ABSTRACT

PARLIKAD, AJITH KUMAR NARAYANAN. Performance Analysis of Intelligent Supply Chain Networks. (Under the direction of Michael G. Kay.)

Supply Chain Management has become the primary competitive weapon in many industries. This thesis describes a model of intelligent supply chain networks that will improve information visibility and flow within the supply chain. In the proposed model, products will have the intelligence to direct themselves throughout the distribution network and will have the capability to be purchased and sold while in transit. The report gives an overview of the supporting technologies that make such a supply chain a reality. It is intended to provide a preliminary outlook at the various issues related to implementation and could be used for future research as a basis for building the infrastructure required for the new model. An effort has been made to provide a design structure for XML identification tags, which will be one of the most critical components of the system. In addition to that, this report will describe the results of a simulation analysis using a model of a hypothetical public logistics network covering the southeastern United States. The network consists of 36 nodes representing the public distribution centers and 59 arcs, which represents various interstate highways connecting them. The simulations help identify the critical parameters associated with the material flow through the network and provide an insight into the capacity requirement of the public distribution centers. The results of the simulations will be used as a benchmark for future research and development associated with building an actual negotiating agent model.

PERFORMANCE ANALYSIS OF INTELLIGENT SUPPLY CHAIN NETWORKS

by

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A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

INDUSTRIAL ENGINEERING

Raleigh

2002

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To my grandfather

Venkiteswaran Parlikad

BIOGRAPHY

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ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my advisor, Dr. Michael Kay for his advice, support, and vision and for being my mentor and guru. Working with him has been a highly rewarding experience.

I would like to thank Dr. Robert Young and Dr. Cecil Bozarth for showing interest in my research and agreeing to be on my committee.

I'm indebted to Dr. Stephen Roberts for his invaluable guidance and suggestions while building my simulation model. He is undoubtedly one of the best teachers I have had in my academic life.

My thanks to Dr. Duncan McFarlane, Research Director, Europe Auto-ID Center, for his input and for giving me permission to include his research activities in my report.

I have to thank my parents and Saju for being patient and for not considering me a nut when I decided to do my second masters! No amount of thanks would be too much for my roommates Baap, Praggy, and Arvy and all my friends (especially Kavitha), for their invaluable support and that occasional pat on the back, which made my stay at NC State a lot easier.

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Chapter 1. INTRODUCTION

Supply Chain Management has become the primary competitive weapon in many industries. Supply chains in practically every industry are at the beginning of a startling reinvention triggered by the rise of the Internet and focused on reducing costs, improving service, enhancing revenues, and empowering both the providers and users of products and services. Customers are hard to keep and costly to replace. Companies face intense competition from traditional powerhouses and new players, and must continue to find new revenue opportunities and increase efficiencies. The lack of direct information flow from customer to the manufacturer has caused many concerns regarding the effective functioning of the supply chain. In spite of the technological advances that provides for smooth information flow, a report from Deloitte and Touché [1] showed that 70 percent of U.S. retailers lack a cohesive eCommerce strategy. One of the potential consequences of imperfect information flow is the "Bullwhip Effect." Lee et al. [2], explains the causes and possible remedies to the bullwhip effect.

An article on cracking the bullwhip effect by Donovan [3] provides some guidelines to alleviate the problems caused by the bullwhip effect. Almost all the solutions mentioned in the article points to eliminating the lead-time for the flow of information and inducing as much flexibility as possible to the system. Joshi [4] describes a series of simulations of the "Beer Game" and found that information visibility and collaboration provide around 40 to 70% reduction in inventory costs alone. Figure 1.1 shows the information flow in a traditional supply chain.

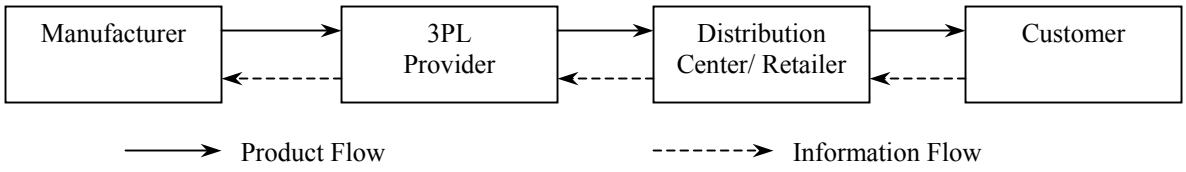


Figure 1.1: Information flow in a traditional supply chain

As can be seen in the figure, there are a lot of intermediate stages between the manufacturer and the customer. Each of these stages acts as information dampers or distorters. Supply chain innovation [5] is essential if manufacturing organizations are to remain competitive. An effective supply chain network can provide:

- An ability to source globally,
- Online, real-time information networked around the organization, giving full supply chain visibility,
- Information management across, rather than only within, organizational boundaries,
- An ability to offer "local" products globally,
- Improved customer response times,
- Lower inventories.

In this thesis, a product driven "intelligent" supply chain is proposed as a solution for these problems. In the proposed model, an "intelligent" product routes itself from the supplier to the customer, deciding its route, customer and price. It will be supported by a public logistics network (PLN) [6] as the backbone. Figure 1.2 shows the information flow in the proposed intelligent supply chain.

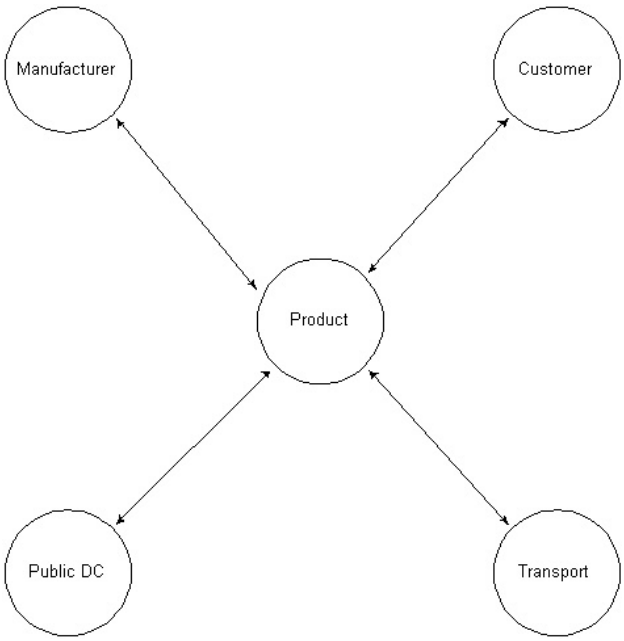


Figure 1.2: Information flow in intelligent supply chain networks

This model ensures continuous and accurate flow of information throughout the value chain [7]. It does not have any intermediate stages that would hamper the smooth flow of information. The "intelligent" product holds the necessary information and makes it available to anyone who would require that information. The supply chain of the future will rely heavily on Internet and the latest in automatic identification technologies. The building blocks of the intelligent supply chain are:

a) **XML** [8], a universal format for web communications, makes it possible to translate information between different computer systems.
b) **UNSPSC Code** [9] (Universal Standard Products and Services Classification Code) will make it possible to hierarchically search for an item by using general categories of products, as opposed to producer-specific coding schemes such as UPC, making it possible to use the Internet to search for similar products from multiple vendors that are located in close geographic proximity.

c) **RFID** (Radio Frequency Identification) or "smart" tags that contain information about the product to which it is attached and will make it possible for an individual package to be controlled by its own intelligent agent.
d) **GUIDs** (Globally Unique Identifiers) can be used as unique serial numbers and can be embedded in an item's RFID tag at the time of its manufacture so that each item is individually identifiable for tracking and negotiating purposes.

This report will provide a model and some preliminary guidelines for implementation and could be used for future research as a basis for building the infrastructure required for the intelligent supply chain. In addition to that, this report summarizes the results of a simulation analysis of public logistics networks and preliminary models of "negotiating" distribution networks. The results of the simulations can be used as a benchmark for future research and developments in building the actual negotiating agent model. Before delving further into the details of the proposed model, current practices in context of a possible logistics and eCommerce scenario will be reviewed.

1.1 Cross-docking facilities

La Londe et al. [10] portrays the importance of cycle time compression in supply chains. In an attempt to reduce the time that material is held as inventory in the logistics system, many American firms are employing a tactic that is often referred to as cross docking. In a cross docking operation, shipments move through a warehouse or a distribution center without being held in storage.

In a traditional retail distribution system, a single shipment of several truckloads of a given item would be received, inspected and moved to storage. The inventory control system

would then recognize the availability of the property and release many small orders for the item to satisfy the requirements at the retail outlets. The orders would be picked from stock, assembled into shipments with other items, and shipped to the stores. In contrast, in a cross docking operation, the incoming shipment would be unloaded, broken down and immediately reassembled into outbound shipments to the stores.

The smooth operation of such a system requires a high degree of co-ordination and centralized control, as well as highly developed data automation and communication capabilities. The cross-docking operation is potentially much more efficient to operate, since storage costs are virtually eliminated and handling costs are effectively halved.

Cross docking plays a crucial role in the design of public logistics network. The distribution centers are high-tech cross docking facilities designed to sort and regroup packages with high speed and accuracy.

1.2 Third Party Logistics (3PL)

Competition and customer demand for timely and flexible delivery are forcing companies to consider ways to increase their competitiveness. Literature on supply chain management [11] recommends that firms concentrate on their core competencies and outsource other activities. For most firms, logistics is not considered to be a core competency. Thus logistics activities are often subject to out-sourcing. This gave birth to a new term in the logistics business community: Third Party Logistics. In a comparison between the spreading of third party logistics in US and European production industries, Lieb et al. [12] used the following definition: “Third party logistics involves the use of external

companies to perform logistics functions that have traditionally been performed within an organization. The functions performed by the third party can encompass the entire logistics process or selected activities within that process."

1.3 Fourth Party Logistics™ (4PL)

Fourth Party Logistics™ (4PL), a new concept in supply chain outsourcing, is emerging as a path to achieve more than the one time operating cost reductions and asset transfers of a traditional outsourcing arrangement. Through alliances between best-of-breed third party service providers, technology providers and management consultants, 4PL organizations create unique and comprehensive supply chain solutions that cannot be achieved by any single provider. Corporations are outsourcing their entire set of supply chain processes to a single organization that will assess, design, build, and run integrated comprehensive supply chain solutions. While the fairly common practice of outsourcing logistics functions to Third Party Logistics Providers (3PL's) delivers substantial benefits such as cost reductions and service improvements, it often does not deliver its full potential. These relationships usually lack the high-level oversight and strategic expertise that can deliver a fully synchronized supply chain. Fourth Party Logistics ™ (4PL) providers deliver a comprehensive supply chain solution complete with the integration and synchronization skills for an optimally leveraged supply chain. A Fourth Party Logistics™ provider is a supply chain integrator that assembles and manages the resources, capabilities, and technology of its own organization with those of complementary service providers to deliver a comprehensive supply chain solution. More information on fourth party logistics systems can be obtained at About.com [13].

1.4 Supply Chain Management and eCommerce

The rules of business have changed. In today's environment, new products are launched and businesses are born every day. Today more than ever, businesses depend on strategic relations with their partners and suppliers to create value chains that will provide a competitive edge in the market. In effect, there is a new network economy emerging where companies trade with partners and customers over the Internet in real time. The virtual corporation is now a reality with companies outsourcing design, manufacturing, distribution and other functions so they can focus on their core competencies. A recent study [14] emphasizes the importance of logistics providers using leading edge Internet technology to adapt to the changing supply chain environment.

In recent years, information systems (IS) have been seen as more than resources that support various business processes. It has been recognized that information systems have the potential to act as a force that can be used by companies to gain significant advantages over competitors. Much has been talked about the importance of Business-to-business (B2B) commerce in the supply chain organization. The advent of B2B business standards and solutions has been explosive in the past five years. A recent forecast by eMarketer [15], a publisher of Internet and e-business information for marketing professionals suggested that worldwide B2B eCommerce will grow 74 percent in 2002 and total $823.4 billion by the end of the year. eMarketer's "E-Commerce Trade and B2B Exchanges" [16] report predicts strong eCommerce growth continuing through 2004, when Internet-based trade is expected to reach nearly $2.4 trillion.

The B2C scenario is also set to follow the same encouraging trend as in B2B. A news article in eBiz Daily [17] forecasted "U.S. B2C sales online will grow from an estimated $25 billion in 1999 to $152 billion in 2002 – and are expected to extend further to $233 billion in 2004." This points to the fact that customers are getting increasingly net-savvy and corporations that do not keep up to the technology will have to see the hard way out.

Yantra, a leading provider of enterprise software for distributed commerce management, describes in their white paper [18] the impact of the Internet on supply chain logistics providers. The paper describes the changing attitude of clients of customers and that real time sharing of information has become the "norm." Clients expect their logistics partners to provide them and their customers with accurate order and inventory status. This expectation places significant strain on logistics providers that often utilize fulfillment systems not designed to work in a real-time environment. Most logistics providers lack a single system that provides real-time status of orders and inventory across their entire fulfillment network. A study [19] published in *Logistics Information Management* predicted that the number of private warehouses will decrease in future and the number of transshipment warehouses will increase. This shows that the idea of public logistics networks (described in detail in the next chapter) goes along with the recent trends in the logistics industry.

Chapter 2. PUBLIC LOGISTICS NETWORKS

2.1 Introduction

A "public logistics network" is proposed as a means to extend many of the features associated with public warehouses to the intelligent supply chain. In addition to providing traditional warehousing and storage functions for hire, a public logistics network would make it possible to negotiate with multiple firms on a load-by-load basis in order to determine the most efficient means of providing the resources needed to complete each stage of a load's transit through the network. Items could continuously negotiate with the logistics resources of the network using simultaneous auctions in order to determine the best route and cost and schedule. Similar to the dynamic pricing used to sell airline seats, a price for each available space on a truck and storage space at a distribution center (DC) could be negotiated in real time for each individual item.

A unique capability of such a network is that a third party can search the network for any type of item in transit. Once located, negotiations can take place and the item might be resold to the third party and redirected to a new destination. The potential utility of this search and negotiate capability depends on the characteristics of items being transported: it is not likely to be needed to locate low-cost, ubiquitous items like toothbrushes because they can be expected to be available at every local store; nor is it needed to locate custom-made, one-of-a-kind products because there are so few of the items available, of uncertain quality, that the use of traditional private logistics networks is likely to be the most efficient. A public logistics network is likely to be most suitable for managing the multitude of commodity-like

items (replacement parts, etc.) that fall in the middle ground between ubiquitousness and uniqueness.

2.2 Public vs. Private Logistics Networks

Currently, it is common for a single logistics firm to handle a load throughout its transport. Although companies like FedEx and UPS have very sophisticated proprietary tracking and control infrastructures, the control of the logistics network is highly centralized. The most notable feature of these private logistics networks is that a single firm controls the network and much of the technology used to coordinate the operation of the network is proprietary. As a result, the principal competitive advantage that a private logistics company has is the barrier to entry due to the very large scale of operation (national or international) required in order to be able to underwrite the development of private facilities and propriety technologies. Nevertheless, a single firm, unless it becomes a monopoly, is ultimately limited in the scale of its operation, resulting in the use of single-firm "hub" DCs. With a limited number of large-scale hub DCs, a load can make many circuitous "hops" before it reaches its destination.

The most salient impact of such a network is likely to be that it would make it possible to separate the different functions of the network so that a single firm is not required for coordination. This would enable economies of scale to be realized in performing each logistics function since each element of the network has access to potentially all of the network's demand. The increase in scale might make it economical to ship in full truckloads throughout the network as opposed to more costly less-than-truckload shipments. This could be possible because a single truck could be used to transport all of the demand associated

with a lane (or link) in the network. Many of the long-haul, single-product full-truckload shipments between private facilities can be replaced by sequences of short-distance hops between public DCs. Links in the network could be served by trucks that are owned and operated by different firms, and each transshipment point (i.e., public DC) in the network could be an independently operated facility. Due to the increase in scale, it would be economical to have many more DCs. Public DCs (which would operate like existing private highly automated hub DCs, but on a smaller scale) could be established in small cities and towns that would never have such facilities if they were served as part of a proprietary, private logistics network.

2.3 A Snapshot

This section presents a brief snapshot of the possible scenario to help better understand the proposed system.

Every manufactured item will have an RFID (see section 3.1) attached to it. The manufacturer generates a GUID and an item specific XML (see section 3.3.1) code derived from the Document Type Definition (DTD) [20] relevant to the UNSPSC code (see section 3.2.1) of the class of products associated with the part. The RFID will be programmed with the GUID given to the item (see section 3.2.2). The XML data will be stored in the Package IP Server (see section 3.4.1) at the manufacturer's premises. If an order has been placed for the item, it will be shipped to the customer; otherwise, it will be stored in the warehouse. Package IP servers at the warehouse/truck will update inventory data (update XML files). The item is shipped across the public logistics network to the customer.

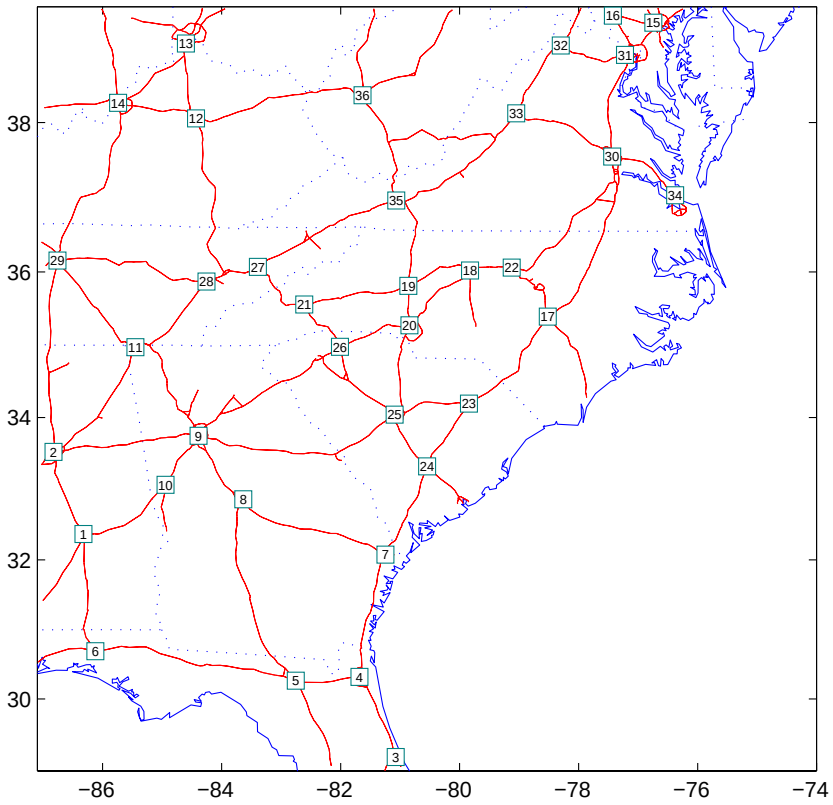


Figure 2.1: Hypothetical public logistics network showing 36 public DCs covering the southeastern portion of the USA and connected via interstate highways.

Now let us suppose that a small machine shop in Raleigh, NC has just had a production machine failure. The spare part needed to repair the machine is too expensive to be stored on-site. In order to acquire the part, the machine shop uses the part's UNSPSC code to contact servers at nearby public DCs to search for items with the same code that are at or inbound to the DCs. Assume that the closest item found was just manufactured the previous day in Jacksonville, FL and is on a truck heading north on I-95. It is intended to be delivered to a firm in Washington, DC. While still in transit, the machine shop's computer can start negotiations with the item's intelligent agent running on a computer onboard the truck. If the item can be used by the Raleigh firm and if the Washington firm does not have an immediate

need for the item, then, after an agent-mediated auction and bidding process, the item could be purchased by the Raleigh firm. All the necessary information about the item can be stored in the "smart tag" attached to the item. The information will be stored in a standard XML format that can be queried and accessed easily by any commonly used browser. When the truck transporting the item on nears the I-95–I-40 interchange, the item would be unloaded at the interchange's public DC (DC 17 in Figure 2.1) and loaded onto the next truck heading to Raleigh along I-40. Within two hours, the item could be in Raleigh and, shortly thereafter, the production machine could be repaired. At the same time, the Washington firm could locate an identical replacement item and, with the revenue from the sale of the item to the Raleigh firm minus the cost of the replacement, may be able to realize a net gain.

Currently, without a public logistics network, the firm in Raleigh would most likely have to either use overnight express delivery to acquire the replacement part, or store in house what might be an expensive part, or use a private company like UPS Logistic Group's Service Part Logistics [21] to provide the urgent delivery of the part within hours. With a public logistics network, the firm can get the quick-response benefits of on-site inventory without its associated carrying cost and most of the benefits of urgent delivery at what is likely to be a much lesser cost due to the increase in scale. Information about any item can be tracked effortlessly using this system, which facilitates seamless information flow throughout the supply chain. As the product finds its way to the customer, it reduces overheads from other components and parties of the supply chain. As all negotiations and settlements are done automatically, the system will work with better efficiency and flexibility.

Chapter 3. ENABLING TECHNOLOGIES

Several key standards and technologies have recently been developed that make the intelligent supply chain possible. A detailed survey was conducted that looked at all the available technologies to come up with the basic building blocks. Table 3.1 shows five major requirements for making this idea feasible and the technologies that satisfy them.

Table 3.1: Enabling technologies

Requirement	Technology
1 Product data storage and transmission	• RFID Systems
2 Product identification	• UNSPSC Code & GUID • ePC (Auto-ID)
3 Data representation in an Interchangeable format	• XML • PML (Auto-ID)
4 Network infrastructure	• Package IP Servers • ONS (Auto-ID)
5 Automated negotiation capabilities	• Intelligent Agents

The Auto-ID Center at Massachusetts Institute of Technology is an industry-sponsored lab charged with researching and developing automated identification technologies and applications. The center envisions a world in which all electronic devices are networked and every object whether it is physical or electronic, is electronically tagged with information pertinent to that object. This coincides exactly with our vision of an intelligent supply chain. Parallel research at the Auto-ID Center provides a good comparison

and reference to our project. This section of the report explains the findings of our research and gives a brief overview of related work at the Auto-ID Center.

3.1. Smart-Tag Technology (RFID)

Smart tags consist of a transponder that is electronically programmed with unique data. These are commercially known as Radio Frequency Identification (RFID) systems, since they transmit data using radio transmitters. Data is read/written on the tag through an antenna or a coil by a transceiver, which is connected to a host computer (at the warehouses in public logistics networks as well as on board trucks). The smart tags can be categorized as active or passive. An internal battery powers active RFID tags. This gives active tags a longer range, but at the cost of bigger size, higher manufacturing/operating cost and limited operational life. Passive RFID tags operate without a separate external power source and obtain operating power generated from the reader. As a result, they are lighter, cheaper and long lasting as compared to active tags. They usually have short read range, and require a high-powered reader. The forte of RFID tags is the non-contact, non-line-of-sight nature of the technology.

Massachusetts Institute of Technology and Science, Boston and University of Cambridge, UK have established Auto-ID Center [22] to investigate issues associated with developing a ubiquitous electronic product coding environment to extend the current bar coding technologies in use in many industrial, retail and commercial environments today. A more detailed description on the research on RFID tags at Auto-ID center can be found in Sarma [23]. Today, companies like Texas Instruments (TI) and Philips Semiconductors are developing and producing RFID technology. The average cost of RFID tags presently is

around 50¢. Researchers at Auto-ID center are exploring ways to develop low cost tags with a target cost of 5¢.

3.2. Unique Product Identification

For efficiently tracking and locating an item across the distribution network, it needs to be assigned a code that is unique to it. A lot of standards codes are in practice today. The Universal Product Code (U.P.C.) [24] is the most prevalently used standard coding scheme. The Uniform Code Council (UCC) UPC code numbering system is a 12-digit numeric sequence. The standard symbol is a series of light and dark lines, together with a human readable numeric equivalent. The UPC code can provide up to 10 unique numbering systems, 100,000 manufacturer identifiers, and 100,000 product types for each manufacturer. Other than the UPC code, each industry has its own coding system for its products (e.g., ISBN code for books). None of these coding systems can be used for unique item identification. For quick search and locate, we require a code which will identify a particular item with a class of products. This means that we need a hierarchical system of coding products. Also, we needed a code that will be unique to each product that is manufactured. The combination of UNSPSC coding scheme and the GUID proves to be a good solution for this hurdle.

3.2.1. Universal Standard Products and Services Classification (UNSPSC) code

Coding products and services according to a standardized classification convention is necessary for streamlining commerce among companies. Products and services that are unambiguously identified with industry-agreed upon names allow purchasing management to

effectively source and analyze expenditures. In addition, machine-readable product names assist marketing and sales functions to find customers and provide better customer and distribution channel services.

To be useful, product classification scheme must be hierarchical, so that individual commodities represent unique instances of larger classes and families. Hierarchical organization allows a given company to focus on a level of specificity that best suit its purposes and situation. Most product coding schemes commonly used such as the UCC and EAN bar codes are not hierarchical and therefore will not serve the purposes of search and analysis.

The Universal Standard Products and Services Classification (UNSPSC) Code [25] is the first coding system to classify both products and services for use throughout the global marketplace. UNSPSC is the result of a merger of the United Nations' Common Coding System (UNCCS) and Dun & Bradstreet's Standard Products and Services Codes (SPSC). The Electronic Commerce Code Management Association [26] (ECCMA) is a not-for-profit, unbiased, membership organization that oversees the management and development of the UNSPSC Code.

The UNSPSC is a hierarchical classification having five levels. The levels allow users to search products more precisely (because searches will be confined to logical categories and eliminate irrelevant hits) and it allows managers to perform expenditure analysis on categories that are relevant to the company's situation.

Each level contains a two-character numerical value and a textual description as shown in Figure 3.1.

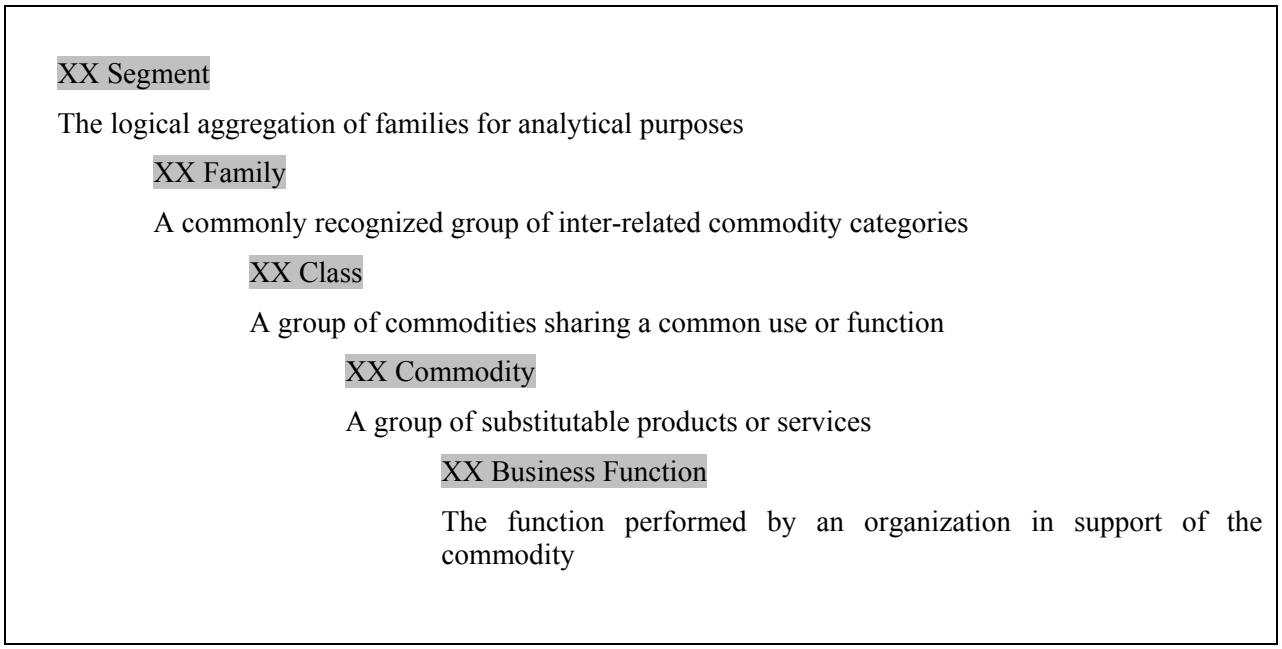


Figure 3.1: UNSPSC hierarchy

B2B standards consortiums such RosettaNet [27] and ebXML [28] have adopted the UNSPSC Code for product coding and classification. This will make UNSPSC a widely used product-coding scheme in the future. The hierarchical structure of the code makes it compatible with the inheritance properties of Object Oriented Programming Languages such as C++, Java, Smalltalk etc., which are the primary coding languages used for creating negotiating agents and e-auctions.

The UDDI (Universal Description, Discovery, and Integration) Project [29] initiated by business leaders like Merrill Lynch and Cargill; technology leaders like IBM, Microsoft, and Sun Microsystems; and innovative B2B companies like Ariba, CommerceOne, and VerticalNet has accepted UNSPSC Code for product/service identification. This makes UNSPSC universally accessible from the UDDI directory services.

For example, the UNSPSC code for office leased addressing machines is 4410210510.

–44 - Segment (Office Equipment, accessories and supplies)

–10 - Family (Office Machines, and their supplies and accessories)

–21 - Class (Mail Machines)

–05 - Commodity (Addressing Machines)

–10 - Business function identifier (Addressing Machines, Leased)

For our purposes, only the first eight digits of the UNSPSC code are relevant. The business function identifier is not important when it comes to selling and buying in the marketplace.

3.2.2. Globally Unique Identifiers (GUID)

To enable tracking and negotiation, products should be individually identifiable. A unique Product ID number should be given to each of the products. We have a readily available unique ID generator known as the Globally Unique Identifier (GUID) that is commonly used in software products. Products are uniquely identified by providing them with a GUID, which is embedded in the tag at the time of production. Many GUID generators are publicly available on the Internet [30]. The manufacturers generate the GUID, which is:

- Random 16-byte user ID, represented as 32 hexadecimal digits

- Constructed by applying a MD5 [31] hash to a string concatenated from the IP address of the requestor, the date and the time of the day in ticks.

The number of GUIDs that can be formed are so large as to accommodate all manufactured objects. Due to the unique combination of factors that goes into the GUID, it is nearly impossible that two GUIDs can be the same.

3.2.3. Electronic Product Code (Auto-ID)

The electronic product code (EPC) [32] was conceived by the Auto-ID center to identify all physical objects. The EPC is a 96-bit code with a fixed 8-bit header. This header defines the number, type and length of all subsequent partitions. Brock [33] explores the differences in approach between the EPC and the Global Trade Item Number (GTIN) and presents a method for integrating the EPC and GTIN. Figure 3.2 shows the 96-bit representation of the EPC Coding scheme.

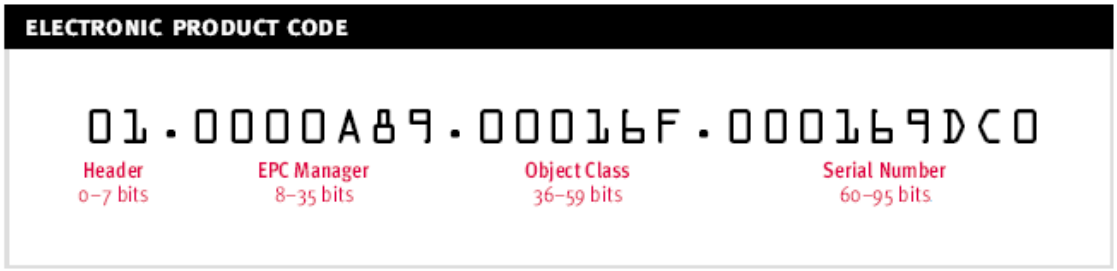


Figure 3.2: 96-bit EPC coding scheme

Although 96 bits fit into many of the RFIDs available, in order to reduce the cost of the tags, the Auto-ID center has come up with a set of 64-bit truncated versions of the EPC. More information on the new versions of EPC can be found in Brock [34].

3.3. Data Representation

3.3.1. Extensible Markup Language (XML)

Extensible markup language (XML) [35] has attracted considerable attention from enterprises interested in employing dynamic information exchange over the Internet between trading partners. XML is a more advanced language than the Hypertext markup language (HTML), which is currently used to exchange data on the Internet. XML allows for the use of special tags before a message that would allow a browser to identify the message. Through the use of those tags, the search agent could immediately recognize the identity of the product and its characteristics.

The following information should be available in the XML tag:

- Item Specific Information
    - Item specific negotiation code
    - Manufacturer & Model
    - Physical Description
    - Other relevant Information
- Instance Specific Information
    - Globally Unique Serial Number
    - Location
    - Price
    - Current Owner
    - Parameter showing the willingness to negotiate
    - Other relevant information

XML tags can be defined for each product on the basis of the UNSPSC code. Item specific information will remain the same for all products having the same UNSPSC code. For each separate product, only the instance specific information needs to be added.

Document Type Definitions [36] (DTDs) define the structure of XML tags for each product, i.e., for each UNSPSC code, there will be a DTD associated with it. The ECCMA Global Attribute Schema (EGAS) [37] is a code that will help to define a standard set of attributes to help users more closely describe the characteristics of a commodity. This actually is an extension of the UNSPSC code. It specifies the attributes that will help identify a particular product. ECCMA has developed an extensive library of attributes corresponding to each UNSPSC code. Figure 3.3 shows the core elements of the DTD and Figure 3.4 shows an example for the XML tag that could be used for photocopiers. The complete example is provided in Appendix A.

```
<?xml version="1.0"?>

<!ELEMENT product
(unspsc,name,productType,manufacturer,location,description,owner,price,date,time,negotiateFlag)>
<!ELEMENT unspsc (#PCDATA)>
<!ELEMENT name (#PCDATA)>
<!ELEMENT productType (#PCDATA)>
<!ELEMENT manufacturer (name,address,manufacture_date*, expiry_date*,itemCode*)>
<!ELEMENT location (name,location_type,address,latlon)>
<!ELEMENT description (attributeSet*)>
<!ELEMENT owner (name, owner_type, address)>
<!ELEMENT price EMPTY>
<!ELEMENT manufacture_date (day, month, year)>
<!ELEMENT expiry_date (day, month, year)>
<!ELEMENT date (day, month, year)>
<!ELEMENT time (hours, minutes, seconds, milliseconds)>
<!ELEMENT negotiateFlag EMPTY>
```

Figure 3.3: Core elements of DTD associated with photocopiers

```
<?xml version="1.0"?>
        <!DOCTYPE product SYSTEM "44101501.dtd">
        <!-- Sample XML Tag for Item Code: 44101501 -->
        <product guid = "FFFFBA60-DD02-11D5-AD1D-00104B98F53A">
                <unspsc>44101501</unspsc>
                <name>Xerox 5818 Copier</name>
                <productType>Photocopiers</productType>
                <manufacturer>
                        <name>Xerox Corporation</name>
                        <address>
                                <street>800 Long Ridge Road</street>
                                <city>Stamford</city>
                                <state>CT</state>
                                <zip>06904</zip>
                                <country>USA</country>
                                <phone>+1-203-968-3000</phone>
                        </address>
                        <manufacture_date>
                                <day>20</day>
                                <month>December</month>
                                <year>2000</year>
                        </manufacture_date>
                        <itemCode>123-456-789</itemCode>

                </manufacturer>
                <location>
                        <name>ABC Warehouse</name>
                        <location_type value = "DC" />
                ……
                ……
                ……
        </product>
```

Figure 3.4: A section of XML tag for photocopiers

Design of XML Tags

For smooth transfer of information between different types of computer systems, it is essential to set a standard format the tags should conform to. Here, an attempt has been made to design a possible standard format that could be used to describe the characteristics needed to define and identify a particular product.

It can easily be seen that for all products, certain information is required for tracking and location purposes. In addition to that, we can see that there are certain characteristics

common to products that fall under the same class or category. This makes it easier to develop standardized tags. The following elements are identified as required for tracking, location, and negotiation that forms the basic structure of all XML tags and is represented by the DTD excerpt shown in Figure 3.3:

- UNSPSC Code
- Name of product
- Type of Product
- Manufacturer
- Location
- Physical Description
- Current owner
- Price
- Present Date
- Present Time
- Flag indicating availability for negotiation.

Each of these elements can be broken down further in sub-elements. The following information can accurately represent the details of the manufacturer:

- Name
- Address
- Date of manufacture
- Date of expiry
- Manufacture Item Code

The XML tag should provide enough details about the location of the package. The package could be anywhere in the network ranging from the factory to a DC to a truck to the customer. The following sub-elements were found sufficient to provide information regarding the location of the package:

- Name
- Type of location (truck, DC, etc.)
- Address
- Latitude & Longitude

Formats of sub-elements such as address, date, time etc will have to be pre-defined to ensure uniformity. In addition to the above, the most important element that helps distinguish between different products is “description”. Attributes for this element will be different for each product. This element can be designed with the help of the attributes provided by EGAS specifications.

The XML structure can be represented by the tree diagram shown in Figure 3.5.

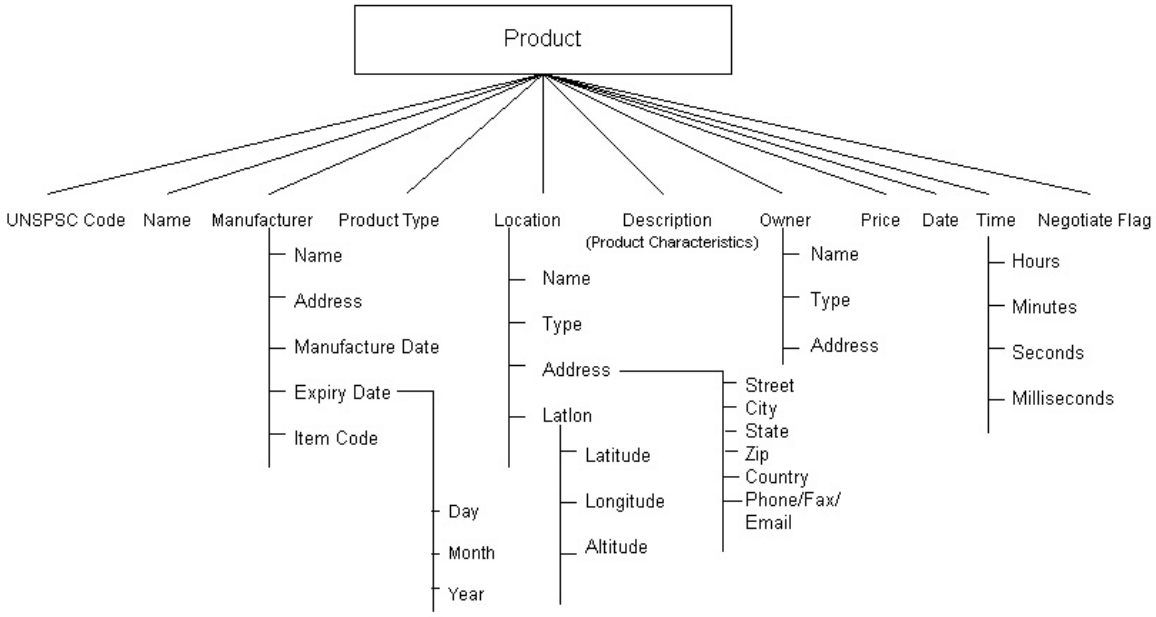


Figure 3.5: XML structure

3.3.2. The Physical Markup Language (Auto-ID)

The Physical Markup Language (PML) [38] is derived from XML and is intended to be a common language for describing physical objects, processes, and environments. PML is essentially an XML schema intended to hold networked information about physical objects. The PML will hold information that describes configuration, location, time, and

measurement of physical objects. Brock et al. [39] provides more information about the design of the physical markup language. The design of PML is found to be similar to that of the XML tags proposed by us. There are minor differences in the design as PML includes data that is necessary for the production of the particular item. In addition to information regarding the current location, PML also holds the history of the item. Also, the most important characteristic that distinguishes PML from our XML tags is that PML indexes the tags with respect to the EPC whereas XML tags indexes them with respect to the GUID and UNSPSC.

3.4. Network Infrastructure

3.4.1. Package IP Servers

The RFIDs are designed to hold the identification code for each item. The XML tags will be stored in Package IP servers, which are computers that hold product information placed in every warehouse, factory and truck. In addition to storing product information in XML databases, these servers also play an important role in searching and agent-based negotiations.

Two types of search models are being considered for locating inventory through the supply network: (a) Peer-to-Peer networks, and a (b) Central server system.

a) Peer – to – Peer (P2P) networking systems.

According to this model, the user downloads a search application from the Package IP central server. This application will be designed to search as well as manage XML databases containing information about products. The application is actually a peer, acting as both

client and server in interaction with a network of similar peers. Before it can begin the search, the peer must be informed (by the user or from its database – which gets the information from the server where it was downloaded) the IP address of the nearest peer to which it can connect. The peer sends its search request to the other peer. It searches its database for the product, and sends a reply back to the sender informing it of the status of the request. Along with the reply, it also sends back information regarding the peers known to it. The user's peer analyzes the reply and sends requests to additional peers if required. The application will be customized in such a way that the user would be able to specify the expanse of the search. The same application will serve as an agent-based negotiations platform.

b) Central Server systems.

In this model, a central server stores the IP addresses and the geographical location of all the Package IP servers. This is achieved by requiring all the Package IP servers to register with the central server. The user logs on to the central server's website and enters the search request. The server sends the request to the Package IP servers in an expanding fashion with respect to geographical proximity (nearest servers first, expanding the search if a suitable match is not found). One of the future research issues is to determine which of the above two systems is the best solution for the kind of system envisioned.

3.4.2. The Object Naming Service (Auto-ID)

The Auto-ID center proposes that the PML tags will be stored in special servers called PML servers. These servers will be connected to the local network or the Internet. The

server is identified via a free look-up system called Object Naming Service (ONS) [40], which functions in a similar manner to that of Domain Name Service (DNS), which is used to locate information resources on the Internet.

3.5. Intelligent Agents

An agent is a system/computer program that can perform a task with a certain amount of "intelligence" due to some specialized skill (learning systems) or knowledge (knowledge bases). Consistent with the requirements of a particular problem, each agent might possess to a greater or lesser degree attributes [41]:

- Reactivity
- Autonomy
- Collaborative behavior:
- "Knowledge-level" communication ability
- Inferential capability
- Temporal continuity
- Personality
- Adaptivity
- Mobility

The modern manufacturing environment has taken a huge leap in the past two decades. The most important trends can be classified into three categories:

- Increased product complexity,
- Supply networks, and
- Increased product variety over time.

Agent technologies are well suited for applications having the following special characteristics: modular, decentralized, changeable, ill structured, and complex. The tasks of design, simulation, and scheduling and control manifest many of these characteristics,

particularly under the impact of modern manufacturing trends listed above, suggesting that agents are a natural way to address them.

Agents are pro-active objects, and share the benefits of modularity that have led to the widespread adoption of object-oriented methods and, are thus best suited to applications that fall into natural modules. All three of the modern manufacturing trends lend themselves to modular analysis. Supply chain networks assign the subsystems and components to different companies, each with its own organizational identity, operational boundaries, and procedures for interfacing with its environment.

Agents can be autonomous. It monitors its own environment and takes action, as it deems appropriate. This characteristic of agents makes them particularly suited for applications that can be decomposed into stand alone processes, each capable of doing useful things without continuous direction by some other process. Supply chain networks are an expression of decentralized approach, and agent-based architectures are an ideal fit to such an organizational strategy.

Modularity and independence combine to make agents especially valuable when a problem is likely to change frequently. Modularity permits the system to be modified one piece at a time. Decentralization minimizes the impact that changing one module has on the behavior of other modules. The structure of modern supply chain networks can be dynamic, changing many times over the lifetime of an information system. This type of complex dynamic behavior is a perfect fit to our model, where items are routed dynamically over the supply network. Transportation and storage prices vary with time and availability. Items are to be re-routed to different customers when demand arises. Space, cost, and time are to be continuously negotiated for as the item makes its way through the distribution network. For

these reasons, the use of intelligent agent systems would be the best approach to tackle this complex system.

3.5.1. Agent Based Negotiation Model

Intelligent agents representing each entity in the supply chain will negotiate with a common objective of transporting items from the manufacturer to the customer with minimum transportation cost. Trucks, distribution centers, and the factory constitute the set of resources in the supply chain. Other players in the supply chain include the manufacturers, customers and the packages. The factory and manufacturer can be represented by a single entity (the manufacturer agent will coordinate internally with the factory agent for resources required, production plans, forecasts, etc.). The model will consist of the following agents:

1. Package (P)
2. Factory and Manufacturer (F)
3. Customer (C)
4. Truck (T)
5. Distribution Center (D)

The package agent will be the central control agent having multi-party negotiating capabilities. The distribution center agents will negotiate with transportation agents for obtaining the cheapest price for space in a truck. Keeping the transportation agents away from the mainstream item negotiation helps to keep the model simple and will reduce the load on package agents. Every agent will have an objective, to maximize the profit of its owner. This stems from Adam Smith's theory regarding the notion of each entity working towards the maximization of its own profit; potentially leading towards the maximization of profit for the whole supply chain.

The distribution center agent *D* is a pricebot/shopbot-like agent. It acts as a shopbot agent as it searches for the best deal available among the trucking agents. It becomes a pricebot agent as it puts up quotes for storage spaces, which changes dynamically over time. The factors determining the price of storage are (a) price quoted by competing DCs, (b) availability of storage over time, (c) demand for storage space, (d) cost of transportation as negotiated with the truck agents, and (e) other operational costs. The trucking agent *T* is a price-bot agent. It quotes the price for transporting items, which changes over time. Factors similar to those affecting the cost of storage at the DCs affect the price quoted by the truck agents.

A brief snapshot of interactions between the various agents is shown in the Figure 3.6.

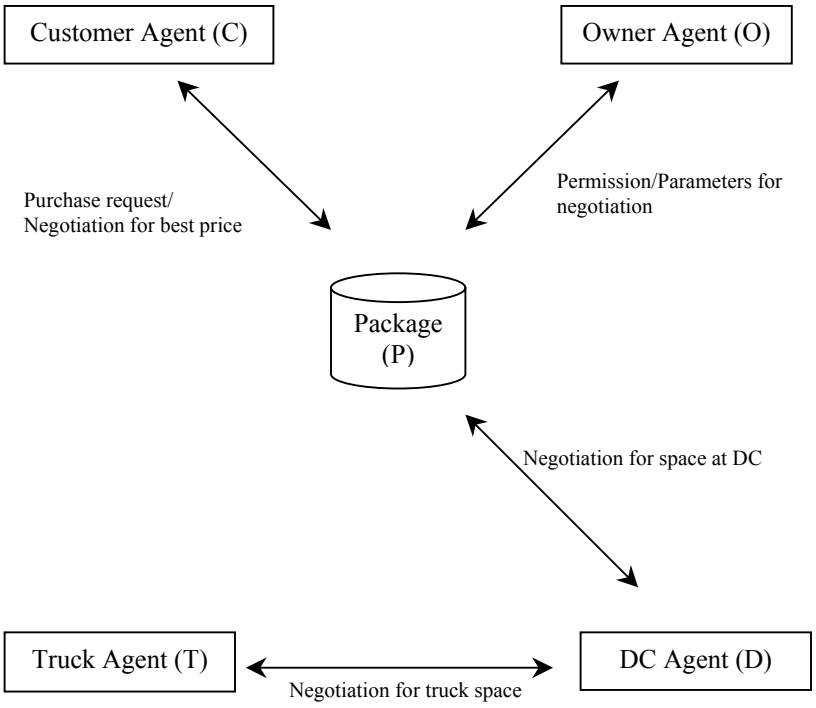


Figure 3.6: Agent based negotiations

Package agents carry information about its configuration, transportation data, price, owner, etc. These agents work for the current owner of the package associated with it. The main goal of the agent is to minimize the cost of ownership of the package. The ownership of the package changes as it flows through the supply chain. It depends on the terms of sale adopted by the trading parties (FOB/CIF). More information regarding the terms of sale can be found in the "Glossary of Shipping Terms [42]." Therefore, the owner agent O can either be the manufacturer F or a customer C.

Negotiations start when a customer initiates a search for a particular item. The search returns results that contain possible candidates for negotiation. The customer selects the packages of his choice and creates agents C_1, C_2... C_n, where n packages are selected for negotiation.

When package agent P_i receives a request for negotiation, it performs the following steps:

1. Obtain permission for negotiation from the owner agent O_j. This is extremely important since the owner might not be willing to negotiate due to policy restrictions.
2. Obtain parameters for negotiation such as price range, shipping policy, time for shipping etc.
3. P_i searches for distribution centers that it could use to ship itself to the new customer in order to obtain the best price for transportation/storage.
4. The package selects the least cost path and calculates the cost incurred in re-routing itself to the new customer. With this as the base, it negotiates with C_i for the best price that it can get.
5. The customer agent C_i receives quotes from all the packages and negotiates with them for the best deal.

The customer receives a comprehensive report of all the negotiations that took place and is given the option of selecting the best deal. The report could also be used as an input to a decision support system (DSS), which could analyze and select the best option.

As the package moves along the public logistics network, it is constantly engaged in negotiations with the resources to obtain the least cost path to the customer. According to the above model, only the package agent has multi-party negotiation capabilities. All the other agents negotiate only with the package agent. This structure provides the model with a better integration, security and minimizes complexity. In addition to this, it allows the model to be integrated with the bigger picture of a *product-driven* supply chain.

Chapter 4. SIMULATION MODELS

4.1 Introduction

Supply chain management is a complex process due to the uncertainty involved at each stage of the chain. Simulation modeling is a suitable tool for analyzing supply chains. This is largely due to the capability of simulation models to capture uncertainty and complexity and the levels of abstraction it allows. Schunk et al. [43] identifies simulation as one of the best means to analyze supply chains. A simulation model was developed in order to analyze the performance of the proposed public logistics network. A number of simulation packages are available commercially. The model was developed using Arena 5.0 [44], a popular simulation package used widely in the industry. A recent survey [45] named Arena to be one of the few simulation packages used for supply chain simulation. Simulation has been used extensively to analyze performances of supply chains. A number of examples for supply chain simulation can be found in the Winter Simulation Conference Proceedings. Jain et al. [46] provides a very good example for a high-level supply chain model that uses Arena 5.0.

A search of supply chain simulations literature showed that almost all the work done to date concentrates on interactions and transactions between various trading firms. In our case, we needed a model that concentrates on the movement of the package and the concept of the package, instead of firms controlling the supply chain. This forced a different approach to modeling the proposed supply chain. The model had to take care of further improvements, which took into consideration, the mechanisms related to negotiations and re-routing.

Because of memory and computational limitations of simulating a large number of packages, an analytical model was developed to get an overall picture of system performance. Although the analytical model was not able to look into the detailed mechanics of the system such as tracking of individual packages and modeling wait times at the DCs, it did bring out important details such as the average transport times for public logistics networks as compared to a hub-and-spoke network and a point-to-point network. More details on the analytical model can be found in Kay et al. [6].

The purpose of simulation was manifold. The analytical model showed that the proposed model would satisfy the demands of the network with respect to time. Economic feasibility analysis would be the next step to extending this analysis. To find out the level of investment required for the public logistics system, it was necessary to build a simulation model of the network. In addition to analyzing the flow performance of the network, the simulation model provided crucial investment data such as the number of trucks required for smooth operation and capacity of the distribution centers.

4.2 Basic assumptions

The road network analyzed consists of the Interstate and US highways in the southeast part of United States. The network consists of 36 distribution centers (nodes) and 59 roads (arcs). Figure 4.1 shows the network used for the analysis. The total supply and demand for each DC is assumed to follow a Poisson arrival rate, proportional to the population of the region surrounding the DC. The population of each region was estimated using the population of the five-digit ZIP Code Tabulation Areas (ZCTAs) [47] surrounding the DC. Refer to Table C.1 (Appendix C) for details on population data.

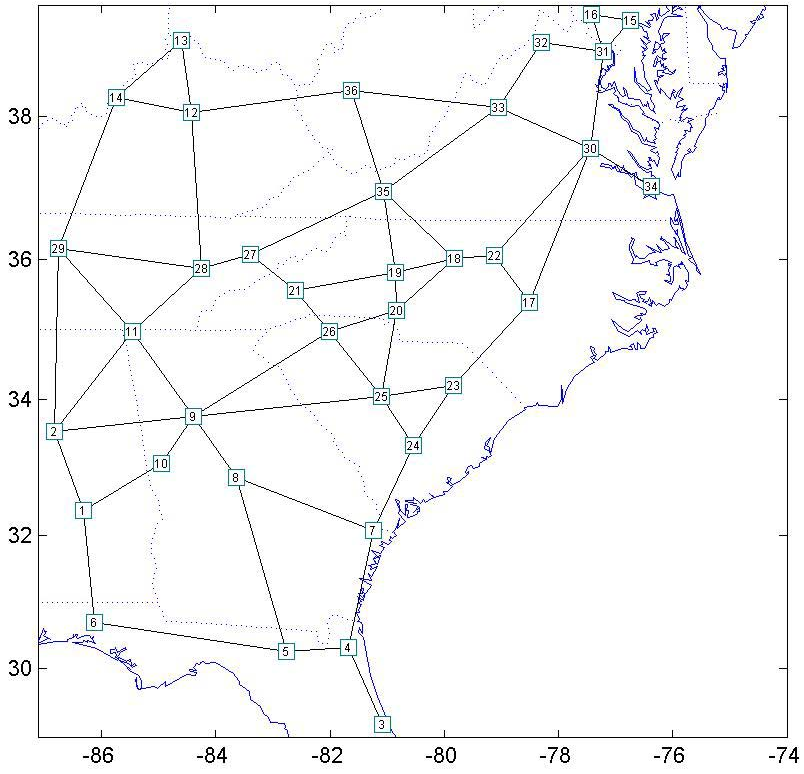


Figure 4.1: Public logistics network used in simulation analysis

Wherever the demand could be satisfied locally, only the processing time of the order is taken into consideration. The processing time of the order is assumed to be one hour. Delivery is assumed to be immediate, i.e., only travel times between the DCs are taken into consideration. Two types of items were modeled, one with a higher priority. 20% of the total demand is assumed to have a higher priority. The trucks are assumed to travel at a speed of 60 mph.

If demand is to be satisfied externally, the item is shipped to the destination DC hop-by-hop using trucks. The shortest path between each pair of nodes is pre-calculated using Djikstra's algorithm and stored in a matrix. The responsibility of each truck is to transport a

full truckload of items to the next node in its shortest path. It will be sorted and grouped with other packages to be shipped to the next node in its shortest path. Therefore, waiting time in public logistics networks consists of (a) grouping of items for a FTL, (b) waiting for availability of trucks, and (c) waiting for availability of loading/unloading bays at DCs. Each truck is assumed to take 10 mins each for loading and unloading. Items having higher priority are pushed to the front of the queue while waiting for trucks.

To avoid long run times, each demand entity in the simulation is assumed to represent 4 orders. The system was simulated as a steady state simulation. Initial analysis showed that the system achieves steady state in 24 hrs. The simulation was run for a period of 10 days. This is done to restrict the warm up period to 10% of the run length. The average number of trucks operating out of each DC and the number of loading/unloading bays at each DC were calculated by running the simulation without any constraints on the number of trucks and bays. The performance parameter analyzed was the time taken to transport items for a distance ranging from 100 to 900 miles. Data collection and analysis was performed for the priority items, which constitutes 20% of the total demand.

Two types of trucking models were initially analyzed. One, where the trucks returned to their home base and another where the trucks get automatically organized according the demand density. It was found that the latter option works better in terms of efficiency and investment required.

The average daily demand of 1.888 million packages was used as the basis for determining a representative range of likely package demands for the region. Since 18.10% of the US population is in the region covered by the network (51.617 out of 285.187 million people [47]), this demand is 18.10% of the average daily demand of 10.434 million packages

handled by UPS throughout the entire United States [48]. UPS demand was used because the type of packages handled by UPS (e.g., less than 150 lbs.) is similar to the type of packages envisioned to be handled by the proposed public logistics network. The U.S. Census Bureau publishes a Commodity Flow Survey [49] every five years that tracks all parcel, U.S. Postal Service, and courier shipments.

4.3 Model logic and development

This section provides a detailed description of the logic behind the simulation model.

4.3.1 Basic design features

- Demand and subsequent packages are represented by entities.
- DCs are modeled as resources having finite capacity (number of bays).
- Trucks are modeled as variables. Each DC is provided with a fixed number of trucks initially. The array *trucksAtNode[n_i]* holds the number of trucks at i^{th} node, where *n* is the number of nodes in the network.
- All processing times and variables are parameterized to make the model flexible and scalable. This becomes especially useful when running multiple scenarios using the process analyzer.
- Multiple random number streams are used for statistical distributions for modeling variability in all of the major inputs.
- As a variance reduction technique, unique common random number streams are used for major factors with variation.

- The network is represented by three matrices and is populated by accessing files stored in text format. (i) Distance matrix, which specifies the shortest distance between each pair of points in the network, (ii) Adjacency matrix, which specifies the neighboring nodes for each node, and (iii) Predecessor matrix, which specifies the next node on the shortest path between each pair of nodes.
- The trucks at each node have to be modeled in two steps. First, the model has to be run without constraints on the number of trucks (give a large value to the variable *trucksAtEachNode*). Calculate the number of trucks required at each node. In the next run, the array that holds the number of trucks at each node will have to be populated from a file that contains results from the calculations.
- Similarly, the number of bays at each node will also have to be calculated by running it with a large capacity first and then changing the capacities to the average utilization value obtained from the initial run.

4.3.2 Simulation model logic

This section describes the logic used to model the public logistics network without negotiation.

(a) Create Demand

Initially, demand is created with exponential inter–arrival times. The arrival rate is calculated by multiplying the average arrival rate of the network (*arrivalRate)* by the number of nodes (*noOfNodes)*.

(b) Assign initial attributes

After creating the demand, initial attributes are assigned to it. The entity is given the following attributes:

1) *IDNo*: Each entity is given a unique ID number sampled from a uniform distribution. This attribute is used to identify the order when it is put into the truck queue (explained later).

2) *TimeIn*: This attribute marks the time when the demand occurs. This is used later to calculate the time taken for the demand to be satisfied.

3) *DemandPoint*: The entity is allocated to a particular node using a discrete distribution that specifies the probability with which the demand falls in that particular node. This probability is proportional to the population at the node. More details on this can be found in section 4.2

4) *dueDate*: This attribute specifies the due date of the order relative to the time at which the demand occurs. It is sampled from a uniform distribution. The due date is not of much use in the current model, but it is added so that it could be used in future models.

5) *realDueDate*: This attribute is provided to obtain the due date in absolute time scale. *realDueDate* = *dueDate* + *TNOW,* where *TNOW* is the Arena expression for the current simulation time.

6) *SupplyPoint*: The supply point is modeled in the same way as that of the demand point. It uses a discrete distribution that specifies the probability with which the supply is from a particular node. More details on the probabilities can be found in section 4.2.

7) *priority:* As explained in section 4.2, there are two types of entities. This attribute specifies the priority value of the entity. A value of one is given to the entity having higher priority.

(c) Delay for processing time & initialize transport attributes.

The entity is delayed for order processing, which is given by the variable *ProcessingTime.* After the delay, the entity acts as the ordered package and is assigned transport attributes (i) *thisNode*, which specifies the node at which the package is (*SupplyPoint)*, and (ii) *nextNode,* which specifies the next node on the shortest route to its demand point, obtained from the predecessor matrix, *pred(thisNode, DemandPoint)*. We then update the inventory at the DC using the variable *inventoryAtDC(thisNode).*

(d) Transportation sub-model

This sub-model takes care of the logic for transporting the package to the demand point.

1) Check if the demand is satisfied at the demand point itself. If so, release the demand after updating the inventory at the DC, *inventoryAtDC(thisNode)*.

2) If the supply is from elsewhere, assign an attribute *arc*, which is the number of the next arc on the shortest path to the demand point. This is obtained from the adjacency matrix, *arc = adj(thisNode, nextNode)*. Since the arc numbers are symmetric, add a negative sign to the attribute when *thisNode* < *nextNode.*

3) Now, the items are batched for the truck capacity, which is given by the variable *batchSize.* The entities are batched according to the value given by the *arc* attribute.

4) After batching, the entities then wait for trucks to become available. This is checked using the variable *trucksAtNode(thisNode)*. When a truck becomes available at the node, the truck is loaded (loading time is given by the variable *LUTime*).

5) The entities are split from the batch and put on an infinite hold that will hold the entities for the travel time. The travel time is assigned to the attribute *TimeToTravel = Distance(thisNode, nextNode)/TruckSpeed,* where *Distance* is the matrix that defines the length of the arcs in miles and *TruckSpeed* is the variable which provides the speed of the truck in mph.

6) At the next node, the items are unloaded and assigned the next node to travel to on its shortest path till it reaches its destination.

(e) Statistics collection

The following statistics is collected:

- Number of orders satisfied
- Number of delayed orders
- Travel time for a range of distances (100–900 miles).

4.4 Model verification and validation

The simulation model was verified by running it with a demand rate of 18,000 packages per day, average truck capacity of five packages and comparing the output with results obtained from the analytical model. It was found that the difference in average

transport time estimates between the analytical model and the simulation model was approximately 3.8% (7.4731 vs. 7.1994 hours, respectively), while the difference in the estimates of the total number of trucks needed was approximately 1.6% (2,008 vs. 1,976 trucks per day, respectively). This difference was found to be acceptable taking into consideration the assumptions made for the analytical model. The model was validated by analyzing the results on capacity requirements of each distribution center. It was seen that the capacity requirements corresponded to the population and importance of the node with respect to its location.

4.5 Results and Analysis

Initial simulations were performed on a one-dimensional (straight line) network with unlimited truck capacity and the model was tested for negotiations and re-routing. It was seen that there was a substantial decrease in the number of delayed orders when parts were allowed to be re-routed. Since this was just a testing ground, these results were of no practical significance other than assuring that negotiations would indeed be beneficial. The first set of simulations was used to analyze the performance (travel time) of public logistics networks with various demand rates, batch sizes, and distances. These performance measures were compared to that of a traditional node-to-node transportation network (where items are transported directly without intermediate stops) with the same resource capacity. Then, to have a realistic view of the system, the model was run using UPS demand data. The last set of simulations analyzed the performance of public logistics networks when packages are re-routed after negotiations.

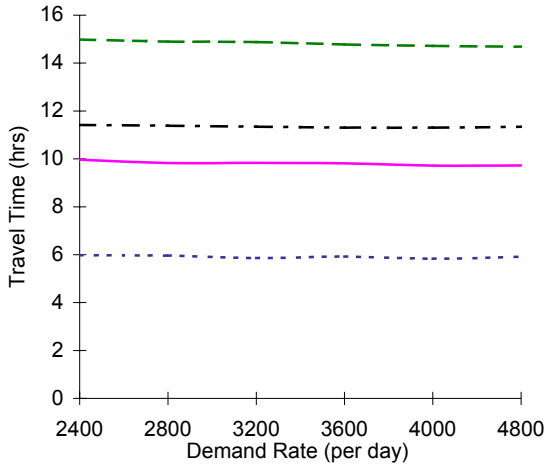


Figure 4.2: Performance of PLN w.r.t. demand rate

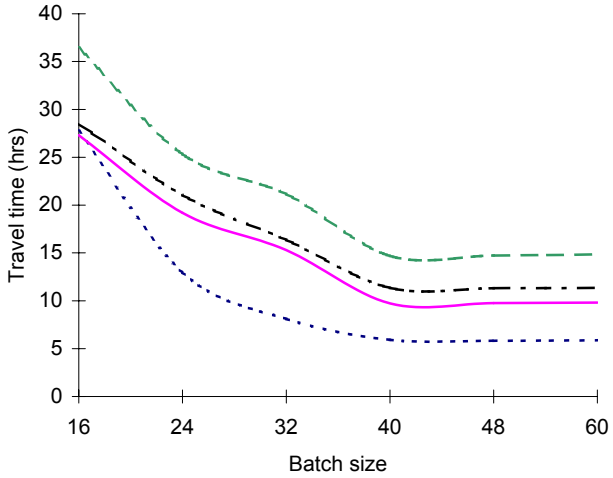


Figure 4.3: Performance of PLN w.r.t. truck capacity

Figure 4.2 shows the performance of public logistics networks with demand rate for various distances. Figure 4.3 shows the performance with batch sizes. It is seen from the graphs that given sufficient number of trucks, demand rate is not an influencing factor for public logistics networks, whereas batch size is. This leads to the conclusion that batch size, which is the capacity of the truck; influences the travel time in a public logistics network more than the demand load. This is due to the fact that when the capacity of trucks is small, we require more number of trucks to handle the demand. If the number of trucks is not increased, products waste time at the DCs waiting for trucks to transport them to the next transshipment point. It is also seen that the performance of public logistics networks improve when we increase the batch size. Nevertheless, for every demand rate and fixed number of trucks, we can see that there is a particular batch size, beyond which any increase in batch size does not result in an improved performance. Any increase in batch size beyond this point

would result in excessive waiting time for FTL batching. This batch size represents the equilibrium between waiting time for FTL batching and time spent waiting for trucks.

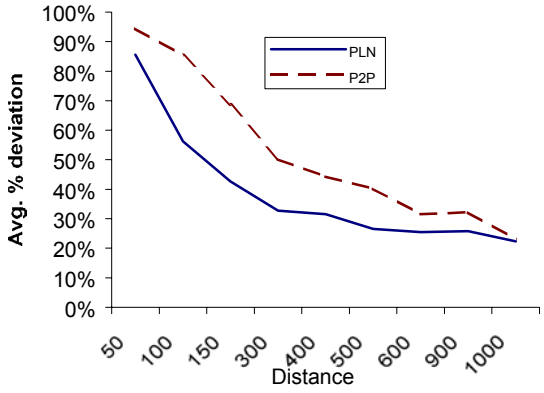


Figure 4.4: Avg. % deviation in transport time

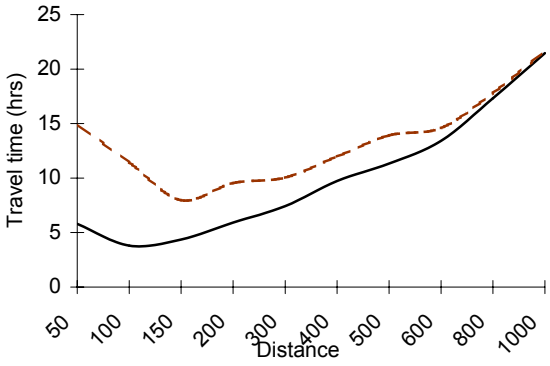


Figure 4.5: Performance comparison

It was crucial to analyze the performance of public logistics networks against ideal transport times.

Figure 4.4 shows the average percentage deviation in transport time for public logistics networks and point-to-point networks from ideal times. Ideal time is the time taken to ship an item for a particular distance if there was no queuing involved for (a) waiting for trucks and (b) waiting for a batch of full truckload of items. It could be seen that for short distances, waiting times in a public logistics network has a very heavy influence in the shipment times, whereas for long distances, it is not much of an issue. In fact, when compared with a point-to-point (P2P) network of the same capacity, it was found that even for short distances, the performance of public logistics networks was superior to that of the P2P network.

Figure 4.5 compares the performance of public logistics networks with a traditional point-to-point network. The graphs are seen to meet as the shipment distance increases. This leads us to the conclusion that, for long-distance shipments, it is better to ship products directly than to use the public logistics network. We can also notice that at short distances the PLN gives a better performance than the P2P network. This is due to the fact that public logistics networks aggregate products to various DCs for node-to-node transit along the shortest path. This allows the DCs to ship products at shorter intervals than in a regular P2P network and thus result in shorter travel times.

The model showed satisfactory results when run with UPS demand rates. The average truckload was assumed to be 150 packages. Table 4.1 shows the flow time results when the model was run using UPS demand data. As a comparison, UPS operates its hub-and-spoke network using a single, overnight sorting delay at the hub [50]. This results in average transport times in excess of 12 hours currently. It is evident that, with an average transport time of 9.3 hrs (see Table 4.1), public logistics networks perform better than existing systems.

Table 4.1: Flow time results with UPS demand data

Distance	Average Flow Time (hrs)
100 miles	3.2
200 miles	5.2
400 miles	9.1
500 miles	11.2
700 miles	14.9
900 miles	19.5
Avg. Overall Flow Time	9.3

One of the most important objectives of the simulation model was to investigate the level of investment required to establish such a system. Although we have not modeled cost into the model, it was possible to get an idea about the capacity of DCs and the number of

trucks. This was the most important motivation for building the simulation model. The results shown are approximations that depend on the assumptions on demand data. But the utility of this model is that it can be adapted to any network and any demand rates. The only limiting factor is that Arena is not optimized for handling large number of entities and it slows down the execution of the simulation model. Nevertheless, with calculated approximations and extrapolation, this model would be capable of providing considerable amount of information that is required to conduct an economic feasibility analysis of the system.

The average number of trucks operating out of each DC and the number of loading/unloading bays at each DC were calculated by running the simulation without any constraints on the number of trucks and bays. Then, the number of bays at each DC was restricted to 20% more than the average number of bays used. The number of bays represents the average number of trucks being serviced at that particular DC at any given point of time. The number of trucks represents the average number of trucks operating out of that particular DC at any point of time. Table 4.2 shows the number of trucks and bays required at the DCs in the central portion of the region under consideration. It can be seen that the most number of trucks and bays are required at DC 9, i.e., Atlanta, GA, which is the major hub for the region. The lowest numbers occur at DC 27, i.e., Dandridge, TN, which is the least populated city among those under consideration. These results also help in verification of the model. Some of the DCs such as 20 and 26 show a very interesting characteristic. The number of bays for this DC is high where as the number of trucks are low. The low number of trucks means that these DCs are sparsely populated, which means that it does not have to cater to huge demands. The high number of bays means that these DCs fall on important intersections

in the network through which most number of "shortest paths" pass. The complete table of results is provided in Appendix C.

Table 4.2: Average number of trucks serviced at each DC at any point of time

DC	Bays	Trucks
8	8	50
9	27	188
10	7	39
11	15	68
19	15	32
20	25	57
21	11	32
25	15	44
26	25	53
27	19	31
28	22	44
29	8	88

4.6 Negotiation model

The last set of simulations was performed to investigate the performance of public logistics networks under negotiated re-routing of packages. The performance measure analyzed here was the number of hops expected to successfully complete negotiations and re-routing. Assuming equal probability of a successful negotiation at each DC, analytical reasoning suggested that the number of hops required would follow a geometric distribution.

Table 4.3 shows results of simulation when packages were allowed to be negotiated and re-routed. We can see that the system performs far better than the geometric distribution. It is also seen that by allowing the packages to be negotiated and re-routed, we are able to reduce the flow times and the number of delayed orders.

Table 4.3: Simulation results under negotiation

Probability P	Number of Hops		Trucks rerouted	Flow Time	Number of Delayed Orders
	Theoretical	Simulation			
No Negotiation	0	0	0	10.314	8649
1	1.000	1	8758	9.244	5268
0.8	1.250	1.035	8740	9.166	5343
0.65	1.538	1.084	8765	9.349	5395
0.5	2.000	1.181	8683	9.427	5447
0.4	2.500	1.3	8693	9.471	5469
0.3	3.333	1.523	8798	9.641	5386
0.2	5.000	2.002	8792	9.847	5549
0.1	10.000	3.312	8661	10.37	5889
0.05	20.000	5.849	8623	11.263	6879
0.02	50.000	10.894	7837	11.657	8103

The results point to a very important characteristic of the system. It can be seen that the system performance deteriorates for very low probability. It is to be kept in mind that the probability value represents the probability of successful location as well as negotiation. We can deduce from the figures in Table 4.3 that the concept of negotiations and re-routing is not applicable for custom-made, one-of-a-kind products. We can also see for very high probability values, the number of hops is less than two. It means that the products are found locally. This leads us to the conclusion that the concept might not be useful to locate low-cost, ubiquitous items. We can conclude that the utility of intelligent supply chain networks would be higher for intermediate products that fall between ubiquitous and unique (probability factors between 0.1–0.2).

Chapter 5. CONCLUSIONS AND FUTURE WORK

This report describes the idea of intelligent supply chain networks and provides an outline of the technology that could be used to support such a paradigm. Parallel research and development efforts at the Auto-ID center and the support it is receiving from industry shows that very soon we can start seeing "intelligent" products driving themselves through the supply chain, providing necessary information at a mouse-click. This research recognizes information flow as the biggest cause for bottlenecks in supply chains and proposes a model that will provide the necessary visibility and flexibility to the system.

The simulation model provides us with a good picture of the operating characteristics and bottlenecks of the system. The model can be used to calculate the capacity of DCs and number of trucks required, given the demand rate. It can also be used to find out the optimum capacity of trucks as demand rate varies. The model provides a good tool for performing an economic analysis, based on which investment decisions can be made. The modular structure of the model allows it to scale to a network of any capacity. The following conclusions can be drawn from the output of the simulation model:

- The important parameters that affect the performance of the system are (a) capacity of trucks and (b) delay at the distribution centers.
- The efficiency of the network increases with distance traveled. This is shown by the fact that the travel times are closer to ideal when distance increases.
- Even for short distances, the public logistics network performs better than a traditional node-to-node network.

- For a particular rate of demand, there is a particular truck capacity that minimizes the waiting times and thus minimizes the travel time.
- Initial simulation results on negotiations shows that the number of hops required for a successful negotiation will be within acceptable limits.
- The potential utility of this search and negotiate capability depends on the characteristics of items being transported: it is not likely to be needed to locate low-cost, ubiquitous items like toothbrushes because they can be expected to be available at every local store; nor is it needed to locate custom-made, one-of-a-kind products because there are so few of the items available, of uncertain quality, that the use of traditional private logistics networks is likely to be the most efficient. A public logistics network is likely to be most suitable for managing the multitude of commodity-like items (replacement parts, etc.) that fall in the middle ground between ubiquitousness and uniqueness.

Future emphasis will have to be on the effective use of all the information that will be available. Information without proper use is worse than having no information at all. The major advantage of this supply chain model is that the information obtained from the products can be plugged into decision support systems and ERP systems to help in planning and control of operations.

This preliminary research work has to be taken up and developed further to explore other means of making this supply chain model a reality. By working closely with the Auto-ID center and exchanging ideas, the *intelligent* supply chain could take shape in the very near future. The present simulation model cannot be used for analyzing various truck-dispatching rules (departing at specific time intervals, departing when a particular number of orders

arrive etc). The Arena models can be obtained from the public logistics network website [51]. The simulation model has to be extended also to include economic analysis and detailed modeling of agent-based negotiations. It is expected that the simulation will have to be done using specialized agent-development tools such as Zeus [52] or Swarm [53] or even have to be designed using a more efficient object-oriented programming language such as Java or C++. These programming environments are more suitable for simulating agent-based negotiations.

The development of the search/track program would be the next big step forward. It would involve the design of Package IP servers as well as the design of agent-based negotiation protocols, in addition to building the agents. A brief guideline on the agent model has been provided in this report. Nevertheless, research needs to be done to find out the best practical way to implement the system. Complementing this work, development of XML tags should also proceed along the guidelines provided in this report. This might require the involvement of ECCMA Global Attribute Schema (EGAS) developers in the project so that the effort that goes into the identification of attributes for each item would not to be duplicated.

The idea of intelligent supply chain networks is set to revolutionize the way modern supply chains operate. As products having “intelligence” start appearing in the market and supporting infrastructure become more and more inter-operable, information bottlenecks will be a thing of the past.

Appendix A: An example for XML Tag & DTD

(a) 44101501.xml

```
<?xml version="1.0"?>
        <!DOCTYPE product SYSTEM "44101501.dtd">
        <!-- Sample XML Tag for Item Code: 44101501 -->
        <product guid = "FFFFBA60-DD02-11D5-AD1D-00104B98F53A">
                <unspsc>44101501</unspsc>
                <name>Xerox 5818 Copier</name>
                <productType>Photocopiers</productType>
                <manufacturer>
                        <name>Xerox Corporation</name>
                        <address>
                                <street>800 Long Ridge Road</street>
                                <city>Stamford</city>
                                <state>CT</state>
                                <zip>06904</zip>
                                <country>USA</country>
                                <phone>+1-203-968-3000</phone>
                        </address>
                        <manufacture_date>
                                <day>20</day>
                                <month>December</month>
                                <year>2000</year>
                        </manufacture_date>
                        <itemCode>123-456-789</itemCode>
                </manufacturer>
                <location>
                        <name>ABC Warehouse</name>
                        <location_type value = "DC" />
                        <address>
                                <street>2518 Avent Ferry Road</street>
                                <city>Raleigh</city>
                                <state>NC</state>
                                <zip>27606</zip>
                                <country>USA</country>
                                <phone>+1-919-839-0731</phone>
                        </address>
                        <latlon>
                                <latitude>015484514</latitude>
                                <longitude>115478856</longitude>
                                <altitude>15445</altitude>
                        </latlon>
                </location>
                <description>
                        <attributeSet label = "family" value = "Office machines and their supplies and
accessories">
                                <dimensions>
                                        <length value = "1" unit = "m"/>
                                        <breadth value = ".75" unit = "m"/>
                                        <height value = "2" unit = "m"/>
                                        <weight value = "50" unit = "kg"/>
                                </dimensions>
```

```
                        <color R = "0" G = "0" B = "255"/>
                        <safety>
                                <instructions> Hello </instructions>
                        </safety>
                </attributeSet>

                <attributeSet label = "class" value = "Duplicating machines">
                        <printingSpeed value = "18" unit = "pages per min"/>
                        <resolution value = "1440" unit = "dpi"/>
                </attributeSet>

                <attributeSet label = "commodity" value = "Photocopiers">
                        <Warm_Up_Time value = "100.0" unit = "s"/>
                        <Standard_Paper_Trays value = "3"/>
                        <Maximum_Capacity value = "40"/>
                </attributeSet>
        </description>
        <owner>
                <name>Sajith Kumar Parlikad</name>
                <owner_type value = "Customer" />
                <address>
                        <street>2520 Avent Ferry Road</street>
                        <city>Raleigh</city>
                        <state>NC</state>
                        <zip>27606</zip>
                        <country>USA</country>
                        <phone>+1-919-835-9199</phone>
                </address>
        </owner>
        <price value = "2275.00" currency = "USD"/>
        <date>
                <day>20</day>
                <month>February</month>
                <year>2002</year>
        </date>
        <time>
                <hours>13</hours>
                <minutes>42</minutes>
                <seconds>56</seconds>
                <milliseconds>125</milliseconds>
        </time>
        <negotiateFlag value = "0"/>
</product>
```

(b) 44101501.dtd

```
<?xml version="1.0"?>

<!ELEMENT product
(unspsc,name,productType,manufacturer,location,description,owner,price,date,time,negotiateFlag)>
<!ELEMENT unspsc (#PCDATA)>
<!ELEMENT name (#PCDATA)>
<!ELEMENT productType (#PCDATA)>
<!ELEMENT manufacturer (name,address,manufacture_date*, expiry_date*,itemCode*)>
<!ELEMENT location (name,location_type,address,latlon)>
<!ELEMENT description (attributeSet*)>
<!ELEMENT owner (name, owner_type, address)>
<!ELEMENT price EMPTY>
<!ELEMENT manufacture_date (day, month, year)>
<!ELEMENT expiry_date (day, month, year)>
<!ELEMENT date (day, month, year)>
<!ELEMENT time (hours, minutes, seconds, milliseconds)>
<!ELEMENT negotiateFlag EMPTY>

<!ELEMENT address (street*, city, (state|county), (zip|pin), country, phone*, fax*, email*, pager*)>

<!ELEMENT itemCode (#PCDATA)>

<!ELEMENT owner_type EMPTY>
<!ELEMENT location_type EMPTY>

<!ELEMENT latlon (latitude, longitude, altitude)>

<!ELEMENT day (#PCDATA)>
<!ELEMENT month (#PCDATA)>
<!ELEMENT year (#PCDATA)>

<!ELEMENT hours (#PCDATA)>
<!ELEMENT minutes (#PCDATA)>
<!ELEMENT seconds (#PCDATA)>
<!ELEMENT milliseconds (#PCDATA)>

<!ELEMENT street (#PCDATA)>
<!ELEMENT city (#PCDATA)>
<!ELEMENT state (#PCDATA)>
<!ELEMENT county (#PCDATA)>
<!ELEMENT zip (#PCDATA)>
<!ELEMENT pin (#PCDATA)>
<!ELEMENT country (#PCDATA)>
<!ELEMENT phone (#PCDATA)>
<!ELEMENT fax (#PCDATA)>
<!ELEMENT email (#PCDATA)>
<!ELEMENT pager (#PCDATA)>

<!ELEMENT latitude (#PCDATA)>
<!ELEMENT longitude (#PCDATA)>
<!ELEMENT altitude (#PCDATA)>
```

```
<!ELEMENT attributeSet ANY>

<!ELEMENT dimensions (length, breadth, height, weight)>
<!ELEMENT length EMPTY>
<!ELEMENT breadth EMPTY>
<!ELEMENT height EMPTY>
<!ELEMENT weight EMPTY>

<!ELEMENT safety (instructions*)>
<!ELEMENT instructions (#PCDATA)>
<!ELEMENT color EMPTY>
<!ELEMENT printingSpeed EMPTY>
<!ELEMENT resolution EMPTY>
<!ELEMENT Warm_Up_Time EMPTY>
<!ELEMENT Standard_Paper_Trays EMPTY>
<!ELEMENT Maximum_Capacity EMPTY>

<!ATTLIST product guid CDATA #REQUIRED>
<!ATTLIST price
value CDATA #REQUIRED
currency CDATA #REQUIRED>

<!ATTLIST negotiateFlag value (0|1) "0">

<!ATTLIST owner_type value (DC|Customer|Transport|Storage|Manufacturer|Other) "Manufacturer">
<!ATTLIST location_type value (DC|Customer|Transport|Storage|Manufacturer|Other) "Manufacturer">

<!ATTLIST attributeSet
label CDATA #REQUIRED
value CDATA #REQUIRED>

<!ATTLIST length
value CDATA #REQUIRED
unit CDATA #REQUIRED>

<!ATTLIST height
value CDATA #REQUIRED
unit CDATA #REQUIRED>

<!ATTLIST weight
value CDATA #REQUIRED
unit CDATA #REQUIRED>

<!ATTLIST breadth
value CDATA #REQUIRED
unit CDATA #REQUIRED>

<!ATTLIST color
R CDATA #REQUIRED
G CDATA #REQUIRED
B CDATA #REQUIRED>

<!ATTLIST printingSpeed
value CDATA #IMPLIED
unit CDATA #IMPLIED>
```

```
<!ATTLIST resolution
value CDATA #IMPLIED
unit CDATA #IMPLIED>

<!ATTLIST Warm_Up_Time
value CDATA #IMPLIED
unit CDATA #IMPLIED>

<!ATTLIST Standard_Paper_Trays
value CDATA #IMPLIED>

<!ATTLIST Maximum_Capacity
value CDATA #IMPLIED>
```

Appendix B: Simulation model snapshots

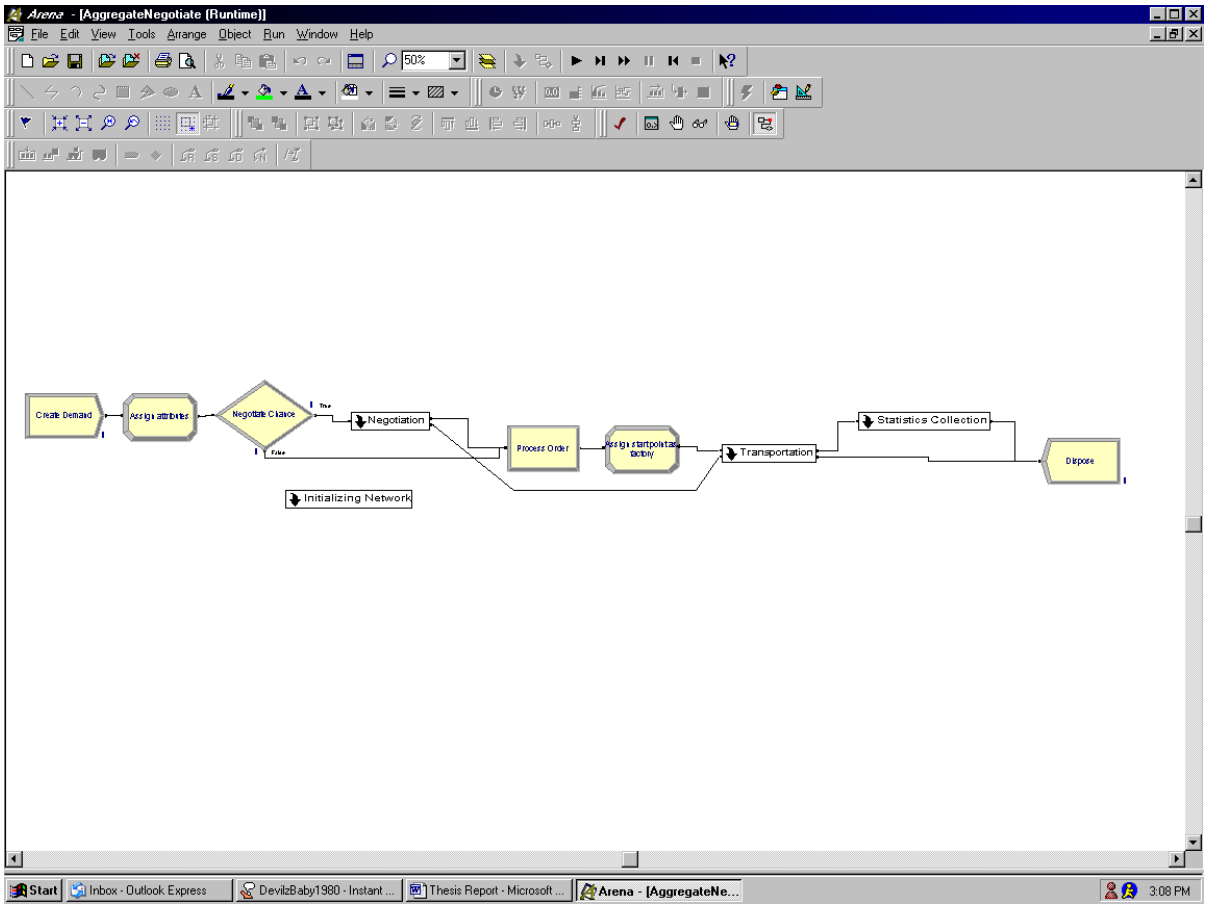


Figure B.1: Simulation model of public logistics networks

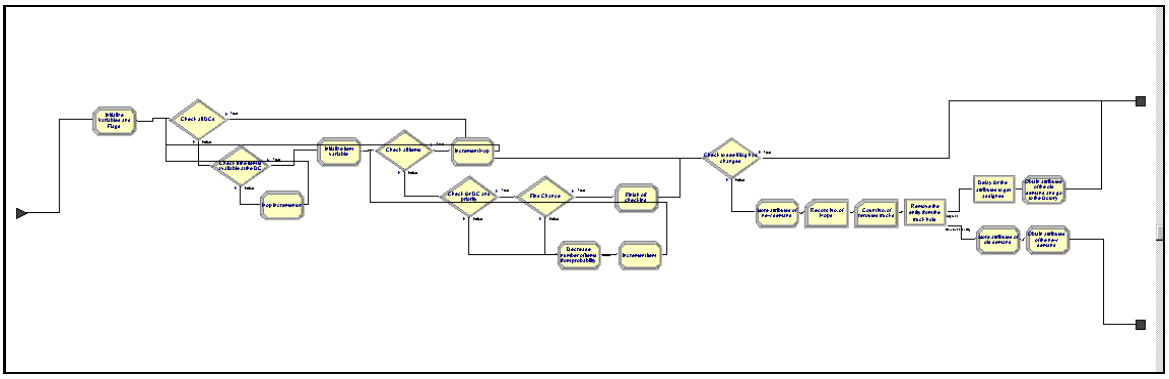


Figure B.2: Negotiation sub-model

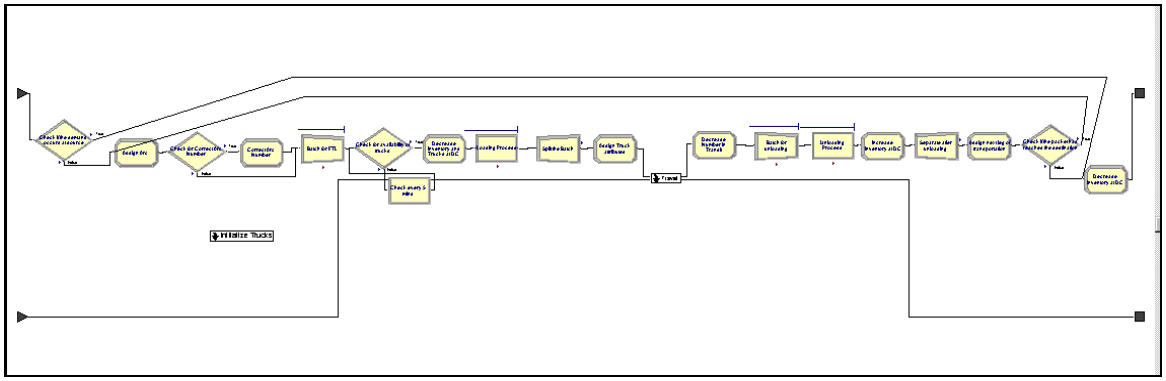


Figure B.3: Transportation sub-model

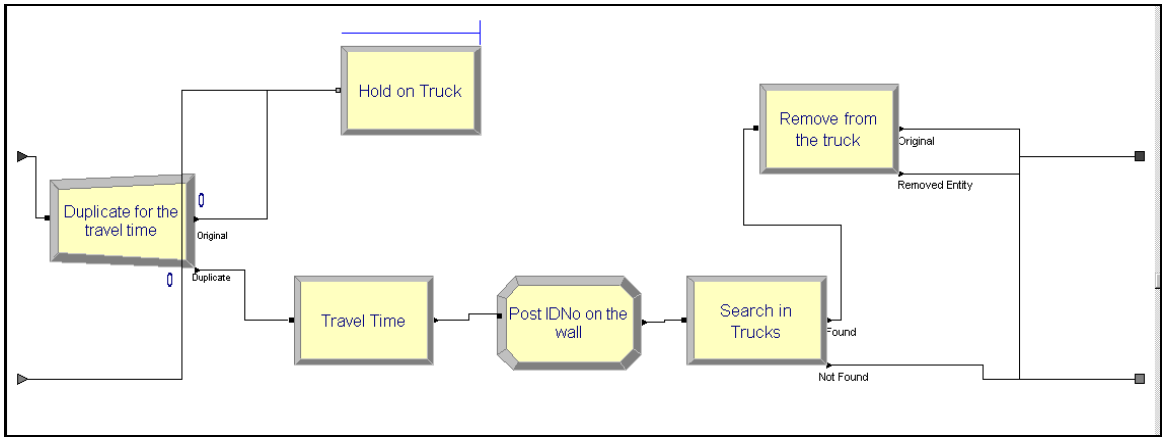


Figure B.4: Travel sub-model

Appendix C: Simulation data and results

Table C.1: DC Population Percentages

DC	City	State	Population (000's)	Pct. of Total Population
1	Montgomery	AL	604	1.17
2	Birmingham	AL	1,509	2.92
3	South Daytona	FL	649	1.26
4	Jacksonville	FL	1,318	2.55
5	Lake City	FL	1,147	2.22
6	De Funiak Springs	FL	947	1.84
7	Pooler	GA	807	1.56
8	Macon	GA	1,024	1.98
9	Atlanta	GA	4,472	8.66
10	LaGrange	GA	804	1.56
11	Chattanooga Valley	GA	1,579	3.06
12	Lexington-Fayette	KY	1,096	2.12
13	Erlanger	KY	2,261	4.38
14	Louisville	KY	2,049	3.97
15	Woodlawn	MD	3,447	6.68
16	Ballenger Creek	MD	452	0.88
17	Benson	NC	2,339	4.53
18	Greensboro	NC	1,292	2.50
19	Statesville	NC	800	1.55
20	Charlotte	NC	1,588	3.08
21	Asheville	NC	809	1.57
22	Hillsborough	NC	1,182	2.29
23	Florence	SC	978	1.89
24	St. George	SC	774	1.50
25	St. Andrews	SC	1,218	2.36
26	Southern Shops	SC	1,414	2.74
27	Dandridge	TN	828	1.60
28	Farragut	TN	1,070	2.07
29	Nashville-Davidson	TN	1,723	3.34
30	Richmond	VA	1,294	2.51
31	Dunn Loring	VA	4,261	8.25
32	Strasburg	VA	446	0.86
33	Staunton	VA	830	1.61
34	Hampton	VA	1,923	3.73
35	Wytheville	VA	1,055	2.04

Table C.2: Complete table of results for bays/trucks at each DC for UPS demand

DC	Bays	Trucks
1	6	36
2	6	78
3	2	48
4	10	82
5	6	72
6	3	66
7	12	40
8	8	50
9	27	188
10	7	39
11	15	68
12	18	55
13	6	133
14	7	118
15	8	202
16	2	27
17	14	100
18	25	51
19	15	32
20	25	57
21	11	32
22	23	52
23	13	41
24	14	35
25	15	44
26	25	53
27	19	31
28	22	44
29	8	88
30	32	56
31	27	225
32	14	25
33	19	39
34	5	109
35	21	37
36	15	82

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