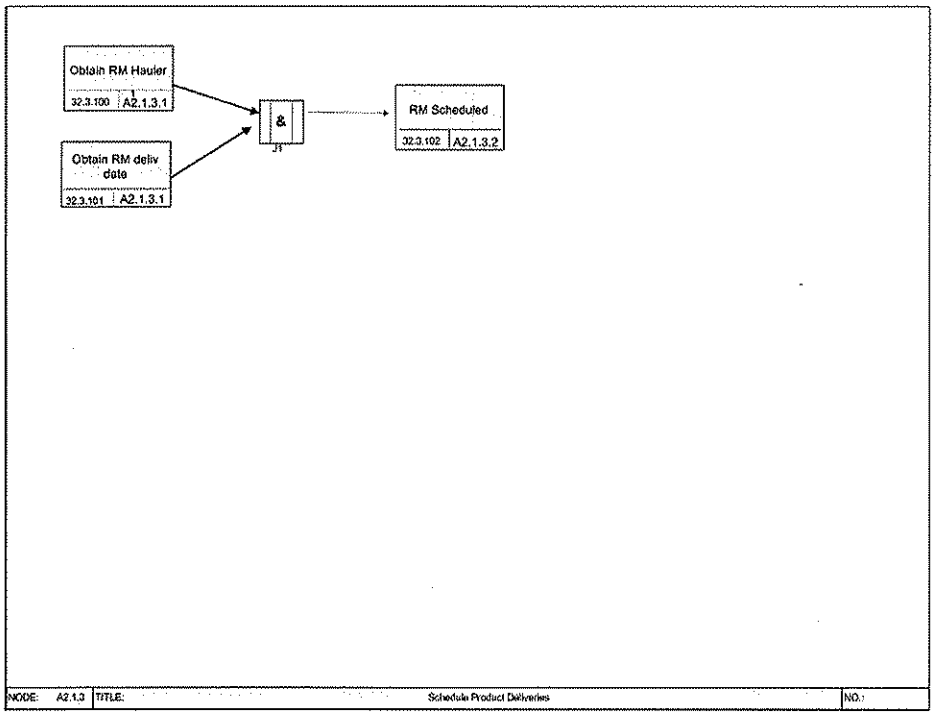

Plan
1
A1
Source
2
A2
Make
3
A3
Deliver
4
A4
NODE: -1
TITLE:
Control Supply Chain
NO.:

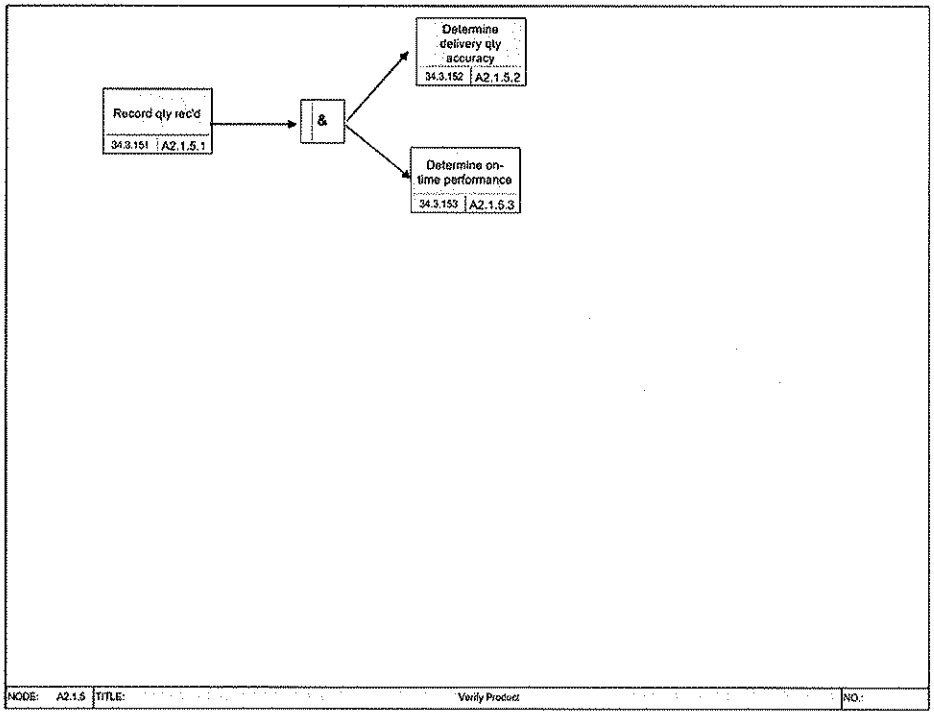

Plan SC
A1.1
Plan Source
A1.2
Plan Make
A1.3
Plan Deliver
A1.4
NODE: A1
TITLE:
Plan Supply Chain
NO.:

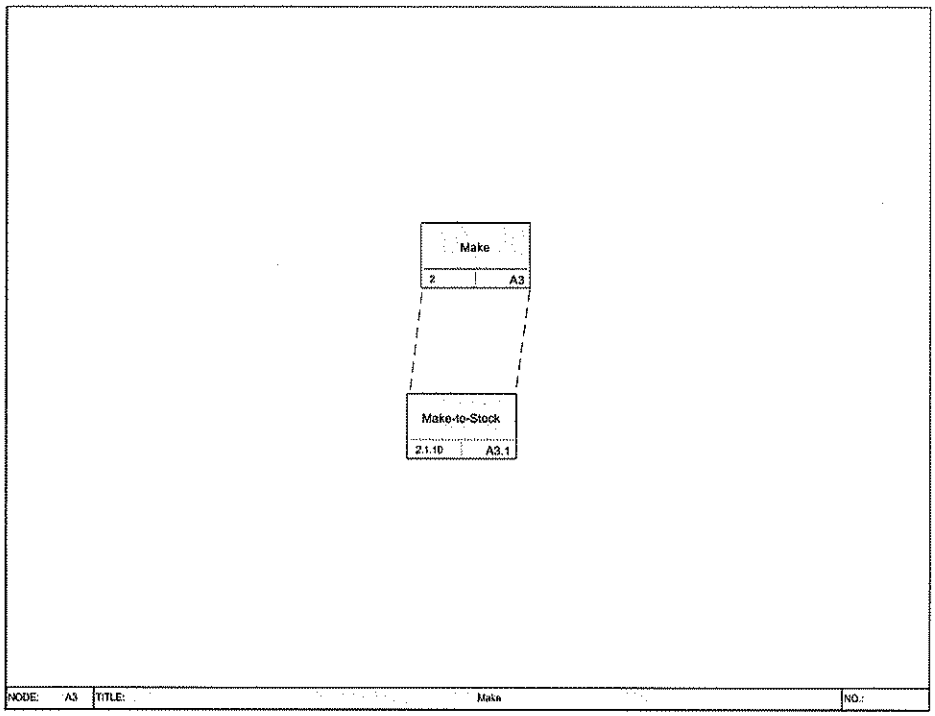

Source
2
A2
Source Stocked Product
2.1.1
A2.1
NODE: A2
TITLE: Source
NO.:

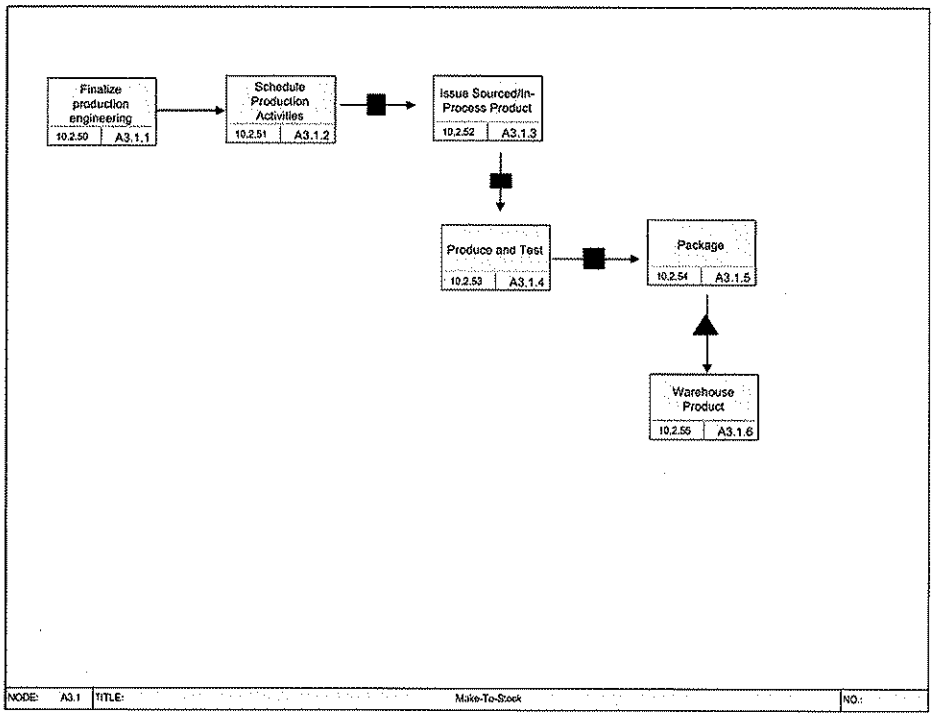

Identify sources of supply
1.2.37
A2.1.1
Select Final Supplier & Negotiate
1.2.31
A2.1.2
Schedule Product Deliveries
1.2.32
A2.1.3
Receive Product
1.2.33
A2.1.4
Verify Product
1.2.34
A2.1.5
Transfer Product
1.2.35
A2.1.6
Authorize Supplier Payment
1.2.36
A2.1.7
NODE: A2.1
TITLE: Source Stocked Product
NO.:

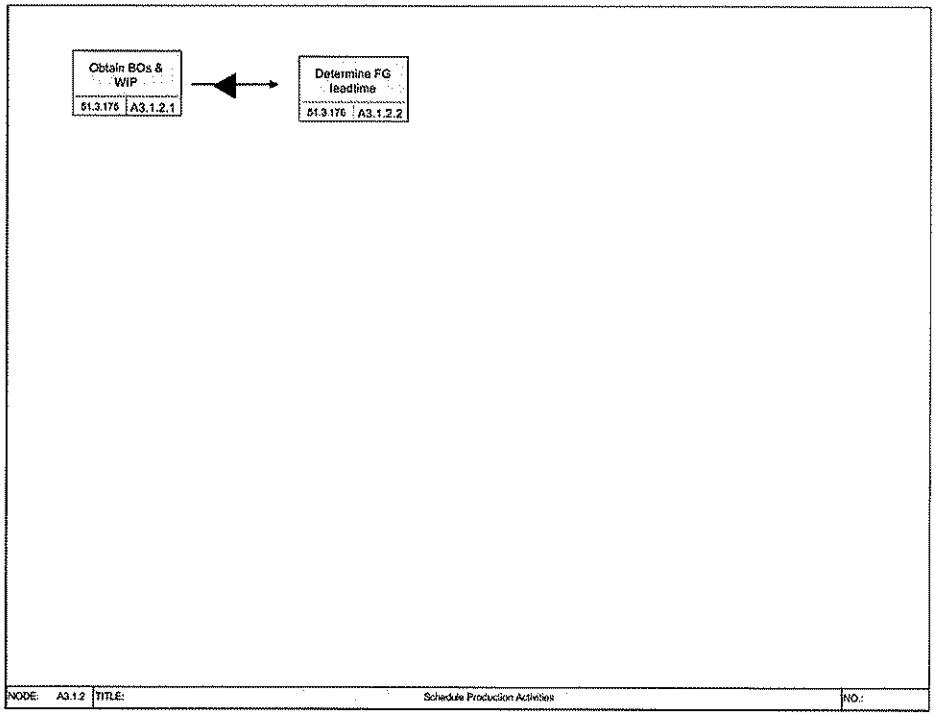

Obtain current supplier info
31.3.100
A2.1.2.1
Obtain alternate supplier info
31.3.101
A2.1.2.1
O
Select supplier
31.3.100
A2.1.2.2
Negotiate
31.3.102
A2.1.2.3
NODE: A2.1.2
TITLE:
Select Final Supplier and Negotiate
NO.:

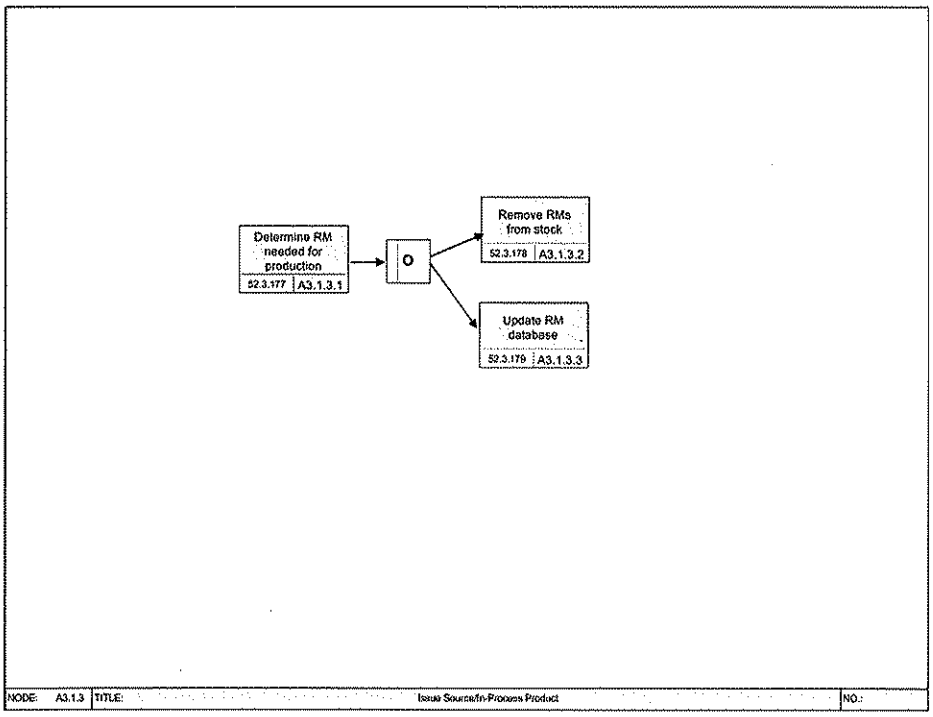

Obtain RM Hauler
32.3.100
A2.1.3.1
Obtain RM deliv date
32.3.101
A2.1.3.1
&
J1
RM Scheduled
32.3.102
A2.1.3.2
NODE: A2.1.3
TITLE:
Schedule Product Deliveries
NO.:

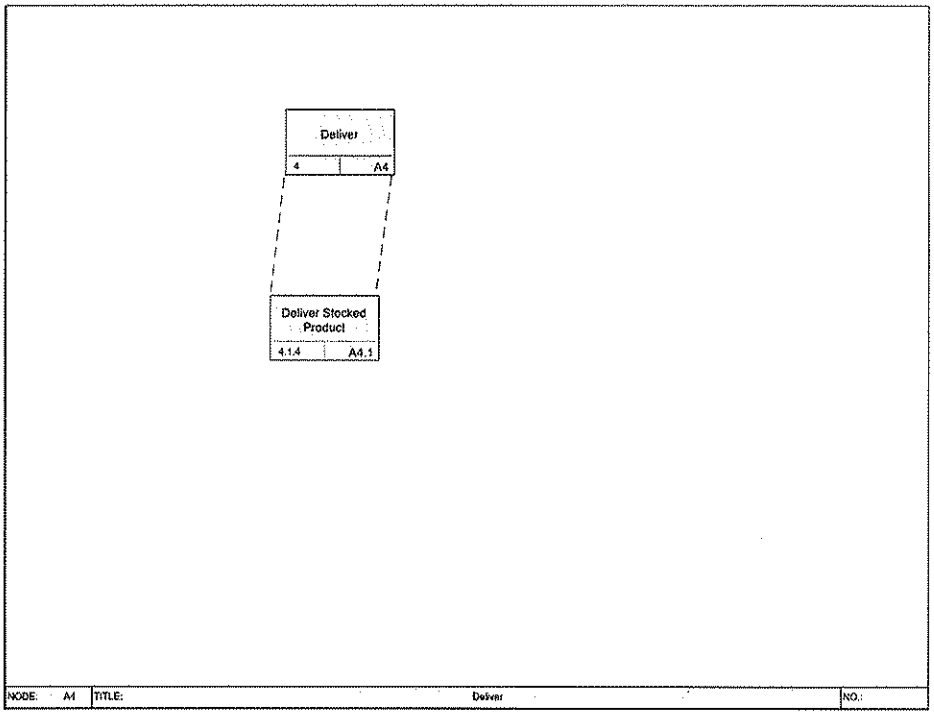

Record qty rec'd
34.3.151
A2.1.5.1
&
Determine delivery qty accuracy
34.3.152
A2.1.5.2
Determine on-time performance
34.3.153
A2.1.5.3
NODE: A2.1.5
TITLE: Verify Product
NO.:

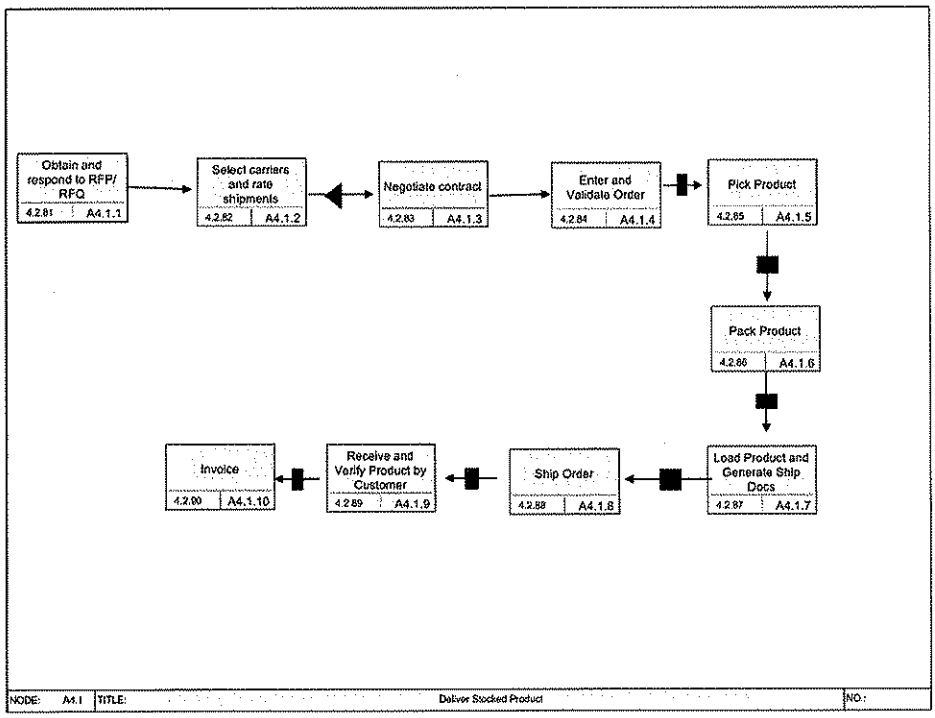

Make
2
A3
Make-to-Stock
2.1.10
A3.1
NODE: A3
TITLE: Make
NO.:

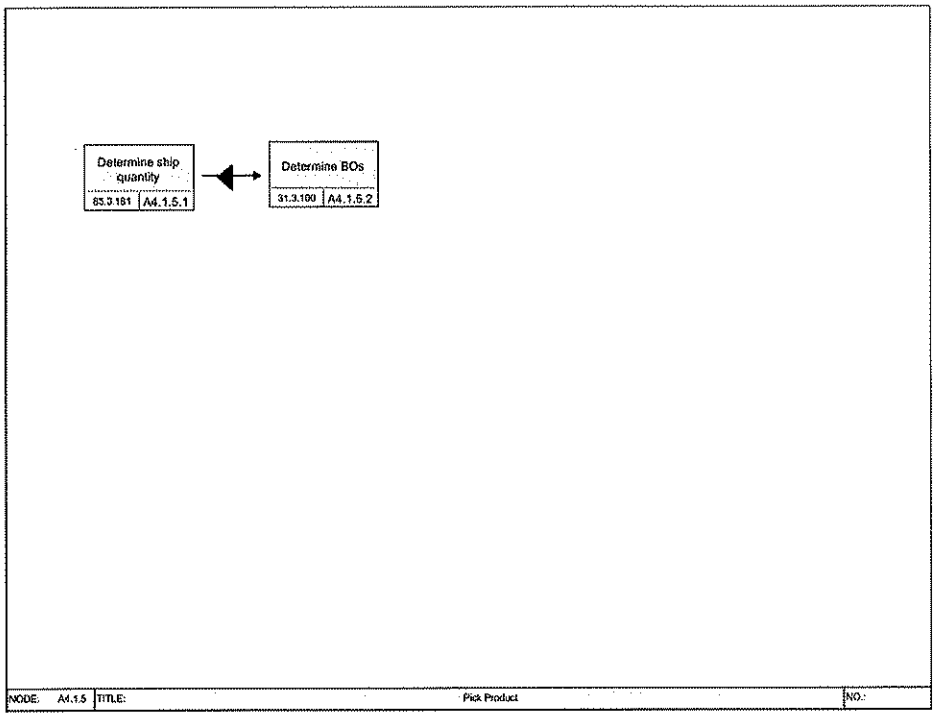

Finalize production engineering
10.2.50
A3.1.1
Schedule Production Activities
10.2.51
A3.1.2
Issue Sourced/In-Process Product
10.2.52
A3.1.3
Produce and Test
10.2.53
A3.1.4
Package
10.2.54
A3.1.5
Warehouse Product
10.2.55
A3.1.6
NODE: A3.1
TITLE: Make-To-Stock
NO.:


Obtain BOs & WIP
51.3.176
A3.1.2.1
Determine FG leadtime
51.3.176
A3.1.2.2
NODE: A3.1.2
TITLE: Schedule Production Activities
NO.:


Determine RM needed for production
52.3.177
A3.1.3.1
O
Remove RMs from stock
52.3.178
A3.1.3.2
Update RM database
52.3.179
A3.1.3.3
NODE: A3.1.3
TITLE: Issue Source/In-Process Product
NO.:


Deliver
4
A4
Deliver Stocked Product
4.1.4
A4.1
NODE: A4
TITLE: Deliver
NO.:


Obtain and respond to RFP/ RFQ
4.2.81 A4.1.1
Select carriers and rate shipments
4.2.82 A4.1.2
Negotiate contract
4.2.83 A4.1.3
Enter and Validate Order
4.2.84 A4.1.4
Pick Product
4.2.85 A4.1.5
Pack Product
4.2.86 A4.1.6
Load Product and Generate Ship Docs
4.2.87 A4.1.7
Ship Order
4.2.88 A4.1.8
Receive and Verify Product by Customer
4.2.89 A4.1.9
Invoice
4.2.90 A4.1.10
NODE: A4.1 TITLE: Deliver Stocked Product NO.:


Determine ship quantity
85.3.181 A4.1.5.1
Determine BOs
31.3.100 A4.1.5.2
NODE: A4.1.5 TITLE: Pick Product NO.: