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Design and Development of a Framework for Traffic Management in a Global Manufacturing Enterprise: The American Standard Case Study

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Dissertation Report

by

Nathaniel J. Melby

A dissertation report submitted in partial fulfillment of the requirements
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2015

We hereby certify that this dissertation, submitted by Nathaniel Melby, conforms to acceptable standards and is fully adequate in scope and quality to fulfill the dissertation requirements for the degree of Doctor of Philosophy.

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An Abstract of a Dissertation Submitted to Nova Southeastern University
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Managed Bandwidth Services (MBSs) use Quality of Service (QoS) guarantees to effectively control traffic flows and reduce network delay. In the past, the provision of MBS in a global manufacturing enterprise was a difficult task for network administrators. However, advances in recently emerging technologies, such as Multiprotocol Label Switching (MPLS), Generalized Multiprotocol Label Switching (GMPLS), Integrated Services (IntServ), Differentiated Services (DiffServ), and Constraint-based Routing (CBR), hold promise to make MBS implementation more manageable. QoS technologies, such as DiffServ and IntServ, offer the benefits of better application performance and delivery of reliable network service. As a consequence of network traffic loads, packet congestion and latency increases still exist and must be addressed by enterprises that intend to support an MBS solution. In this investigation, the author addressed an issue that is faced by many large manufacturing enterprises, i.e., the addition of latency and congestion sensitive traffic such as Voice-over-Internet Protocol (VoIP) to networks with limited bandwidth. The goal of this research was to provide global manufacturing enterprises with a model for bandwidth management in their offices and plants. This model was based on findings from a case study of traffic management at American Standard Companies.

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Chapter 1

Introduction

Managed Bandwidth Service (MBS) provides Quality-of-Service (QoS) guarantees by effectively and reliably controlling multimedia traffic flows (Kotti, Hamza, & Bouleimen, 2009). MBS uses QoS to reduce network delay by shaping traffic flows (Velauthapillai, Harwood, & Karunasekera, 2010). Various methods are used to control traffic, including traffic shaping and policing mechanisms as well as Integrated Services (IntServ) and Differentiated Services (DiffServ) technologies (Velauthapillai et al., 2010).

MBS is distinguished by its capabilities in improving network performance and application availability in production environments at large-sized corporations such as American Standard Companies (ASD [the Dow Jones stock symbol]; Lombardo, Panarello, & Schembra, 2011). ASD is an $11 billion global manufacturing enterprise, with over 60,000 employees, with a number of business sectors, including Trane Commercial Systems (TCS), Trane Residential Systems (RS), American Standard Bath & Kitchen (B&K), and Westinghouse Air Brake Company (WABCO). TCS and RS specialize in the design, engineering, and manufacture of commercial and residential heating, ventilation, and air conditioning equipment; B&K, in the design, engineering, and manufacture of plumbing fixtures; and WABCO, in vehicle control systems such as high-end braking systems for heavy commercial vehicles. Each ASD business sector is a large global manufacturing company in itself, with offices in major cities across the world. In this study, the author will focus on the TCS business sector, the largest business sector within ASD.

In the absence of MBS for preventing bursty traffic from interfering with seamless traffic flows at ASD, the communications equipment is not always capable of ensuring QoS guarantees and provisioning dependable, reliable, scalable, and available network applications and services (Kotti et al., 2009). In its absence, manufacturing enterprises must determine the types of traffic that take priority (Kotti et al., 2009). The implementation of QoS, when MBS is not present, is a challenging and demanding task in present-day networks, especially in production environments (Kotti et al., 2009). Production environments are mission-critical to enterprises and are more complex than are test or development environments. Thus, in the absence of MBS, it is challenging to identify potential failures prior to production implementation.

The core technologies that facilitate the realization of MBS include QoS, Class of Service (CoS), and a high-speed network backbone that supports end-to-end QoS delivery. QoS provides a guarantee of bandwidth to specific types of traffic, and CoS groups similar traffic types into classes with established priority levels relative to other traffic classes (Karsten, 2011).

The author determined class-based implementation solutions to network performance problems, including latency, jitter, congestion, and delay (Kotti et al., 2009). By supporting a network migration from a Virtual Private Network (VPN) technology to Multiprotocol Label Switching (MPLS), the author demonstrated the routing speed of MPLS and determined the performance benefits of the use of CoS and QoS at ASD. As a consequence, ASD will be able to converge latency and jitter insensitive technologies, such as Voice-over-Internet Protocol (VoIP; Alia, Lacoste, He, & Eliassen, 2010). GMPLS was discussed, as it is a theoretical alternative in the literature but is not a practical option. Generalized Multiprotocol Label Switching (GMPLS) is a next-generation technology that extends MPLS and has potential for use in this type of implementation. However, GMPLS has limited availability for enterprises, as this technology is not commercially available (Sancak, Kantarci, & Oktug, 2010).

The ASD corporate network configuration features an integrated array of network technologies and architectures that support business sector operations. An IT Center of Excellence (CoE) under the ASD umbrella, American Standard Business Services (ASBS), supports Information Technology (IT) operations. Currently, the infrastructure employed by ASD consists of a Frame Relay (FR) network (for business sectors B&K, RS, and WABCO), a backbone, and an Internet Protocol (IP)-based site-to-site VPN that supports TCS. Plans are underway to migrate from these technologies to a common MPLS backbone. MPLS operates at Layer 2, or the data link layer, and Layer 3, or the Network Layer, of the Open Systems Interconnection (OSI) Reference Model (Figure 1).

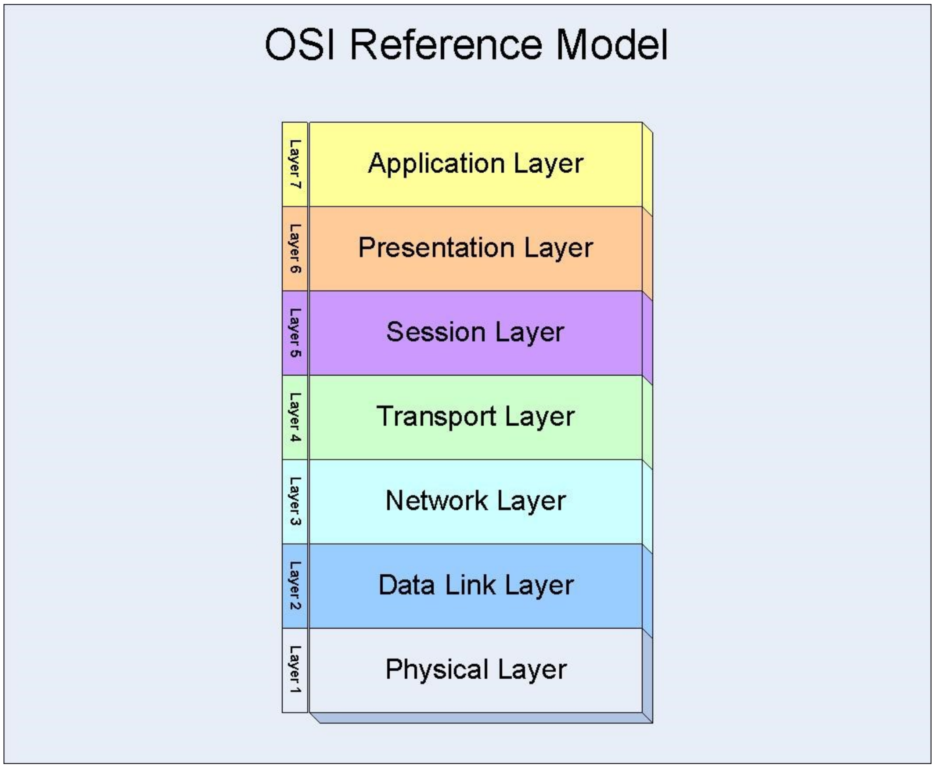

Figure 1. Open Systems Interconnection (OSI) Reference Model for network communication.

MPLS forwards packets marked with labels that adhere to integrated rules for multicasting, load balancing, and QoS, defined by the Internet Engineering Task Force (IETF) Request For Comments (RFC) 3031 (Katramatos, Shroff, Yu, McKee, & Robertazzi, 2009). Labels are applied to packets in the MPLS architecture by Label Edge Routers (LERs) to support high-speed switching by label switch routers (Katramatos et al., 2009). A seminal study by Molnar and Vlcek (2010) showed that global network carriers install high-speed MPLS backbones, which consist of LERs and LSRs, traditional Layer 2 Ethernet and Asynchronous Transfer Mode (ATM), and Layer 3 Internet protocol (IP) packet forwarding with the simplicity and speed of label-based switching. By using label switching instead of traditional switching methods that feature IP packet and header information, high-speed backbones eliminate the time required to process path selection (Molnar & Vlcek, 2010b). Research initiatives that involve the use of MBS in MPLS applications focus on networks that are similar in terms of size and complexity to the ASD network, such as TeraPaths and the Internet2 Phoebus project (Katramatos et al., 2009). In preparation for corporate deployment of VoIP, ASD requires QoS as a part of an MPLS MBS to provide reliable service to customers (Namee, 2009).

Remote users access the ASD IP network via VPN client connections to head-end units located within their respective regional data centers. At ASD, regional data centers, also called enterprise data centers, support redundancy and dependable access to core regional applications. These centers are in La Crosse, Wisconsin (WI; the Americas region); Boeblingen, Germany (the European Union [EU]); the Middle East, Africa, and India region; and Shanghai, China (the Asia region). Prior to the utilization of CoS and QoS technologies, bursty traffic from sites aggregated at the regional data centers resulted in network gridlock and congestion, thereby causing extensive network and application downtime. With the guarantees provided by CoS and QoS, MPLS can effectively streamline congestion and manage bursty traffic (Molnar & Vlcek, 2010b). In this investigation, the author examined the types of traffic on the ASD network that are critical to business objectives and their relationships to other traffic types. The use of ASD computing resources to support this study was approved by ASD, per the signed letter of permission (Appendix A). Based on the findings, the author provided a model for traffic classification within ASD that can be used by other large global manufacturing organizations. Traffic classification helped to ensure the availability of important networked applications and foster bandwidth optimization.

As noted, the author focused on the TCS business sector and MBS issues from the perspective of large-sized manufacturing companies. The author is a member of the American Standard Business Services (ASBS) Global Data Network Engineering and Architecture team. This team is charged with designing the ASD network, ensuring standards compliance, facilitating the development and implementation of policy, managing hardware, and supporting regional operations teams.

Problem Statement and Goal

Problem Statement

The problem that was investigated in this study was how to effectively manage ASD network traffic to accommodate ASD requirements for reliability, dependability, scalability, and availability. ASD operations require high performance in each of these areas to support the present corporate mission of a converged network that supports VoIP (Namee, 2009). MBS technology offers benefits such as ease of network capacity planning and management (Pathak, Zhang, Hu, Mahajan, & Maltz, 2011). Recent demands for network convergence place emphasis on the ability to manage networks with acceptable performance and cost effectiveness (Namee, 2009). Today's Internet quality standards, in terms of network availability and performance, are not immediately comparable to the service levels provided by the public switched telephone network (PSTN; Namee, 2009). To raise the service level and performance of the data network to a level that is comparable to the PSTN of today, technologies and tools such as CoS, QoS, and MPLS are increasingly used to improve performance and manage bandwidth, particularly in large-sized transnational corporations.

To address the problem, the author used a case study method to analyze the plan, design, and implementation of an MBS framework at ASD. The existing Wide Area Network (WAN) infrastructure uses a combination of carrier-provided backbone technologies, including FR, VPN, ATM, and MPLS network technologies. By transitioning the variety of existing networks to an MPLS backbone, ASD will improve support efficiency and migrate the existing FR, VPN, and ATM backbone networks to a faster and more scalable WAN technology, supported by an optical fiber backbone (Molnar & Vlcek, 2010b).

Each of the WAN technologies in use at ASD, with the exception of MPLS and ATM, lacks a provision for QoS or traffic management. As a result, the architecture is not capable of providing service levels necessary for a mission-critical or convergent network. The speed and throughput capabilities of MPLS hold several performance advantages over ATM, a dated technology still widely implemented in communications carrier networks, including increased resilience, enhanced routing via Open Shortest Path First (OSPF) or Border Gateway Protocol (BGP), and traffic engineering from a single point (Hanshi & Al-Khateeb, 2010). These characteristics have resulted in a broadened use of MPLS by network providers (Hanshi & Al-Khateeb, 2010). Through a migration to MPLS across the WAN, CoS and QoS architectures, such as IntServ and DiffServ, can also control and manage traffic more efficiently than can best-effort methods (Molnar & Vlcek, 2010b). IntServ and DiffServ provide low latency and guaranteed service to critical traffic to ensure traffic throughput. In comparison to IntServ, DiffServ is more scalable due to the less-demanding resource and administration requirements in large network deployments (Chen, Wu, Chang, & Lei, 2011).

Goal

The goal of this investigation was to design, develop, and implement a model for classification, prioritization, and management of network traffic. The model was developed from a case study of traffic within the TCS sector of ASD and proven in implementation by increasing network efficiency within the TCS sector. The TCS sector is the largest business sector of the company and manufactures commercial heating, ventilation, and air conditioning (HVAC) systems, controls, and technologies. Due to the nature of ASD's manufacturing-based business, the model will benefit other large-sized manufacturing companies as well.

According to Zhang and Bao's (2009) classic presentation of traffic engineering concepts, qualitative and quantitative techniques and methods can be used to facilitate the resolution of traffic problems. The IETF is an international organization that develops Requests for Comments (RFCs) to support standardized Internet operations. The author utilized qualitative and quantitative techniques to derive a model that was congruent with the phases of the Modern Systems Development Life Cycle (MSDLC). According to the classic work by Whitten and Bentley (2007), the MSDLC methodology has five phases, including Phase 1, or the Planning Phase; Phase 2, or the Analysis Phase; Phase 3, or the Design Phase; Phase 4, or Implementation Phase; and Phase 5, or the Support Phase. The author also incorporated the four steps of the IETF Traffic Engineering Process (TEP) model into the five phases of the MSDLC. The TEP model consists of the following four steps: Step 1, definition of relevant control policies that govern network operations, Step 2, feedback mechanisms that involve the acquisition of measurement data from the operational network, Step 3, network state and traffic workload analysis, and Step 4, performance optimization (Zhang & Bao, 2009). The goal of this study related most directly to the performance optimization step of the IETF TEP model. However, all steps of the TEP model have been integrated into the model developed in this research.

Research Questions

Yin (2009) stated that the identification of research questions is a crucial step in case study research. Research questions should be designed so that they can provide guidance to the study but not provide so much direction that they restrict the research conducted (Woodside, 2010).

In this investigation, the author has addressed the following research questions:

1. What types of traffic exist on a manufacturing enterprise network that are considered to be critical to business objectives? (Erbad, Najaran, & Krasic, 2010).
2. What specific factors must be considered in creating a framework for enterprise traffic management in a manufacturing organization? (Erbad et al., 2010).
3. How can a manufacturing enterprise ensure the availability of critical enterprise applications and services during periods of heavy network traffic? (Chi, Ravichandran, & Andrevski, 2010).
4. How can a manufacturing enterprise use the MSDLC framework to protect critical network-based business processes? (Pang, 2009).
5. How should a manufacturing enterprise prepare itself to ensure survivability of future VoIP traffic? (Pang, 2009).

Relevance and Significance

According to Chi et al. (2010), information exchange is critical to the operations of a manufacturing organization in the present-day competitive business environment. When critical enterprise applications are not available to manufacturing systems, production can stop, and a manufacturing business will then incur major losses (Chi et al., 2010). According to Chi et al., as the use of networks accelerates in providing critical business processes, the company experiences rapid reactions to changes in the business environment. This relationship has a greater impact when critical applications fail to function.

According to Pang (2009), subsequent to the events of September 11, 2001, large-scale companies built principles of high availability, redundancy, and diversity into their networks to prevent catastrophic failures. These principles were appropriate for protecting Layer 1, or the Physical Layer, Layer 2, or the Data-Link Layer, and Layer 3, or the Network Layer, of the OSI Reference Model (Pang, 2009). However, failures continue to occur at Layer 4, or the Transport Layer, Layer 5, or the Session Layer, Layer 6, or the Presentation Layer, and Layer 7, or the Application Layer, of the OSI Reference Model due to high link utilization. Protection for these higher layers must be built into network survivability designs (Pang, 2009). Networks also are vulnerable to cyber incursions (Stallings, 2013). Without this design consideration at Layers 4, 5, 6, and 7, a network could survive a total link failure but not a utilization-based network attack (Pang, 2009).

Bursty traffic results in high link utilization rates by generating large amounts of network activity and flooding the network, resulting in inaccessible and inoperable applications (Erbad et al., 2010). Bursty traffic also can contribute to security incursions that result from worms, viruses, and denial of service (DoS) attacks, thereby disrupting or shutting down networks in industry (Stallings, 2013). Security problems that result from cyber incursions and traffic bursts, as well as their effect on traffic flows, were examined in this investigation.

Erbad et al. (2010) investigated the use of dynamic QoS management on Ethernet networks and created a Data-Link Transport Protocol (DLTP) for real-time operation. Sommers, Barford, and Eriksson (2011) identified an optimization-based approach for QoS routing in high-bandwidth networks and determined that the complex task of optimization be implemented in a simple and manageable form in large networks. Karsten (2011) described QoS as a mechanism for controlling traffic from dynamic sources and provided a methodology for evaluating QoS and traffic overhead. These techniques promote the survival of traffic on a network by reacting to changing traffic patterns and facilitating QoS policies for continued survival of critical traffic. However, a comprehensive QoS and MBS framework for a manufacturing enterprise has yet to be defined (Stephens, Cox, Rixner, & Ng, 2011). In this investigation, the author extended the classic work of Molnar and Vlcek (2010b) by examining the use of QoS in combination with an MPLS backbone, and the implementation of QoS and an MBS framework in MPLS.

As noted by Littman (2002), communication services are becoming increasingly distributed. The ASD network has grown from a centralized hub-and-spoke WAN architecture that supported centralized computing processes to a complex, meshed architecture that facilitated distributed processing operations. At TCS, the focus of this inquiry, the network infrastructure supports databases and other applications such as Customer Relationship Management (CRM) and Enterprise Resource Planning (ERP) systems that facilitate supply chain management, manufacturing, and automation processes, along with traditional operations and manufacturing management procedures. These applications and the business processes that they support enable TCS to be responsive to the needs of customers, while keeping costs as low as possible. In a classic work, Simchi-Levi, Kaminsky, and Simchi-Levi (2000) noted that enhancing productivity, reducing costs, and improving responsiveness are key to the success of technology implementation in manufacturing. Improving traffic management on the TCS network will prevent application performance problems, leverage the lower costs of a future converged network, and improve responsiveness by reducing network delay, thereby resulting in enhanced productivity.

By combining and integrating processes within TCS, such as technology strategy, supply chain management, operations management, and manufacturing, the organization can become scalable, agile, and more productive than its predecessors, at a fraction of the cost (Simchi-Levi et al., 2000). However, the FR and VPN networking technologies, specifically, the hub-and-spoke network design, which allows TCS to increase productivity, makes TCS operations vulnerable to incursions (Pang, 2009). In the current hub-and-spoke design, bottlenecks occur at remote site WAN routers and aggregated links to the regional data centers (Pang, 2009). To address these types of vulnerabilities, the author developed a comprehensive MBS strategy to promote survivability of traffic on the TCS network, which will allow important traffic to pass other, competing types of traffic.

Limitations and Delimitations

Due to the dynamic environment at ASD, influences beyond the control of the author affected this investigation. These influences are directly related to ASD strategic and tactical business objectives, the impact of rapidly changing technologies on ASD traffic, technology updates through the course of the study, data expansion on the ASD network, and resource availability (Pang, 2009).

This ASD MBS investigation was chosen based on its significance to the body of research and the ability to benefit ASD (ASD, 2009). This initiative consists of four individual projects, specifically, WAN migration to MPLS, traffic management on the WAN, traffic management on the LAN, and enterprise application survivability. IT staff and financial resources were limited and needed to be taken into consideration for the initiative. Funding for these projects was allocated from the general IT department budget and, as such, was limited to the funds allocated. That staff members assigned to this initiative also must complete their daily assigned workload and the fact that the WAN carrier has a limited ability to support related activities both delayed completion. Additional time was necessary to complete the investigation, the project timeline was affected by the ASD funding allocation processes and the availability of funding at the time of request.

Another limitation is the size of WAN lines and their average utilization rates. Numerous TCS offices have T-1 leased lines that carry a capacity of 1.54 Mbps of traffic (ASBS, 2009). A high level of average link utilization on an individual T-1 line could require a bandwidth upgrade to realize the benefits of QoS or CoS support guarantees and assurances. Additionally, latency and/or jitter can adversely affect critical traffic in a way that impedes delivery of real-time or streaming voice data.

Although the target implementation was a large-scale project, the timeline for completion was delimited to a short period of time, i.e., three months (ASD, 2009). In addition, the complexity of the respective designs for traffic classification requires a high level of detailed analysis that resulted in additional administrative overhead for TCS operational network teams. A design for traffic classification that is too complex for the existing routers and switches in the network could cause devices to perform poorly, and the Central Processing Unit (CPU) and memory in production devices may be over-taxed (Pang, 2009). A negative impact on daily manufacturing operations was not an acceptable consequence of this investigation for TCS because manufacturing delays or outages will immediately result in financial losses to the company. The availability of maintenance windows, which are not allowed during a ten-day window surrounding the end of each month, for the one-year target timeline for each of the projects included in this investigation, also was a limitation. Major changes to hardware configurations or infrastructure would be applied in one of four quarterly maintenance windows, as high-risk network maintenance is conducted only during these limited times.

Barriers and Issues

The deployment of MBS technologies in a large global manufacturing organization such as ASD was a barrier to successful development of the model due to the broad scope of the deployment. The complexity of the large enterprise network and the associated complexities of designing, planning, and implementing MBS on such a network introduced a risk of critical network outages and resistance to implementation by riskaverse business leadership (Vahdat et al., 2010). In addition, organizational issues within ASD, including equipment and architecture configurations that deviate from corporate standards and IT staff and resources that are challenged with operating at maximum efficiency, was addressed. An additional issue included the business sector's hesitation to allow applications that are considered their most important to be prioritized at a level lower than are critical applications of other corporate business sectors. This was a barrier, as business leaders initially resisted the implementation of the model because their applications were not listed as the highest priority. The difficulty of introducing a high level of traffic control into the TCS network, which is expected to result in a configuration that optimally yields greater network efficiency, was resolved by implementing a structured traffic classification and prioritization model (White, 2010).

Manufacturing organizations such as TCS are traditionally the home of enterprise applications that were developed internally (Boehm, 2011). These highly customized applications are very sensitive to latency and jitter and, as such, can render traffic manipulation techniques unusable. In recent years, however, commercial off-the-shelf (COTS) software has been introduced to meet the needs of large-scale manufacturing enterprises such as ASD (Boehm, 2011). Currently, COTS software is more appropriate for large manufacturing organizations than for smaller manufacturing companies because it carries a higher return on investment (ROI) for the large organization (Weiss, 2011). The additional need for ASD to integrate MBS into the existing network infrastructure, without a prohibitive investment in network upgrades, and the accommodating constant corporate demand for better ROI in IT initiatives, was examined as well. A costly investment in network infrastructure upgrades would exceed the financial limitations of the company and prevent implementation of this model at ASD.

Communications carriers such as Verizon and AT&T make MPLS commercially available for widespread use. With this capability, ASD can implement low-cost end-to-end QoS delivery (Sommers et al., 2011). Prior to MPLS availability, third-party appliances and tools enabled traffic classification but limited network administrators to focusing on controlling traffic at centralized points within their networks and not across the network as a whole. The high costs of these types of appliances and tools, however, limited widespread deployment by enterprises. To maximize existing technology investments, any existing appliances and tools must be integrated into the QoS design.

When considering the use of MBS provisions in the TCS network, the author identified existing and future technologies for the network and took into account costs, project timelines, hardware and software availability, network topology, and applicable interoperability standards (Pang, 2009). The findings from the TCS network facilitated development of the end-to-end, strategic network architecture plan developed in this investigation (Pang, 2009).

Definition of Terms

Bandwidth Management. The control of data flow in a network to provide consistent, reliable, predictable, and manageable flows of traffic (Lucent, 2011). MBS methods include best-effort, QoS, ToS, CoS, and grade-of-service (GoS) traffic shaping, traffic policing, and other functions that can manipulate or control traffic and that affect capacity planning.

Best-effort. A network level of service that is without QoS guarantees (Sanju, Barlet-Ros, Duffield, & Kompella, 2011). The provider offers the best level of service available but recognizes that a negative impact that results from traffic congestion also will affect the network link.

Border Gateway Protocol (BGP). The protocol routes traffic between networks. BGP promotes high network availability by allowing multihoming or connections to multiple remote locations and failover to available routes. Internal BGP (IBGP) operates on interior devices, while External BGP (EBGP) operates on edge, externally-facing devices (Pang, 2009).

Class of Service (CoS). A set of characteristics of a type of QoS. According to the IETF (as cited in Molnar & Vlcek, 2010), CoS defines the boundaries of a specific type of QoS. Services that belong to a class can be defined by either quantitative or qualitative values, such as a 100kbps limit on FTP traffic flows or a 1000-session limit on CIFS.

Data Compression. A technique for reduction of transmitted data without loss of information. Data compression reduces packet loss and contention for bandwidth (Yamamoto & Nakao, 2011).

Differentiated Services (DiffServ). An architecture for QoS developed by the IETF as an alternative to IntServ (Molnar & Vlcek, 2010a). One advantage of QoS over IntServ is the number of services provided by the network to support greater scalability.

DiffServ Code Point (DSCP). An element of DiffServ to mark packets that travel through the network. DSCPs select per-hop behaviors that are defined and applied at or adjacent to the edge of the network (Chen et al., 2011).

European-1 (E-1). A dedicated network connection that supports a transmission rate of 2.048 megabits per second (Mbps). The rate difference between T-1 and E-1 reflects the use of an extra eight 64kbps channels for E-1 (White, 2010).

Enterprise Resource Planning (ERP). A system for improving and reengineering manufacturing, distribution, purchasing, business planning, and supply chain operations. ERP implementations typically involve process analysis and process improvement activities (Basu & Lederer, 2011).

European Telecommunications Standards Institute (ETSI). An organization primarily responsible for managing and developing telecommunications standards in the European Union (ETSI, 2011).

Frame Relay (FR). A type of packet-switched network technology that supports data transmission over fixed networks (White, 2010). FR is a commonly-used technology in many corporate WANs (White, 2010).

Grade of service (GoS). Category of services as it relates to disasters and survivability (Molnar & Vlcek, 2010a). The probability of disruption and survivability of the network in a disaster are taken into account when categorizing. Categories that range from grades that include critical application services only to grades that incorporate all business application services are defined by GoS.

Institute of Electrical and Electronics Engineers (IEEE). A standards organization that facilitates operations in sectors that include telecommunications and computers, aerospace, biomedicine, electric power, and consumer electronics (IEEE, 2011a). IEEE serves as a source for professional and technical standards.

IEEE 802.3. A standard that defines the data channel collision detection technique of Carrier Sense Multiple Access/Collision Detection (CSMA/CD) media access control for Ethernet networks. The IEEE 802.3 Working Group (WG) addresses such issues as congestion management and frame expansion (IEEE, 2011b).

Integrated Services (IntServ). The first QoS architecture designed for IP networks. IntServ was the basis for extension of the best-effort network model, including the independence of data flows and management of resources by applications to meet performance requirements (Molnar & Vlcek, 2010a). IntServ reserves bandwidth to provide QoS.

International Telecommunications Union (ITU). An organization based in Geneva, Switzerland, that assists international governments and the private sector to promote global telecommunications standards (ITU, 2011).

International Telecommunications Union-Telecommunications Standardization Sector (ITU-T). One of three sectors of the ITU. Formerly known as the International Telegraph and Telephone Consultative Committee (CCITT), ITU-T is responsible for standards in all areas of telecommunications (ITU-T, 2011).

Internet Engineering Task Force (IETF). An organization of network vendors, designers, and researchers tasked with the growth, evolution, and operation of the Internet and development of RFCs (IETF, 2011).

IP Precedence. A three-bit field in the type-of-service byte in an IP header. The IP precedence field assigns values from 0 to 7 to packets to prioritize, classify, and mark traffic (Samak, El-Atawy, & Al-Shaer, 2011).

Low Latency Queuing (LLQ). A queuing method that uses weighted fair queuing (WFQ) and class-based WFQ that supports the addition of a priority queue to traffic classes and reserves bandwidth in the priority queue for the queued classes themselves (Sanju et al., 2011).

Management Information Base (MIB). A central information store for simple network management protocol (SNMP) data. Each managed host runs a process that maintains the MIB. The MIB contains information about hardware, utilization, and transmission rates (Heo, Kim, & Choi, 2010).

Modern Systems Development Life cycle (MSDLC). An organized approach to business information system development. MSDLC includes five phases, specifically, the planning, analysis, design, implementation, and support phases. In MSDLC, more emphasis is placed on the analysis phase than on the other four phases (Whitten & Bentley, 2007).

Multiprotocol Label Switching (MPLS). A high-speed technology that improves network performance by enabling the addition of a label to each packet of information. MPLS routes the traffic within the confines of the MPLS network. This technology is defined by the IETF in RFC 3031 (Sommers et al., 2011).

Net Flow. Provides data records about traffic flows between hosts on a network, including source and destination IP addresses, amount of traffic sent, and protocol (Rossi & Valenti, 2010).

Per-Hop Behavior (PHB). Describes aggregated packet processing at a network node (Molnar & Vlcek, 2010a). DiffServ uses PHB to aggregate traffic that requires similar treatment when traffic passes through a DiffServ enabled device (Molnar & Vlcek, 2010a).

Policing. A mechanism associated with QoS architectures whereby a traffic contract is identified at the time a connection is established. Any traffic that exceeds or violates the agreement is identified and discarded (Pathak et al., 2011).

Policy-Based Management (PBM). A system that manages QoS and other network resources (Mearns, Leaney, & Verchere, 2010). The system is based upon conditional rules. Service-level Agreements (SLAs) define performance targets with PBM by providing a definition of acceptable levels of latency, jitter, and utilization.

Quality of Service (QoS). The intrinsic, perceived, and assessed performance of a network in support of daily operations. Perceived QoS is important to users, and a provider must account for intrinsic QoS, the normal service level of daily operations, to meet customer performance expectations (Molnar & Vlcek, 2010a).

Quality of Service (QoS) Policy. Establishes conditions, actions, and rules for traffic flow (Mearns et al., 2010). General data about the flows and policies, such as circuit utilization or percentage of available bandwidth, are used for policy decision making (Mearns et al., 2010).

Real-time Transport Protocol (RTP). A protocol for transporting audio and video across data networks. RTP facilitates real-time applications such as video conferencing and VoIP (Li, Zhang, & Yuan, 2011).

Resource Reservation Protocol (RSVP). A signaling protocol used for resource reservation between receiver and sender. Typically implemented in conjunction with IntServ, RSVP assures resource availability for traffic flows (Molnar & Vlcek, 2010a).

Shaping. Controlling the volume of traffic that traverses a network by altering the traffic stream or the rate of transmission (Velauthapillai et al., 2010). Traffic shaping smoothes bursts of traffic to provide a more consistent flow (Velauthapillai et al., 2010).

Simple Network Management Protocol (SNMP). A management protocol and a set of standards that communicate with network devices such as routers and switches connected to TCP/IP networks. A process runs on these devices, which maintain the MIB for the hosts (Heo et al., 2010). SNMP version 2 is the most popular version of SNMP, and SNMP version 3 improves the security of the previous version (Heo et al., 2010).

Terrestrial-1 (T-1). A dedicated network connection with a transmission rate of 1.544 Mbps. The T-1 transfers voice and data in a digital format (White, 2010).

Traffic Classification. Divides network traffic into classes or divisions based on the type of network traffic (Pathak et al., 2011). Traffic classification enables diverse services such as security and QoS (Pathak et al., 2011).

Traffic Marking. The act of changing or establishing attributes of a traffic class. An example of traffic marking is modification of the CoS or DiffServ Code Point (DSCP) value (Bauer, Beverly, & Berger, 2011).

Type of Service (ToS). A byte in the IPv4 (IP version 4) header. Redefined in IETF RFC1391 to retain precedence bits, one of the bits and the delay, throughput, and reliability fields are used as a ToS field. A previously unused bit is used in ToS as a must be zero (MBZ) bit (Samak et al., 2011).

Virtual Private Network (VPN). A network that uses public networks to connect private logical links, allowing for VPNs to be created across networks such as the

Internet. Encryption and authentication ensure that transmissions remain private and tunnels establish connections (Sommers et al., 2011).

Weighted Fair Queuing (WFQ). An algorithm for managing network congestion, based on separation of packets in a conversation pair. WFQ enables the sharing of bandwidth between this pair. When used to manage network behavior, WFQ increases and reduces transmission rates and optimizes network performance (Sanju et al., 2011).

Summary

In this chapter, the author presented the problem investigated and the research goal, which was to provide a framework for large global manufacturing enterprises when they deploy MBS technologies at their facilities. Based on the findings, the author defined a model for large global manufacturing enterprises to plan, design, configure, and implement MBS provisions. The research questions, relevance and significance of the research, limitations and delimitations, and barriers and issues were presented. Finally, key terms were defined. A list of acronyms is found in Appendix B.

Chapter 2

Review of the Literature

This chapter presents a review of the literature relevant to the use of MBS technology as applied to network capacity planning and management. The chapter begins with a historical review of the literature, followed by the design and implementation of MBS strategies in global manufacturing enterprises, and then technologies that may be used to manage bandwidth and traffic flows to maximize performance. The chapter concludes with a summary.

Historical Review

Prior to the advent of traffic management technologies such as IntServ and DiffServ, only best-effort service was used for disparate traffic types traversing data networks. In best-effort service, packets are processed as they are received and as quickly as possible (Molnar & Vlcek, 2010b). There is no guarantee, however, that delivery will take place or that there will be delay, either of which would prevent the application responsible for the traffic from functioning properly. Best-effort service is a problem because an aggregation of links converging into a single connection can create massive traffic congestion problems and an overrun of available bandwidth. This overrun is commonly found in Internet connections where a single egress point is used by multiple corporate offices (Molnar & Vlcek, 2010b). Currently, Internet Service Providers (ISPs), such as telephone companies, cable internet providers, and satellite Internet providers, and many large enterprises use best-effort service on their networks (Molnar & Vlcek, 2010b). As a result of the limitations of best-effort service, the technologies and best practices used for enabling traffic management emerged, such as IntServ, DiffServ, and NetFlow traffic analysis, and QoS emerged for enterprise networks.

Various technologies, such as Dense Wavelength Division Multiplexing (DWDM) and MPLS, are capable of solving network congestion problems by facilitating advanced management of multimedia networks and traffic flows. Molnar and Vlcek (2010b) recommend the use of DWDM, coupled with the Ethernet, traffic engineering, and packet switching technology to control congestion and unplanned latency. He et al. (2010) described the utilization of MPLS, in conjunction with traffic engineering, as a way to increase network resilience. Several types of architectures for enhancement of QoS provisioning are available. DiffServ, IntServ, constraint-based routing (CBR), and MPLS architectures are used to support QoS in high-speed networks (Katramatos et al., 2009; Littman, 2002; Molnar & Vlcek, 2010b; Zhang & Bao, 2009).

Traffic Management Technologies

Quality of Service (QoS)

Sharma, Katramatos, and Yu (2011) evaluated the potential for a dynamic data-link protocol to handle real-time applications over shared or switched Ethernet. Sharma et al. demonstrated that QoS management over Ethernet can be used to achieve desired QoS results on LANs. Adaptation of a dynamic mechanism to provision traffic quality has subsequently been proven to be effective across multiple transport mediums (Samak et al., 2011).

IETF RFC 3272 provides a description of principles of traffic engineering (TE; Zhang & Bao, 2009). TE techniques are procedures for mapping traffic into tunnels and provide metrics for performance evaluation. With TE as a basis for engineering traffic on IP networks, including the Internet, the IETF Network WG defined the design, concepts, and methods for evaluating performance of IP-based networks. Key outcomes of the IETF WG included technologies to combat traffic congestion and enable dynamic routing. Recommendations for Internet traffic engineering, strategies for reducing traffic congestion through traffic prioritization, and a taxonomy of traffic engineering systems were described by the IETF WG for more efficient network usage (Zhang & Bao, 2009). The WG describes traffic management on IP-based networks and incorporates seminal QoS concepts, including differentiated services and performance metrics.

Increased reliance on data networks for critical business application transport has shown problematic application usability due to performance issues when bandwidth is not efficiently used by current best-effort techniques. The response time of a traffic-sensitive application can range from very high to very low. Magdalinos, Kousaridas, Spapis, Katsikas, and Alonistioti (2011) discussed distributed processing and QoS use to optimize application traffic across IP networks. They noted that a fuzzy controller is used to initiate reactive actions when QoS deteriorates and intervention is needed. QoS management in distributed processing systems can be faster than that of traditional systems and improves upon existing technology that is based on best-effort policy (Magdalinos et al., 2011).

In a seminal work, Wang and Sun (2010) used constraint-based path selection algorithms for QoS routing. These authors focused on restricted shortest-path and multi-constraint pass algorithms. Their findings indicated that constraint-based path selection allowed for the identification of patterns that satisfy QoS constraints to promote performance in data networks.

Karsten (2011) described service-oriented computing as a technology to enable business and provide web services. QoS is presented as a means to locate and control a dynamically changing number of service providers, and Karsten presents a method for evaluation of QoS of web services and providers (Karsten, 2011). Overhead and trust concerns for the dynamic computation model are also discussed as a limitation of the model. According to Karsten, a large overhead is created during implementation of the dynamic computation model.

Integrated Services (IntServ)

The IntServ architecture for traffic management is based on network resource reservation. Before traffic traverses a link, the path that the traffic will pass is established, and the resources needed are reserved. Proposed by the IETF in RFC 2210, IntServ is designed to be separated from a signaling protocol to enable other mechanisms to reserve resources (Bless & Rhricht, 2011). The signaling protocol, known as RSVP, is a fundamental piece of IntServ that can be used by applications to request network resources. In cases for which requirements for resources and service levels are quantified, IntServ parameters can be used in conjunction with network administration control modules to interface between the network and application (Bless & Rhricht, 2011). Although IntServ provides the ability for finite control, the use of per flow processing and per flow stateful measurement can cause concern when scalability is desired because it requires significant processing power in a large deployment (Sharma, Katramatos, & Yu, 2011). Bless and Rhricht noted that an extensible IP signaling protocol can be used to provide QoS to the Internet for multicast, bridging end-to-end service across heterogeneous networks. Problems of scalability in the stateful environment of IntServ RSVP were included as limitations of the IntServ technology when large deployments are required, and the DiffServ approach to QoS was presented as an alternative in a comparison of architecture behaviors.

Differentiated Services (DiffServ)

In a DiffServ architecture, packets are marked with values to create classes of packets. Different levels of service are applied to each class to enable prioritization of classes based on class survivability. This design allows for greater scalability than does IntServ, while still basing the architecture on aggregate traffic management (Vahdat et al., 2010). A fundamental concept in DiffServ is the ability to push control of per-flow operation to the edge of the network and, thus, provide switches and routers with only simple functions that are left at the network core (Vahdat et al., 2010). This stands in direct contrast to IntServ, as DiffServ networks have a lower assurance level in comparison to the per-flow controls used by IntServ (Vahdat et al., 2010).

Sponsored by the IETF, the DiffServ WG has focused on standardizing a small number of specific traffic behaviors to set DiffServ fields (Black, Brim, Carpenter, & Le Faucher, 2001). These behaviors are defined as per-hop behaviors and increase the efficiency of the DiffServ protocol. Black et al.'s classic work specifies a standard track protocol for the Internet community in regard to per-hop behavior identification. The DiffServ WG defines a 16-bit encoding mechanism for the identification of DiffServ per-hop behavior and protocol messages. These advantages resulted in RFC 3140's supplanting RFC 2836 as the standard for per-hop behavior identification.

An initiative to design a Policy Information Base (PIB) was proposed by the IETF DiffServ WG in March 2003. This PIB would map service requirements to resource capability, which would surpass the limitations of IntServ (Dias, Sadok, Fernandes, & Kelner, 2010). RFC 3317 provides a description of a PIB for implementation of the DiffServ architecture on a switch or router (Dias et al., 2010). By using a PIB, classes can be provisioned to aid in the control of policy in network resources. The provisioning services described by Dias et al. may be used with other DiffServ classes to provide policy-controlled mapping of service requirements to device resource utilization.

Constraint-based Routing (CBR)

CBR enables routes to be established in the network for traffic to flow, when metrics such as available bandwidth, delay, and jitter are evaluated by a routing protocol. This approach adds additional intelligence to routing, when compared to the widely used interior gateway protocols (IGPs; Molnar & Vlcek, 2010). A number of algorithms are proposed by researchers to facilitate constraint-based path selection in CBR, including heuristic algorithms to aid in path selection based on a set of QoS constraints (Wang & Sun, 2010).

The goal of CBR is to identify efficient paths that can satisfy the established QoS constraints to resolve less optimal traffic routing. This problem is commonly known as the QoS-based routing problem (Wang & Sun, 2010). By combining network state information provided by routing protocols with application requirements and availability of network resources, CBR is another state-based type of QoS routing. The assumption that network state information is predominantly static and has been distributed to the network using QoS based routing protocols is made in CBR to reduce complexity in the protocol design. Some of the algorithms considered in constraint-based path selection include restricted-shortest-path (RSP) algorithms, such as exact, optimal approximation, backward-forward heuristic, Langrangian-based linear composition, and hybrid algorithms (Wang & Sun, 2010). The Multi-constrained Path (MCP) problem, a problem of multiple paths that are attractive to the RSP algorithm, is evident when multiple feasible paths between source and destination exist that simultaneously satisfy multiple routing constraints.

Several other algorithms, known as MCP algorithms, are proposed to solve the MCP problem. These include Jaffe's approximation, fallback, tunable accuracy multiple constraints routing algorithm (TAMCRA) and self-adaptive multiple constraints routing algorithm (SAMCRA), Chen's approximate, randomization, heuristic multiple constraint for optimal path (H_MCOP), limited path heuristic, and A*Prune algorithms (Wang & Sun, 2010). Heuristics also have been proposed to address problems in scalability and large networks. At present, CBR is an area of continuing research and could be applied to enterprise traffic management as a solution for QoS constraints.

Multiprotocol Label Switching (MPLS)

MPLS uses IP packet switching based on a label that is added to packets when they enter an MPLS enabled network in between Layers 2 and 3. After the label has been applied, routing and classification are based on the label, which allows for less complex and faster packet switching than did prior methods. Label-switched paths (LSPs) provide a means for less complicated routing and path determination than did predecessors such as ATM with cell-switching and signaling protocol overhead. As a fundamental component of MPLS, LSPs establish paths based upon traffic type and current network utilization. By establishing paths in this manner, traffic may be optimized for delivery of voice, video, and data traffic and congestion can be efficiently managed.

MPLS is a Layer 2/Layer 3 technology that includes the capability to forward packets and integrate rules for multicasting, QoS, and load balancing. Recently, MPLS has become a topic of much discussion and attention in industry due to its ability to integrate efficiently with other QoS architectures.

Hybrid/Combination Architectures

The scalability and complexity issues inherent in IntServ outweigh the high level of resource reservation guarantee. Similarly, DiffServ shows problems in treatment of different flows that are aggregated to a single point in the network topology, which creates increased processing and memory needs and strong deficiencies in the simplicity and scalability of the technology (Mearns et al., 2010). IntServ and DiffServ technologies were designed to be applied to Network Layer IP routing, typically based upon Shortest Path First (SPF) routing methods. This method of routing does not consistently use the network infrastructure efficiently, and, as a result, bottlenecks may occur (Mearns et al., 2010).

Several models combine architectures to form designs that may be superior to the architectures individually. Due to the heterogeneity that is inherent in both enterprise networking and the Internet itself, these models of hybrid architectures include the best characteristics of each design but require an enterprise network design that matches the key characteristics of the hybrid architecture (Molnar & Vlcek, 2010b).

Sharma et al. (2011) presented a flexible resource scheduling framework for integrated services operation over DiffServ networks. IntServ is used to deliver end-to-end quality of service to applications. Interoperability with DiffServ networks is included focused at provisioning IntServ support over DiffServ networks. To connect an

IntServ network to a DiffServ network, this framework provides a transport for IntServ carried by DiffServ in the network.

Epiphaniou, Maple, Sant, and Reeve (2010) proposed an architecture that incorporates behavior aggregate (BA) mapping in MPLS LSPs. Their architecture evolved into IETF RFC 3270. In this model, a set of BAs can be mapped onto a single LSP, or an individual BA can be mapped onto an LSP. Linking BAs to LSPs makes it possible to meet the needs of traffic engineering, flow protection, and services on the network.

Molnar and Vlcek (2010b) discussed MPLS and its role in telecommunication and data network convergence. Sharma et al. (2011) discussed IntServ and DiffServ, and a framework for integrating MPLS and IntServ was presented as a hybrid architecture. This architecture has been tested in a simulator, and the results included better performance in delay, jitter, packet loss, and bandwidth. Samak et al. (2011) extended Molnar and Vlcek's work by focusing on control plane signaling to improve efficiency and by addressing PHB fairness problems by focusing on the MCP problem.

Lee, Chen, and Sun (2007) developed worst case fair weighted fair queuing with maximum rate control (WF2Q-M) by combining IntServ, RSVP, and DiffServ to gain the efficiency of DiffServ with the ability to support IntServ, RSVP WF2Q-M for advanced rate control. The core networks of Lee et al.'s model are DiffServ networks and are referred to as transit networks, with IntServ used in adjacent networks, which allows for interoperability in heterogeneous network architectures requiring end-to-end QoS (Molnar & Vlcek, 2010b).

Each hybrid model carries characteristics that are distinct from the other models. Each model supports a limited set of architectures and uses an established signaling protocol. Models such as the CBR label distribution protocol proposed by Molnar and Vlcek (2010b) use a combination of technologies to bridge the gaps between heterogeneous networks by including support for technologies such as DiffServ, IntServ, and MPLS. In this way, they provide end-to-end service level guarantees to all of the networks that are interconnected and support the protocols that are native to the network.

Generalized Multiprotocol Label Switching (GMLS)

GMPLS extends MPLS by providing routing and signaling for devices that switch via time, packet, wavelength, and fiber (Adnan, 2010). The common control plane in GMPLS has the ability to increase ease of management by automating provisioning of connections from end to end and includes QoS.

GMPLS helps move toward dynamically-switched networks by providing centralized management and a distributed control plane. A database is continuously updated by network devices for service provisioning and is centralized to reduce network management costs and downtime. The goal of GMPLS is to provide a common control plane that replaces separate control plane instances for each data plane switching layer, which results in increased interoperability and management across different physical network infrastructures (Adnan, 2010). This interoperability and management is beneficial in times of disasters that can disrupt business operations or during times that the recovery of networks that contain multi-layer transport networks is needed (Sancak et al., 2010). In times of outage, the ability to rapidly provision circuits and utilize the distributed GMPLS control plane allows for much more efficient static and dynamic recovery compared to MPLS (Sancak et al., 2010).

Internet Engineering Task Force RFC 3270 (IETF RFC 3270)

IETF RFC 3270 was authored in 2002 by the IETF Network Working Group responsible for DiffServ development. The target goal of this RFC was to create a flexible solution to support DiffServ operations over MPLS networks (Epiphaniou et al., 2010).

IETF RFC 3270 integrates DiffServ traffic management over MPLS networks (Epiphaniou et al., 2010). The RFC 3270 proposal includes the use of BAs and mapping to LSPs to match DiffServ and traffic management objectives within the network. With this solution, an administrator may map different sets of BAs to separate LSPs. This solution also allows an administrator of an MPLS network to choose mapping for DiffServ BAs onto LSPs to meet MBS and traffic protection goals for the network (Molnar & Vlcek, 2010b).

MPLS is a technology that is at the core of many large networks, including those of the largest global network carriers and large national research education networks (NRENs) such as the Pan-European research network (GEANT2) and the Greek Research and Technology Network (Kotti et al., 2009; Molnar & Vlcek, 2010b). The scalability provided by MPLS is demonstrated by its support of flow aggregation with end-to-end service guarantees that are enabled, which eliminates the need for individual flow control in each path segment (Epiphaniou et al., 2010). MPLS domains contain services that are supported by a per-hop design, and bandwidth and buffer space are pre-allocated in the LSR in correspondence with each individual service.

Models to enhance the interoperability between QoS schemes have been proposed by investigators such as Molnar and Vlcek (2010b) and are based upon the model developed by Epiphaniou et al. (2010) and that in RFC 3270. According to Molnar and Vlcek, the model proposed in RFC 3270 is advantageous for the following reasons: providers can determine how service classes are routed outside of their respective domains; mapping between the BAs and LSPs is flexible; support for in-place and future per hop behavior is included; restoration and protection is flexible; protection and restoration of MPLS devices is subsequent to topology changes; MPLS and DiffServ are combined; IPv4 and IPv6 are supported; use of label space is efficient; and LSP messages are optimized. A major drawback of RFC 3270, however, is its inability to support IntServ/RSVP (Molnar & Vlcek, 2010).

Service-level Metrics

Several network measurements may be used to track performance and continuity. Pang (2009) defines metrics as “quantitative measures of system or network behavior” (p. 205). Measurement of performance in large-scale enterprise networks is complex because multiple measurements are required to evaluate network efficiency. Often, these measurements are used to establish SLAs, values that are agreed upon between provider and customer to ensure satisfactory performance of the network. SLAs and metrics are used to establish service objectives to be met by the provider (Pang, 2009). Metrics are used primarily to manage network bandwidth and QoS.

Delay

Delay is a measurement of the time from transmission to reception of a signal and concerns a network's ability to process traffic. This measurement is commonly used to analyze VoIP traffic flows (Molnar & Vlcek, 2010b).

Latency

Latency is the time taken for a transmission to travel from a point of origin to a point of destination, measured in units of time (Pang, 2009). This measurement is usually conducted in milliseconds. Latency differs from delay, as latency includes the time needed for network equipment, such as switches, routers, or hubs, to process the traffic.

Jitter

Jitter, a measurement of variation in latency or delay, can prove problematic for real-time traffic types, or streaming traffic. VoIP applications use jitter as a primary performance measurement (Alia et al., 2010). Jitter, J, can be measured in the following manner, where l (peak) is the highest measured latency and l (avg.) is the average over the sample population: $J = l(\text{peak}) / l(\text{avg.})$.

Throughput

Throughput is defined as "the net carrying capacity of an element corrected for overhead" (Pang, 2009, p. 58). By measuring throughput, it is possible to identify bottlenecks and problems in the network. To measure throughput, an understanding of each transmission technology, protocol, or components, such as memory, storage, CPU, and other hardware components, is needed. By understanding the function and expected performance of a device, it is possible to determine whether the device is operating in accordance with expectations. Throughput is a theoretical value and is based on design and operation values of the network or hardware under assessment. These design and operation values include expected output of events per second, data per second, and processes per minute. Throughput is also referred to as burst capacity, in reference to the largest burst of traffic that a network connection can successfully carry (Pang, 2009).

Loss

Packet loss can take place when networks become congested or transmission and reception problems occur. Often, packet loss is the result of a cache or buffer overflow in a hardware device itself. In prudent network design, packet loss should be avoided at all times, regardless of the type of traffic flow (Molnar & Vlcek, 2010b). A common type of loss is seen in Ethernet networks, when too many devices attempt to access the same network resource simultaneously (Pang, 2009). In Ethernet networks, this is referred to as a collision, and collision detection schemes are used to reduce the frequency of occurrence.

Response Time

Response time concerns round-trip latency from the perspective of the end user (Pang, 2009). Response time refers to the time between the transmission of a request from the source and the receipt of a response from the destination host.

Utilization

Utilization is a measurement of capacity, based upon congestion or use of a network link. A measurement of utilization also may be applied to other types of resources, such as memory or processing capacity in a central processing unit (CPU). Utilization is the ratio of observed capacity to theoretical capacity (Pang, 2009). For example, for any unit of measurement q, utilization, U may be calculated: $U = [q(\text{observed}) / q(\text{theoretical})] \times 100\%$.

Bandwidth

In data networking, bandwidth typically refers to the capacity of a given network link (Pang, 2009). For example, the bandwidth of a T1 line is 1.544 Mbps. In data networking, bandwidth also can be referred to as the data transmission rate (Pang, 2009). This is a capacity measurement, in contrast to the wireless and radio communication definition of bandwidth, which refers to a spectrum of frequencies.

Managed Bandwidth Services (MBS)

Katramatos et al. (2009) use an MPLS VPN to extend MBS to other types of networks. Based upon the queuing approach of a Class-based Weighted Fair Queuing (CBWFQ) mechanism, Katramatos et al. used an implementation of CBWFQ to guarantee bandwidth to network connections. A simulation environment was used to test the proposed solution and evaluate characteristics of performance. These tests use bandwidth reservation for traffic flows and throughput measurement to evaluate the solution. Katramatos et al.'s study contributes to the research on MBS by providing a comparison of best-effort performance evaluated by an MPLS network and an outline of MBS applied to large networks such as NRENs, GEANT2, and GRNET3.

Kotti et al. (2009) presented guidelines for designing and implementing MBSs in a large-scale, high-speed backbone network in the context of GRNET3. They also discussed a management application for provisioning the service, which makes provisioning of QoS and MPLS less time-consuming for network administrators. MPLS technology and DiffServ are used within the architecture to facilitate QoS. Layer 2

MPLS VPNs provide point-to-point connectivity, and traffic tagging allows priority queuing to be included. Traffic engineering characteristics, including fast rerouting and load balancing, are used for high-availability. This work provides an understanding of the implementation of QoS in a high-speed research and education network, based upon an MPLS backbone.

In a classic work on broadband networking technologies, Littman (2002) provided an overview of principal modern communications technologies and discussed developments and innovations in telecommunications on a global basis. Littman also discussed the rapid growth of the technologies used in communication, such as ATM, wireless, QoS, and MPLS. Many of these networking technologies, including MPLS, Gigabit Ethernet, 10 Gigabit Ethernet, and wireless local area networks, are used in the implementation of ASD's global data network to provide more reliable and faster performance. To achieve the goals of these modern enterprises in terms of large-scale WAN implementations, MPLS scalability and versatility as a WAN transport method are advantageous (Littman, 2002).

Network Management

The criticality of information sharing to the operations of a manufacturing organization in today's competitive business environment is discussed by Chi et al. (2010). The researchers found that modern manufacturing organizations rely on data network and enterprise applications to produce their products and to deliver products for customers. Chi et al.'s study of the enablement of multiple IT organizations provides empirical evidence on information technology productivity and competitive advantage. Information technology use and productivity levels are evaluated in Chi et al.'s work, and productivity gains from the implementation of information technology are measured to demonstrate that an enterprise reaches higher levels of productivity when IT systems are operational.

Relevance to this investigation is exhibited in a parallel drawn by Chi et al. (2010) between criticality and productivity levels in manufacturing organizations, which establishes the importance of critical systems to productivity results. Chi et al. (2010) noted two measurements used to evaluate the importance of IT systems to the business: (a) criticality of traffic flows, the importance of the traffic flows to the operation of systems; and (b) level of criticality, the relative importance of traffic flows compared to other flows.

There considerations for technology availability and network management must be made based upon local conditions in each country. For example, network costs increase in developing countries, and high bandwidth technologies are limited by carrier networks. Tripathy and Patra (2011) provided a model for granting QoS guarantees that have been defined in SLAs. This model focuses on efforts to recover from failures as a consequence of the direct cost of SLA violation, which may vary based upon the country. Tripathy and Patra also stated that, in other countries, impacts of outages and performance problems on the data network can be effectively managed internally within an organization by establishing SLAs to hedge business risks (Tripathy & Patra, 2011).

Tripathy and Patra (2011) discussed communications networking service-levels, a framework of service-level goals and techniques that may be used to achieve networking service goals. They noted that service-based systems, network systems, and web systems are used to establish basic network service levels. They also discussed trends in network management and provided recommendations for verification of network maintenance and service-level best practices as means to define SLAs without the need for the involvement of highly technical IT staff.

Moore, Shannon, and Brown (2002) chronicled the events of the Code Red worm virus propagation of July 19, 2001. Their foundational work is one of the few serious attempts to review the fast spread of the worm and its impacts on businesses and government. Moore et al. showed that the propagation of a virus can create a distributed denial-of-service (DDoS) situation in the network, as thousands of infected client computers spread the virus and saturate network links with more traffic than the links can accept, which causes a service-outage condition. A description of the methodology used to trace the spread of the worm is included.

MBS and QoS could be used in current networks, such as the ASD MPLS network, to prevent the spread of heavy utilization that results in network-based application disruptions (Sakellari & Gelenbe, 2010; Sharma et al., 2011). The risk of a virus and threat of heavy network utilization experienced in 2001 remain the same today, as viruses such as 2008's Conficker virus and 2010's Stuxnet virus continue to penetrate and affect critical infrastructures, years after they were initially introduced (Dittmann, Karpuschewski, Fruth, Petzel, & Munder, 2010; Greengard, 2010).

Sancak et al. (2010) noted that the use of Network Layer recovery mechanisms in conjunction with a protocol suite to quickly provision end-to-end optical links in a class-based delivery mechanism results in more cost-effective recovery. The authors demonstrated that a rapid recovery enhances cost-effectiveness in networks with multilayer needs by avoiding the costs of prolonged outages.

Weiss (2011) brought COTS into organizations to determine whether it could increase productivity in enterprises. The researcher found that an increase in productivity was gained due to the efficiency of a standard software implementation, which lessened support efforts and IT resource requirements, compared to custom software implementations. A growth in the use of commercial software by enterprises results in an increased enterprise reliance on network capacity, availability, and performance as well as transition toward a software ecosystem with applications for critical business processes (Weiss, 2011).

Erbad et al. (2010) used congestion control algorithms incorporated in TCP to analyze the impact of burst suppression on traffic survival. They found that only large traffic bursts cause performance problems. By using a transport mechanism to combat bursts, technologies such as DiffServ can eliminate large traffic bursts.

Voice-over-Internet Protocol (VoIP)

Neupane, Kulgachev, Elam, Vasireddy and Jasani (2011) evaluated QoS with multiple VoIP endpoints by testing the performance of each endpoint. They found that the delay is mainly dependent upon the receiving endpoint. Typical ranges for latency and jitter in the network were used, and ToS defined voice as the priority traffic class. As a result, jitter was reduced to near zero, and latency was reduced to .001 to .024 milliseconds. Neupane et al. compared QoS techniques with DiffServ and MPLS techniques and found that QoS with heavy traffic had the greatest performance with the lowest latency (.001) and jitter (0). This work is relevant to the present study, primarily due to its QoS comparison to FR, and its establishing performance and security guidelines for VoIP using QoS. By establishing ranges for latency and jitter, voice traffic performance can be guaranteed when latency and jitter are within acceptable ranges (Neupane et al., 2011).

Namee (2009) conducted an assessment based on the leg and loss measurements on mesh networks, using voice quality measures to capture quality of VoIP. Different types of voice traffic paths that are typical in enterprise networks were evaluated for characteristics that affect service quality in a test environment. Network loss, delay, jitter, and variability were analyzed in the test environment, and the findings indicated that many backbone paths led to poor performance due to asymmetric routing. Namee noted that there has been a shift in expectations placed on network performance and service quality toward higher availability and better service quality, as compared to a greater user tolerance for outages in data networks than in voice networks in the past.

Sommers et al. (2011) investigated the role of MPLS in network survivability. They stated that the migration of government FR, ATM, and VPN networks to MPLS backbones for increased network survivability shows that MPLS is a highly survivable and commercially available technology.

Summary

Best-effort service processes packets as they are received. Such service, however, does not guarantee that delivery will take place or provide a robust way to prevent delay (Molnar & Vlcek, 2010). Traffic engineering, combined with MPLS, can help to increase network resilience (He et al., 2010). QoS provisioning may be enhanced through the use of IntServ, DiffServ, CBR, and MPLS in high-speed networks (Katramatos et al., 2009; Littman, 2002; Molnar & Vlcek, 2010; Zhang & Bao, 2009).

Service-level metrics such as latency, jitter, delay, throughput, loss, response time, and bandwidth are used as key measurements of network performance (Pang, 2009).

Chi et al.'s (2010) traffic flow measurements may be used as key network management metrics to relate traffic flows to business criticality, particularly among bursty traffic types. By establishing service provider SLAs, business risk from critical network and application outages may be hedged (Tripathy & Patra, 2011). As voice and data networks converge, traffic management principles and QoS protection are required for network and business survivability (Sommers et al., 2011).

Chapter 3

Methodology

Research Methods Employed

To address the issue of network performance and, specifically, to determine the types of network traffic that are considered to be critical to manufacturing, the author conducted a case study at TCS. The author included a description of ASD and TCS network architecture, developed the categorizations of traffic and benchmark traffic loads, and categorized business location types, system types, and end-user requirements in this research.

For this case study, this author examined the types of traffic that exist on the network of a manufacturing enterprise, defined criticality of traffic flows to the enterprise and level of criticality, and developed an MBS framework that can be used by other large-scale manufacturing enterprises. In turn, this undertaking will provide the manufacturing enterprise's critical application traffic flows with the ability to survive periods of heavy traffic.

The MSDLC method was used to implement an MBS initiative in a global manufacturing enterprise. MSDLC has five phases: planning, analysis, design, implementation, and support (Whitten & Bentley, 2007). Whitten and Bentley's system analysis and design process, including concepts, tools, techniques, and applications, was used to frame the initiative. While classical methods are proven and repeatable, emergent methods focus on more detailed technical subdomains, such as security, and, as such, emergent methods were used in this study.

More specifically, for this investigation, the author used an explanatory, holistic, single-case approach (Yin, 2009). The author followed the typical single-case model outlined by Yin and used a qualitative method to develop trends and understand a phenomenon. According to Woodside (2010), a case study that includes a collection of specific internal knowledge of the organization is the best method available to understand the issues inherent in a manufacturing enterprise. The author reviewed past failures of critical enterprise services, and the impacts of degraded network performance in regard to the ability of a manufacturing enterprise to continue operation. This information was consolidated by the author to understand general trends and used them to establish a framework for traffic management.

To establish the framework, the author undertook an in-depth study of the traffic types on the network of a manufacturing enterprise and developed an understanding of the criticality of certain traffic types and the relationships between them. The author also established criteria for classification of network traffic for QoS implementation and for business location types to identify specific requirements for QoS in sales offices, manufacturing plants, corporate offices, and parts centers, and end user requirements that could be used as guidelines for enterprise manufacturing organization traffic management. The framework, considered to be the goal of the study, was structured using the MSDLC method.

The author used a case study method as defined by Yin (2009) in a final framework using the MSDLC. This case study included MBS projects that were implemented by the author at TCS, resulting in an overall enterprise MBS framework recommendation. There were several projects in this case study: WAN migration to MPLS, traffic management on the WAN, traffic management on the LAN, and enterprise application survivability. The author studied the migration of the WAN to an MPLS network as a part of the WAN migration to the MPLS project and documented the milestones of the project as an implementation model for large manufacturing enterprises. In the traffic management on the LAN project, the author defined the QoS policies for traffic to traverse the LAN and documented these policies as a part of the MBS framework. The author used the enterprise application survivability project to identify the most critical applications and included these prioritizations in the QoS policies. ASD provided permission to use findings from these projects, included in the case study in Appendix A. These projects were implemented using the methodology of the MSDLC systems analysis and design process. This process was described in detail by Whitten & Bentley (2007). The MSDLC process was used to form the basis of a framework for the goal of the study, which was to develop a model for the implementation of MBS in global manufacturing enterprises, based on the results of the four key project initiatives.

Case Study Method

Yin (2009) defined the case study method as an empirical inquiry that "investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (p. 12). Most often, case studies are used to conduct research when the primary questions of the investigation are based upon "how" or "why" questions (Yin, 2009). In essence, the case study method is used when a researcher intends to cover conditions of context and to show that these conditions are pertinent to the problem being studied. Yin (2009) stated that survey-based research methods attempt to focus on context and phenomena, but the ability of the survey research to investigate the context is limited by the survey designer's number of questions asked and variables to be analyzed, in addition to the limitation of the number of respondents that can be surveyed. The author addressed these limitations by using qualitative analysis and technical data from network traffic, including packet data from switches and routers.

Yin (2009) also considered technical characteristics of distinguishing phenomena and context, as well as data collection and analysis strategy, in the second part of his definition:

> The case study inquiry copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result benefits from the prior development of theoretical propositions to guide data collection and analysis. (p. 19)

The case study research method involves an examination of current events in a real-world setting, and typically is conducted in situations in which the author has little control over the events to be studied. According to Woodside (2010), case studies are based on field-oriented research. The author conducted the case study in a real-world field setting, specifically, a global manufacturing enterprise. This setting provided the author with access to an actual environment.

Case study research is commonly considered a form of qualitative research, but often a blend of qualitative and quantitative components are included in studies that use this method. Although direct observation is not always used as a data source in case study research, it may be used in cases where it is necessary to understand phenomena in a complex organizational environment (Yin, 2009). The author used direct observation as a data source in the enterprise application survivability and traffic management on the LAN projects.

The case study portion of the work was conducted as single-case study. Yin (2009) noted that the first step in case study research is the careful construction of the research design. In the sections that follow, the five components of case study design are discussed in relationship to the research that was undertaken. These case study components involved developing research questions and propositions, determining the unit of analysis, and establishing the criteria for interpreting results (Yin, 2009).

Research Design

According to Yin (2009), research questions constitute the most important component of the case study. For this case study, the author addressed the following research questions:

1. What types of traffic exist on a manufacturing enterprise network that are considered to be critical to business objectives? (Erbad et al., 2010).
2. What specific factors must be considered in creating a framework for enterprise traffic management in a manufacturing organization? (Erbad et al., 2010).
3. How can a manufacturing enterprise ensure the availability of critical enterprise applications and services during periods of heavy network traffic? (Chi et al., 2010).
4. How can a manufacturing enterprise use the MSDLC framework to protect critical network-based business processes? (Pang, 2009).

5. How should a manufacturing enterprise prepare itself to ensure survivability of future VoIP traffic? (Pang, 2009).

According to Yin (2009), research questions are used to provide direction to the case study. To develop the research questions, a methodical literature review was undertaken. The foundational question that directed the study of the TCS MBS initiatives was: Can MBS be effectively designed, managed, planned, controlled, and implemented in a large global manufacturing enterprise?

Another important stage in the design process is the development of the propositions of the study (Yin, 2009). The propositions act as boundaries and guide the author to focus on the research questions. In the study, the propositions were as follows:

1. The MSDLC method can be replicated and, as a result, supports the development of a design that other large global manufacturing enterprises can replicate and use in MBS initiatives (Whitten & Bentley, 2007).
2. The outcomes that result from the TCS MBS initiative will apply to MBS initiatives in other, similar enterprises.
3. Issues addressed in conducting the TCS MBS initiatives are typically encountered in other large-sized global manufacturing enterprises.
4. The MSDLC framework serves as a method for design, planning, configuration, and implementation of an MBS solution in a large global manufacturing enterprise (Whitten & Bentley, 2007).

In case study, design, the unit of analysis defines the case of the research (Yin, 2009). According to Yin, an embedded, single-case study typically incorporates subunits of analysis and can have multiple units of analysis. The author used the ASD La Crosse, Piscataway, and Tyler offices as the units of analysis in the research. The observation of each of these offices and the performance of the network at these locations allowed the author to understand the viewpoint of the users as the internal case study participants (Yin, 2009). Traffic management effectiveness is a subunit of analysis and was used by the author to support the validity of the model developed. By passing network traffic that otherwise would have been congested, delayed, or dropped, the author increased the validity of the model.

The author related several pieces of information from the same case study to a theoretical proposition, which was an aspect of case study design identified by Yin (2009) as linking data to propositions. The final component of case study design, according to Yin, is the establishment of criteria for interpretation of the study findings. The data that are gathered throughout the course of this case study will be analyzed with the intent of showing that the processes, methods, and technologies used as well as the issues encountered in the TCS MBS initiatives apply to other large global manufacturing enterprises that undertake similar initiatives. The MSDLC framework provided criteria for interpretation of the research findings, and the planning, design, and implementation plan for the TCS MBS undertakings from the MSDLC process were used. This plan was used by the author to show that the MSDLC method is not only appropriate for but also capable of being used as a framework for the design, planning, and implementation of enterprise MBS in a large global manufacturing enterprise.

Specific Procedures Employed

The author utilized a case study of the ASD MBS initiatives, using the single-case method described by Yin (2009), and in conjunction with the MSDLC methodology described by Whitten and Bentley (2007), to develop an implementation model for large manufacturing enterprises to use to implement MBS. The MSDLC methodology supports the planning, design, and implementation of the MBS initiatives. The author used the single-case study approach to collect, analyze, and interpret findings to report the results of the investigation. The author used a pattern-matching method of analysis to compare case study results to predicted patterns known as prepositions (Yin, 2009). The final report was presented in reverse chronological order to reduce bias toward earlier events in chronological case studies, as this bias has been identified by Yin as a challenge in case-study research. The planning, design, and implementation phases of each initiative at TCS was based on the MSDLC framework.

TCS Bandwidth Management Initiative

The TCS bandwidth management initiative consists of four projects:

1. WAN migration to MPLS. The author documented the migration of the TCS WAN to MPLS and provided TCS with a WAN backbone that can support end-to-end QoS. QoS is not supported on the existing TCS WAN.
2. Traffic management on the WAN. The author established CoS and QoS on the TCS WAN. CoS and QoS are not currently provisioned in the TCS WAN in the existing WAN infrastructure.
3. Traffic management on the LAN. The author established CoS and QoS on the TCS LAN. After CoS and QoS were established on the WAN, they also were enabled on the LAN for end-to-end service.
4. Enterprise application survivability. The author identified critical enterprise applications and prioritized them in the CoS and QoS designs to promote

prioritized application survival over other traffic types that compete for bandwidth. CoS and QoS require this structure to define the traffic types that are most important and to protect them against traffic that competes for bandwidth.

The investigation and implementation of MBS initiatives at TCS was endorsed by ASD (D. Skrove, personal communication, November 14, 2005). ASD also funded the initiative and chose these projects as the most cost-effective way to resolve existing network traffic control problems (Appendix A). The author, a communications analyst on the ASBS IT Global Telecommunications Engineering and Architecture team, provided guidance for each of the MBS projects.

The author acted as a project consultant and coordinated day-to-day project activities with the Regional Network Operations teams. In addition, the Regional Network Operations teams and Engineering team worked with the technical operations staff of the network carrier to facilitate link activation and decommissioning. Hardware and software was purchased with funds from the ASBS IT budget.

The author also served as technical liaison to each of the TCS bandwidth management initiatives and coordinated day-to-day project activities with regional network operations teams. In addition, the author assisted in project architecture design activities, led hardware standards development efforts, and created an architecture design document that was used by ASD to articulate design goals within the enterprise. Funds for hardware, software, and technical training was allocated in the ASBS IT budget. To be consistent with internal company procedures, ASD also required an internal cross-charge for service to the TCS business sector (ASBS, 2009).

WAN Migration to MPLS

To streamline traffic routing, simplify enterprise network architecture, and provide the flexibility of vendor independence, TCS has migrated WAN links to an MPLS-based solution that takes into account technologies that are currently employed (ASBS, 2009). The WAN migration to MPLS project supports the migration from the existing VPN, FR, and ATM links to the MPLS backbone. To move from these technologies to MPLS, a leased infrastructure from a global network carrier was required. This initiative required the identification of the network carrier as well as evaluation and implementation of standard network hardware and MPLS links. For this initiative, WAN links were decommissioned and replaced by new MPLS hardware and wiring plant.

The author made the following assumptions about this initiative: MPLS links will be available to most TCS locations through the selected carrier, and this carrier will be able to assist the ASBS Network Operations teams, throughout the migration from IPVPN to MPLS, in procuring hardware and determining the initial hardware configuration. Some network carriers have limited resources in some areas of the globe, including Latin America and South America, where government-run telephone companies are prevalent (Hasson, 2010). By using strong carrier employees and resources in these locations, TCS will be able to use the carrier as the primary point of contact instead of the telephone companies (Hasson, 2010).

Technical and managerial considerations for this project included the ability of the carrier to assist three regional ASBS Network Operations teams in developing remote configurations and monitoring equipment on the MPLS network. The carrier and ASBS Network Operations monitored network links and hardware to provide up/down interface status and utilization statistics for availability and utilization monitoring (ASBS, 2009). This allowed for network capacity planning and future design engineering, while ensuring users that outages or problems will be quickly identified and resolved. In addition, by sourcing hardware from a single point within ASD, this migration ensured that WAN routers at TCS locations met the standards defined by the ASBS Engineering and Architecture team, as some in-place equipment was installed by other technical groups before the formation of ASBS IT within ASD.

Installed equipment must meet the requirements of both TCS and the network carrier to ensure that QoS delivery can be attained without disruption. New routers or appliances that are installed at TCS sites are cabled and installed in equipment racks in accordance with industry and organizational standards, such as Telecommunications Industry Association (TIA) 568, the commercial building telecommunications cabling standard (TIA, 2011). Due to the expenses of wireline installation, devices such as routers, switches, and appliances used the in-place cabling.

The WAN migration to MPLS provided technical benefits to ASBS IT Global Telecommunications, as it flattened the network architecture and introduced the benefit of a fully-meshed design (Kotti et al., 2009). In addition, the project allowed MPLS-based links to support QoS in the form of DiffServ. The WAN migration to MPLS benefited TCS personnel by enabling network availability at FR hub locations and by providing increased performance of mission-critical applications as a result of QoS deployment.

The WAN migration to MPLS project took place over a 12-month period. Phase 1, or the Systems Planning Phase, and Phase 2, or the Systems Analysis Phase, was completed in six months. For Phases 1 and 2, the author identified the sites that were candidates for migration, potential network carriers, and TCS business requirements.

Phase 3, the Systems Design Phase, was completed over the course of a month. This phase included the identification and testing of WAN router hardware. Additionally, hardware lifecycle documents were created, and the hardware was established as an approved standard by ASBS IT. Then, Phase 4, the Systems Implementation Phase, was completed in one year. Phase 4 involved hardware procurement, equipment configuration, and development and distribution of configuration and troubleshooting documentation for WAN router hardware, link cut-over, decommissioning of the old network links, and MPLS link activation.

The final phase, the Systems Support Phase, or Phase 5, of the WAN migration to MPLS will be ongoing until the network is either replaced or migrated to a new technology. Phases 1 through 5 are shown in Figure 2. The effectiveness of this project was defined by factors such as carrier and ASBS technical support availability, workload, and project management. These factors ensured the project timeline, and the efficiency of the link cut-over itself. In addition, project success was determined by the ability of the ASBS and carrier network teams to coordinate changes efficiently together and the ability of TCS network users to seamlessly connect to the ASD WAN.

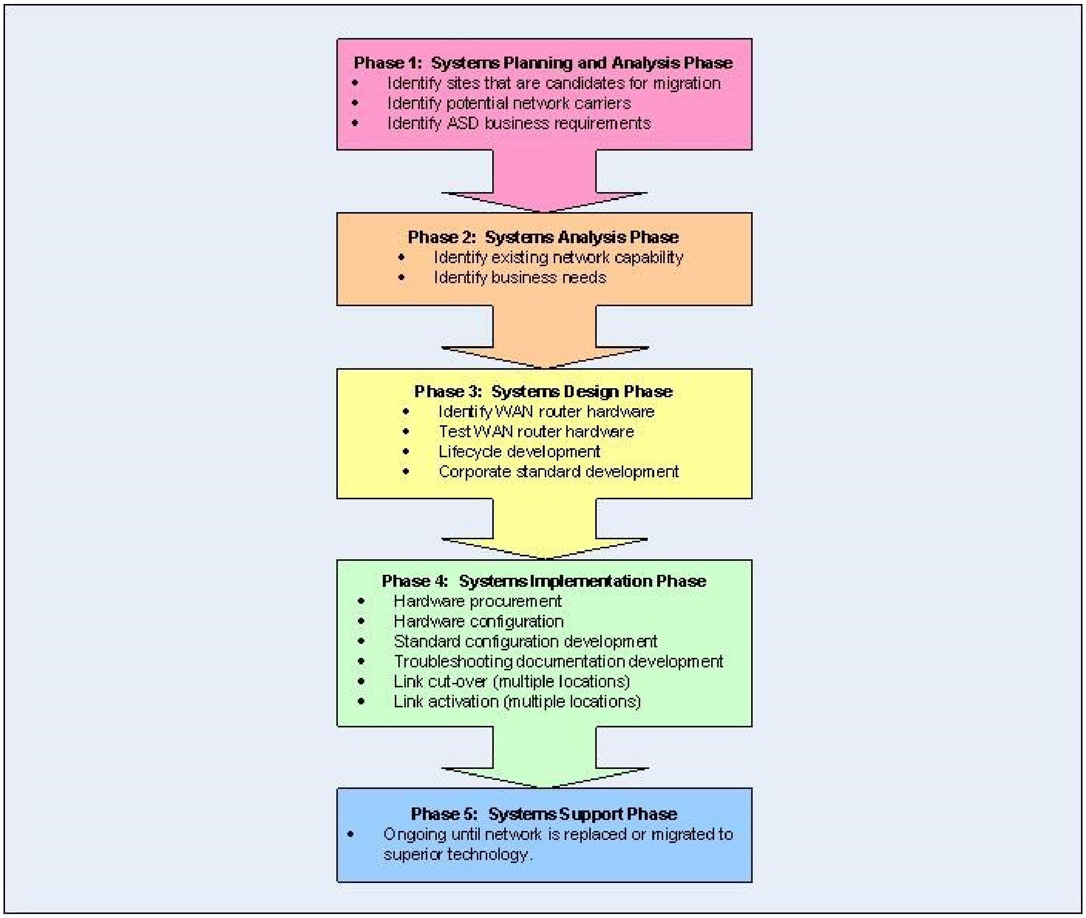

Figure 2. WAN migration to MPLS project systems development life cycle.

WAN Traffic Management Project

As a large global organization within ASD, TCS's WAN includes hundreds of individual locations that are interlinked using WAN technologies that include FR, VPN, and ATM. Some WAN links use a third-party network appliance to manage QoS for certain traffic types. Typically, appliances are used at sites with more than 300 users (ASBS, 2009). The decision to implement an appliance at a site is based upon costs, link size, and number of users. The appliances use traffic shaping and policing combined with CoS traffic classification to provision QoS. After completion of this project, these appliances will be phased out at sites with fewer than 800 users, and QoS will be provisioned at every site's router.

The goal of the WAN traffic management project was to provide a network solution for TCS locations to facilitate traffic management via QoS and enable scalability to support users at any WAN site. Generally, this solution features a router-based traffic control application, such as DiffServ, and/or an appliance-based solution (Kotti et al., 2009). Each site will benefit from the use of these provisions, as application and network traffic is controlled by the network hardware in the backbone of the network instead of at the end-user or application server.

This project involved the evaluation, selection, and installation of routers and traffic management appliances at TCS locations worldwide. Small- to mid-size locations will use routers for traffic management, while larger locations may use an appliance or a combination of a router and appliance. Initially, these features will be tested in the La Crosse, Wisconsin, test environment and in a pilot on a point-to-point link from Shanghai to Taicang, China, and then will be used on the three enterprise data center WAN links of La Crosse, Wisconsin; Boeblingen, Germany; and Shanghai, China.

In this project, traffic management needed to be transparent to the user. Any impacts from changes made to traffic flows needed to keep application performance, at a minimum, at the status quo or improve the performance of applications. In addition, any location that supports WAN traffic via a router needed to migrate to MPLS prior to initiation of this project.

Technical and managerial considerations included the ability of the network operations team to configure and manage the network devices with limited local support at the site. Typically, the local site contacts are familiar with cabling and interconnecting network devices but are likely the site's receptionist or financial person. Due to this limited site contact expertise, the installers of the equipment needed to have clear instructions, and the equipment was required to be operational after it was plugged in and powered on (ASBS, 2009).

Each piece of network hardware used in this project needed to comply with standards for data communications and traffic management. In addition, the devices should have been able to integrate with existing network equipment and the WAN carrier's requirements (Kotti et al., 2009).

The ability to manage network traffic on the WAN will provide benefits to the network users on-site through the improved performance and balance of network traffic as well as to users outside of the site that require access to resources hosted on-site. In addition, this was a step toward preparation for an IP telephony deployment at ASD, and stability of traffic flows will make any incoming or outgoing calls at the site understandable to people at both ends of a conversation. Potentially, this project affects all networked computer and telephone users at ASD.

The completion of the WAN traffic management project took place over a nine-month period. Phase 1, the Systems Planning Phase, as well as Phase 2, the Systems Analysis Phase, were completed in one month. The Systems Planning Phase of the project involved the identification of the hardware requirements for the test environment, of the requirements for implementation at the enterprise data centers, and of any other TCS locations to serve as pilot sites. Pilot sites were locations where traffic management dramatically improved network performance or locations where traffic management provided strategic value to the enterprise. The Systems Analysis phase of the project had several goals, but the primary goal was to determine the business-based requirements and structure for the traffic flows of the enterprise on the WAN. This phase also involved a review of the executive requirements, user requirements, current traffic flows and network performances, and current network architecture.

Phase 3, the Systems Design Phase, was completed during a period of six months. This phase focused on the link utilization and traffic flow design, including the allocation of bandwidth for specific traffic types on the WAN, and selection, purchase, and testing of hardware in the test environment as well as software for remote administration of the network hardware.

Phase 4, the Systems Implementation Phase, took nine months to complete. During this phase, the author focused on network hardware purchasing, configuration, installation, load testing, performance testing, equipment burn-in, and implementation. Documentation and training were created and distributed to network operations teams and other ASBS IT support staff during this phase as well. Phase 5, the Systems Support Phase, will be ongoing until the traffic management hardware is either upgraded or replaced in the future. Phases 1 through 5 are shown in Figure 3, which was developed by the author based on the MSDLC phases (Yin, 2009).

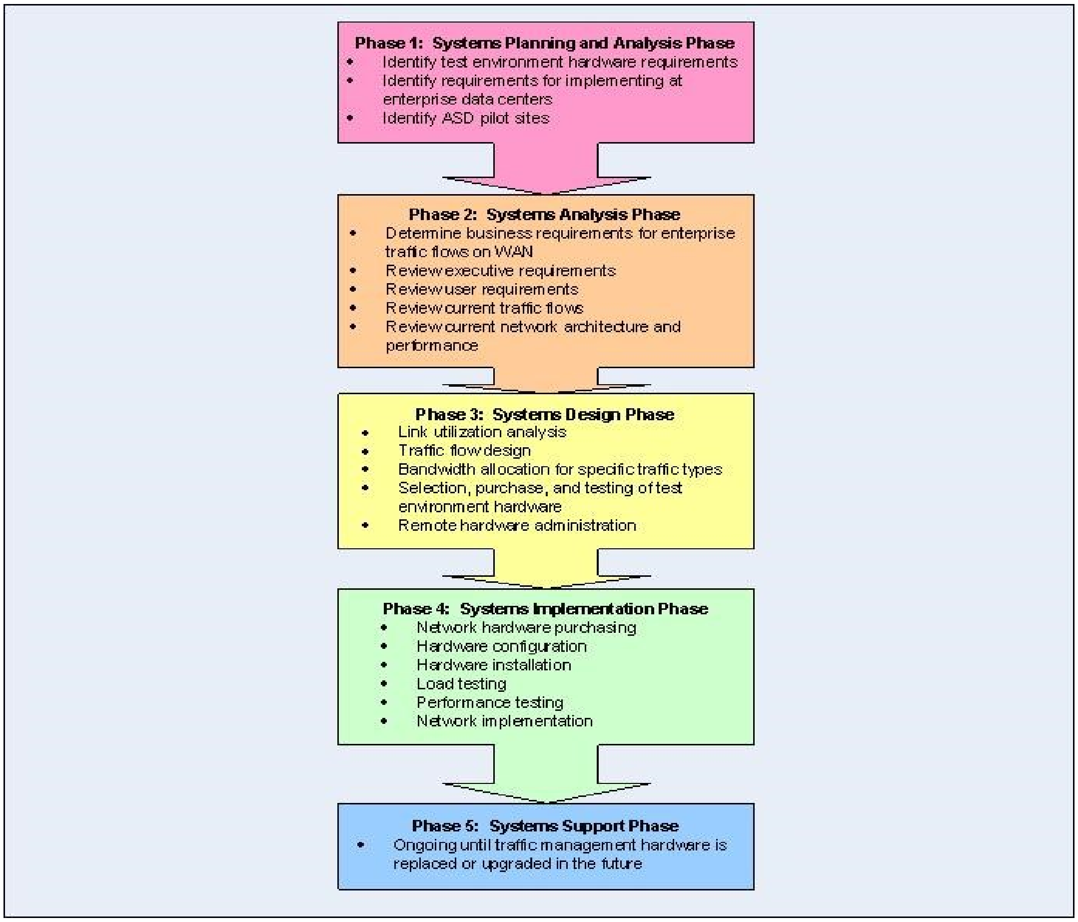

Figure 3. Traffic management on the WAN project systems development life cycle.

Factors important to the success of the WAN traffic management initiative were determined by the transparency of the WAN and user-perceived network performance improvements. In addition, the ability of the design to scale for usage in multiple locations on the TCS WAN was considered an important success factor (ASD, 2009). Further, the hardware costs, configuration and installation costs, time, and efforts required to install the network hardware also contributed to the success of the project.

LAN Traffic Management

According to Samak et al. (2011), MBS must be managed from points as close as possible to the originations and destinations of traffic flows. This end-to-end concept is very important, specifically in the application of sensitive interactive types of traffic, such as IP telephony. As a result, enterprises such as ASD will need to push traffic management designs into the LAN itself. The goal of the LAN traffic management project was to provide provisions for survivability of important types of network traffic on the LAN to maximize performance.

This project involved classification, marking, and management of traffic types, specifically, classification of traffic that traverses LANs at TCS. The approaches for managing LAN traffic were determined by the researcher (Kotti et al., 2009).

TCS supported development of a solution that may be applied as a standard corporate solution, and traffic management can be applied to the LAN at each site to meet the needs of the specific location (ASBS, 2009). The first implementations involved the Enterprise Data Center sites and high-utilization LANs, such as large sales offices and business unit locations.

ASBS Network Operations teams configured, deployed, and managed the solutions using network management tools and servers in data centers within their respective regions. Standards established by the Engineering and Architecture team were followed for configuration of switches, routers, and network equipment. In addition, strategies for using in-place LAN hardware and providing a capability for future upgrades were examined by the author (ASBS, 2009). The addition of traffic management to the TCS LAN will be transparent to network users because it will prevent major network outages, perform work during business-approved maintenance windows, and improve the overall user experience. Tactics for maintaining and/or improving the performance of current mission-critical applications running on the network were explored by the researcher

(ASBS, 2009). The TCS organization will benefit from this enhanced performance of core applications and the greater reliability of utilities such as IP Telephony.

The timeline for completion of this project was one year. Phase 1, or the Systems Planning Phase, and Phase 2, or the Systems Analysis Phase, was completed within three months. For the initial phase, traffic types were identified and classified. For Phase 2, the hardware and software requirements necessary to classify, mark, and manage traffic on the LAN were identified by the author.

Phase 3, or the Systems Design Phase, took four months to complete. This phase involved the development of the specification for marking and manipulation of traffic on the LAN as well as identification of special cases that were inherent to the target site traffic patterns. Phase 4, or the Systems Implementation Phase, was completed in six months. For this phase, the author focused on hardware procurement and configuration, hardware installation, and troubleshooting documentation for use by ASBS support teams. Phase 5, or the Systems Support Phase, will continue until the implementation is replaced or upgraded. Phases 1 through 5 are shown in Figure 4.

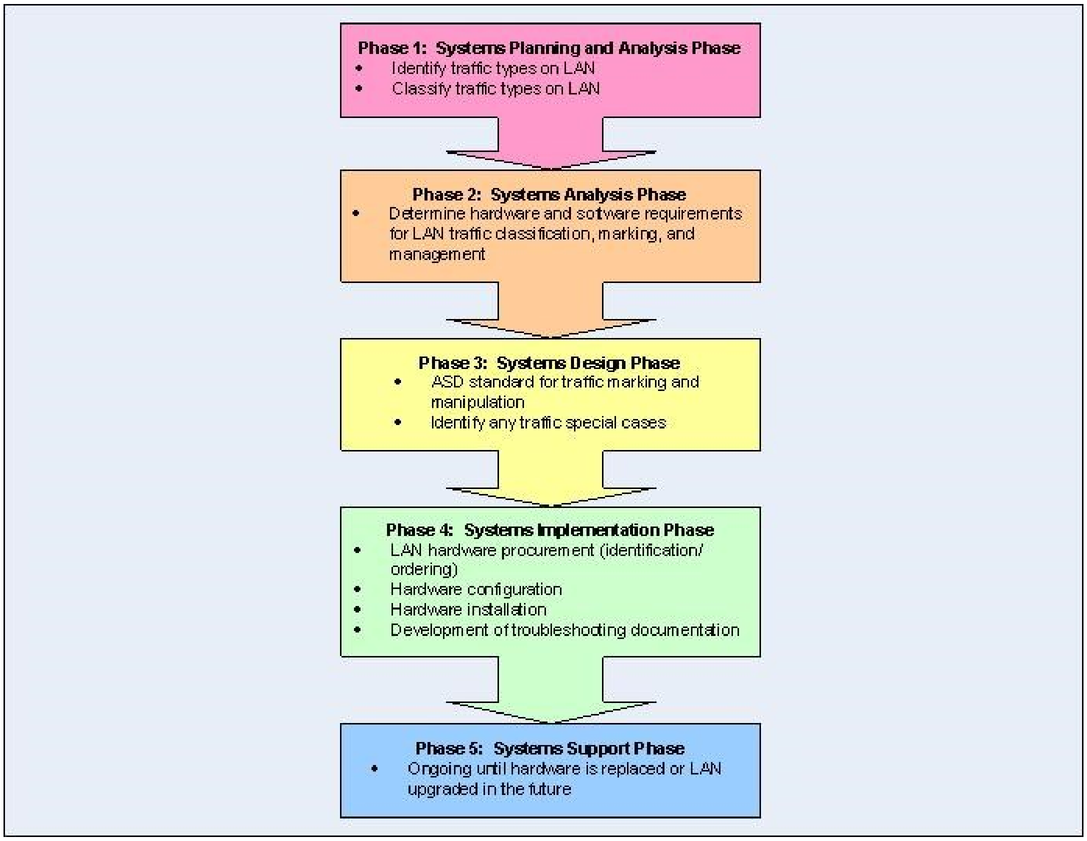

Figure 4. LAN traffic management project systems development life cycle.

Success of the LAN traffic management project was defined by several factors, including the degree to which the implementation promotes survival of mission-critical applications in the event of bursty traffic. In addition, this initiative was considered effective because a workable design was created that can be implemented on an as-needed basis, without causing a negative impact on the network.

Enterprise Application Survivability

A primary concern of ASBS Global Telecommunications, and one of the main reasons for undertaking the traffic management projects, was the survivability of mission-critical traffic (ASD, 2009). Mission-critical applications provide the most important functions as related to the organization's manufacturing, inventory, finance, accounting, and customer satisfaction. The goal of the enterprise application survivability project was to ensure that mission-critical applications are not disrupted by bursts of other traffic on a network link. This project took a holistic view of the enterprise and resulted in a hierarchy of network traffic that defines priority of traffic types over others.

The scope of the enterprise application survivability project included the design, evaluation, and implementation of a network traffic hierarchy at TCS, prioritizing important traffic over bulk data transfers and other bursty traffic, using QoS. In addition to protecting the mission-critical traffic, the project also provided the basic framework for traffic management, implemented in the LAN traffic management and WAN traffic management projects.

The first assumption of this project was that the QoS framework for traffic management was needed before the LAN traffic management and WAN traffic management projects required the use of this framework for their respective tasks. In addition, it also was assumed that, without a defined framework and methodology for implementation of traffic management on both the LAN and WAN, the enterprise could have been subjected to smaller, individual deployments of differing traffic priorities at the site level (Chen et al., 2011).

Managerial and technical considerations for this project included the ability of the Engineering and Architecture teams to balance the differing requirements of the business sectors as well as individual applications in the final design (Chen et al., 2011). In addition, considerations were made for the nature of the traffic type itself as well as the criticality of the application to the enterprise. For example, a mission-critical application from one of the business sectors could be composed mainly of batch data transfers that have the ability to hinder performance of sensitive transactional traffic in other business sectors' critical applications if prioritized equally (Chen et al., 2011). Further, consideration was given to the ability of the Engineering and Operations teams to configure and deploy the design with a manageable level of complexity and with ease of troubleshooting in mind. The system also needed to be easy to change in case of an event that disrupted the balance of traffic on the network.

The target population that will benefit from the enterprise application survivability initiative is the entire user base of the TCS global network. The hierarchy defined by the author will protect the information flow of the enterprise and will provide a benefit to the project teams as they pursue the LAN traffic management and WAN traffic management projects.

The completion of the enterprise application survivability project was achieved in six months. Phase 1, or the Systems Planning Phase, and Phase 2, or the Systems Analysis Phase, was completed in two months. In the Systems Planning Phase, the author identified the existing traffic types on the network and the relationship of the traffic types to applications and the ASD business sectors that they serve. In the second phase, the Systems Analysis Phase, the author identified the method for distinctively separating the traffic types and identified mission-critical applications.

Phase 3, or the Systems Design Phase, took one month to complete. In this phase, the author determined the priority of each of the identified traffic types by identifying application and traffic characteristics as well as criticality to TCS operations. In this phase, the author also focused on the design of an environment for testing the QoS design. In Phase 4, or the Systems Implementation Phase, the author focused on the procurement, configuration, and installation of the test environment hardware and the testing of the QoS design. In addition, support documentation was created, and training sessions took place during Phase 4. Phase 5, or the Systems Support Phase, will be ongoing until the design is either replaced or upgraded. Phases 1 through 5 are shown in Figure 5.

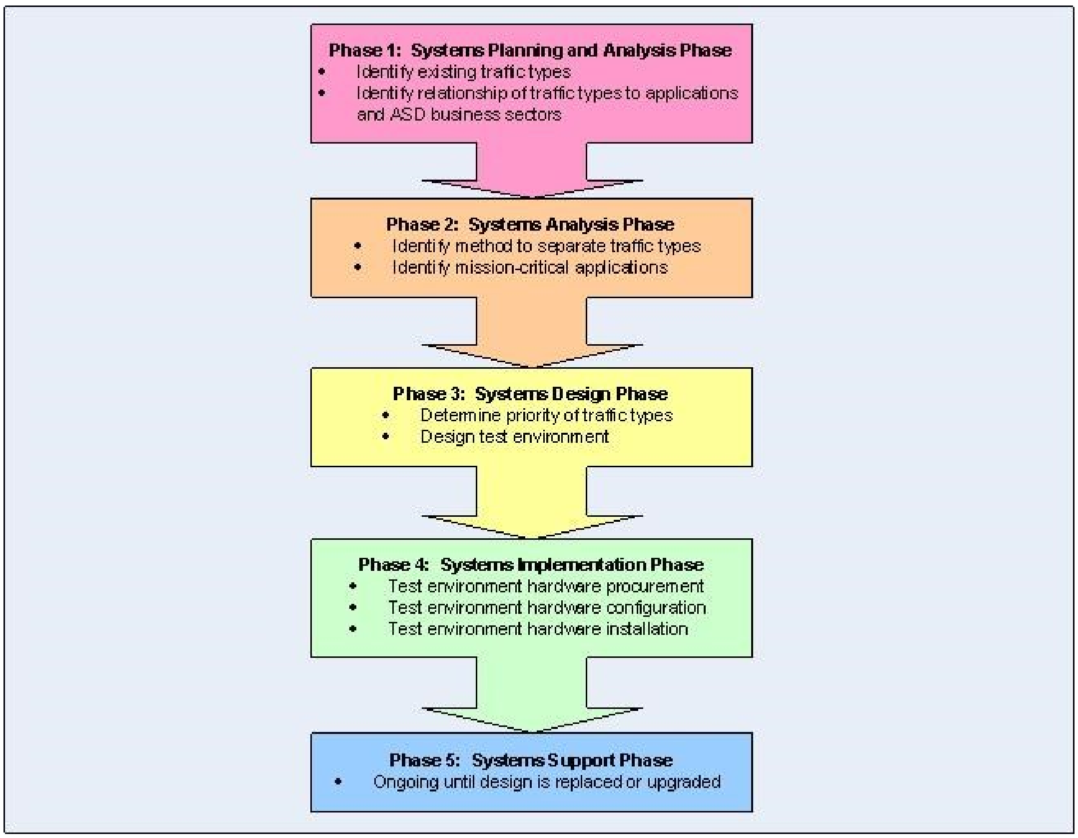

Figure 5. Enterprise application survivability project systems development life cycle.

The success of the EAS project was defined by several factors, including the ability to define the mission-critical applications and traffic in comparison to other traffic types, as well as the ability to distinguish between traditionally bursty traffic types and other flows. For the EAS project, the author defined success by the reliability, scalability, and simplicity of the design as the implementation of traffic management expands across TCS sites.

Reliability and Validity

The data and information used in a research study must be reliable, meaning that the approach to the research should be repeatable (Yin, 2009). Data and information also must be valid, resulting in plausible and trustworthy information (Yin, 2009). To ensure the reliability and validity of the study, the author employed a variety of strategies that included protecting data integrity, multiple resources, and peer review of results. The activities in the projects were preserved by the frequent referral to relevant parts of the case study data in the case study report narrative (Whitten & Bentley, 2007; Yin, 2009).

Yin (2009) classified reliability, construct validity, and internal and external validity as important case study quality attributes. By utilizing a reliable case study research design and conducting the research using a pattern-matching method of analysis, the author supported internal validity as well (Yin, 2009). The pattern-matching method of analysis compares case study results to predicted patterns known as prepositions (Yin, 2009).

The depth of the study was assured through the use of multiple empirical resources, such as Stephens et al.'s (2011) study of scalability in enterprise networks, Sharma et al.'s (2011) study of end-to-end QoS implementation with flexible reservations, and Samak et al.'s (2011) policy verification scheme for DiffServ networks. Moreover, the author compared generalizations about the projects at ASD with considerations from case study research methods about whether the case was typical (Whitten & Bentley, 2007). The author also compared generalizations about traffic categorization from this investigation with characteristics of large global manufacturing enterprises such as ASD and other large-size companies that can benefit from the findings of this study.

According to Yin (2009), case study research that is peer reviewed by multiple experts adds rigor and validity. The final draft of the study report underwent a review by participants in the study and a panel of peers and subject matter experts, thereby ensuring the rigor and validity specified by Yin.

Format for Presenting Results

After evidence analysis was completed, the case study report was written in a narrative format that followed the logic of the research and sequence of events. This method was presented as effective for case study research by Woodside (2010). Yin (2009) also recommends that the case study report provide evidence ordered sequentially. The TCS MBS initiatives case study report also used a time-based chronological order to describe, detail, and explain events and mapped them to the MSDLC framework. This approach also was used to validate propositions identified by the author that were causal in nature, whether deterministic, indeterministic, or influential, by mapping them to the MSDLC framework (Woodside, 2010).

When the case study report was completed, the author synthesized the findings from this investigation, in conjunction with research from the literature, to build the model. The development of the MBS model was the goal of this inquiry, and, as noted, the model was built in conjunction with the MSDLC (Whitten & Bentley, 2007). The author also used the MSDLC framework to establish a framework for MBS initiatives in large-sized global manufacturing enterprises.

Resource Requirements

Throughout the study, several resources were used. Scholarly publications such as journal articles, textbooks, conference proceedings, and online academic publications were used to support the MBS model. In addition, the author employed ASD project management tools, such as the project charter, cause-and-effects matrix, and failure modes and effects analysis tools, as well as ASD network and support documentation and additional unpublished literature used at ASD. The use of ASD computing resources such as hardware, software, facilities, documentation, and staff had been approved per the signed letter of permission (Appendix A).

For the study to be conducted, the following resources were provided by ASD:

1. Assignment of the author as project consultant for the TCS MBS initiatives.
2. Support of management within the manufacturing enterprise, as well as assignment of members of the enterprise's Information Technology (IT) staff, to the resulting implementation projects.
3. Assignment of members of the ASD Global Data Networks Engineering and Architecture team to serve as resources for the project during all phases.
4. Availability of individuals within the enterprise for projects.
5. Funding for equipment, hardware, and software purchase and installation.

All resources were approved by executive leadership at American Standard Companies, per the signed letter of permission in Appendix A.

Summary

For this investigation, the author used an explanatory, holistic, single-case study approach to develop an MBS model for global manufacturing enterprises (Yin, 2009).

The author followed the typical single-case model outlined by Yin and used a qualitative method to develop trends and understand MBS requirements for global manufacturing enterprises. The MSDLC method was used to implement a solution to the MBS requirements and to develop a structure for QoS policy. Each of the ASD initiatives used the MSDLC method for execution: WAN migration to MPLS, traffic management on the WAN, traffic management on the LAN, and enterprise application survivability. The five phases of MSDLC, planning, analysis, design, implementation, and support (Whitten & Bentley, 2007), were followed.

The results of this study were compiled by the author in a narrative format, in reverse chronological order, to reduce bias toward earlier events. Observations were conducted at key offices as units of analysis, and traffic management effectiveness was used as a subunit of analysis to ensure validity (Yin, 2009). The author compared generalizations about the projects at ASD with considerations from case study research methods about whether the case was typical, compared generalizations about traffic categorization, and conducted a peer review of the study results to ensure rigor (Whitten & Bentley, 2007).

Chapter 4

Results

Data Analysis

In this study, the author used an embedded, single-case study methodology, using the ASD La Crosse, Piscataway, and Tyler offices as the units of analysis in the research. Performance of network traffic in the headquarter offices for the key ASD businesses and corporate functions is key to ASD manufacturing operations (ASBS, 2009). Traffic management effectiveness was used as a subunit of analysis.

To support the resilience of the ASD data network, the global network team configures equipment for business offices and manufacturing sites according to strict corporate standards. This team supports outage and incident response and troubleshooting as well as disaster recovery planning.

The author investigated the implementation of network technology by the ASD offices to determine how MBS could be utilized to increase network performance and resiliency. To frame the investigation, a case study framework was used (Yin, 2009). This framework included propositions that were identified during the literature review. To enhance the reliability of this study, the author used evidence of network traffic that otherwise would have been congested, delayed, or dropped as well as other sources of evidence, including ASD internal reports, and ASD technical documentation, to collect information on the single unit of analysis and to increase the validity of the model (Yin, 2009).

To understand the performance of the network during periods of heavy traffic congestion, and the ASD response to this problem, it is important to understand key roles within the ASD organization. Key roles include the chief information officer (CIO), technical director, network managers, and network engineers. The CIO is responsible for the continuity of information technology services to the enterprise, and the network director is responsible for a functional and sustainable network design. The network managers implement and manage the network projects, equipment, and personnel, and the network engineers configure equipment and perform problem diagnostics.

Yin (2009) identified six sources of evidence to be collected in case study research: documents, archival records, interviews, direct observations, participant observation, and physical artifacts. Documents, archival records, direct observations, and physical artifacts were used by the author. Documents such as project plans, meeting agendas, and technical documents were collected. Archival records were used in the form of organizational charts, budget data, and internal strategy documents. Direct observations of the technical and business environment were used casually. Physical artifacts, such as equipment configuration files, also were collected to support the investigation.

Yin (2009) also identified three main principles of data collection for case studies: use of multiple sources of evidence, creation of a case study database, and maintenance of a chain of evidence. In this investigation, the author used indexing tools, databases, spreadsheets, and productivity tools as software applications to manage the collection of evidence. Multiple sources of evidence were used to triangulate converging findings and increase construct validity. A chain of evidence was maintained using the link between case study procedure and initial study questions, and storage of evidence in the software applications, such as an indexing program to manage references and citations, was maintained for later review.

Proposition 1: MSDLC Method for MBS

Proposition 1: The MSDLC method can be replicated and, as a result, supports the development of a design that other large global manufacturing enterprises can replicate and use in MBS initiatives (Whitten & Bentley, 2007). In support of critical voice services on the ASD data network, ASD requires QoS as a part of an MPLS MBS to provide reliable service to customers (ASD, 2009). The MSDLC method was used, as it has been proven to be a classic and repeatable method for implementation of technology projects (Whitten & Bentley, 2007).

The evidence collected in the study showed that ASD requires the capability to preserve critical classes of traffic on the data network, including business-sensitive critical applications, and voice and video traffic. The ASD IT strategic plan (2009) included the use of common project management principles, including the MSDLC method, to support the overall design of MBS at ASD. Project teams responsible for implementation of MBS using the MSDLC process reported that the systems design was based upon an intersection between the ASD business processes, the technology and applications that support manufacturing including Cincom software, a Product Lifecycle Management (PLM) application, an Enterprise Resources Planning (ERP) system, and the flows of traffic across the network that support VoIP.

This case study demonstrated that ASD management identified the need for a framework for MBS to be implemented in a manufacturing enterprise. The implementation of MBS provides core technologies that balance flows of traffic in the network, including QoS, Class of Service (CoS), and a high-speed network backbone that supports end-to-end QoS delivery (Karsten, 2011). These core technologies play a key role in the survivability of sensitive traffic classes, such as VoIP, by providing classification, reporting, and prioritization of bandwidth for the highest-sensitivity data packets.

MBS is a way to increase the efficiency of the data network by providing a focused plan for network traffic to flow through routers and switches (Pang, 2009). Case study evidence revealed ASD's interest in the use of QoS as a technology to layer on top of CoS and to support the need for uninterrupted manufacturing as a part of internal solutions proposed in the 2009 *ASBS Products and Ser*vices catalog. ASD IT had a specific interest in any technology that would improve the quality of VoIP, to support business continuity during heavy WAN utilization. This robustness was planned in future system upgrades in the La Crosse, Tyler, and Piscataway offices.

Documentation identified the MSDLC process as capable of implementing MBS in a global manufacturing enterprise environment. MSDLC provides an organized, five-phase approach to business information system development. Specifically, the planning, analysis, design, implementation, and support phases have been used to implement IT information systems in a variety of environments, including global manufacturing enterprises.

Proposition 2: Application to Other MBS Initiatives

Proposition 2: The outcomes that result from the TCS MBS initiative will apply to MBS initiatives in other, similar enterprises. The case study evidence showed that TCS and ASD are representative of many large global manufacturing organizations.

Organizationally, the business is structured around major manufacturing locations tied to specific brands and product lines. The business functions within ASD are consolidated into a business services organization that provides IT, accounting, finance, payroll, and other corporate processes as a service to each of the ASD businesses, including TCS.

Case study evidence also showed that MBS, CoS, QoS, and high-speed WANs were being investigated by other similarly structured manufacturing organizations. ASD had been approached by industry peer companies that were inquiring about the QoS design implemented at TCS, with a desire to implement a similar design within their data network. MBS implementation challenges were topics that had been discussed in executive briefings and conferences for manufacturing organizations, and included in the overall roadmap for IT services (ASD, 2009).

Proposition 3: Similar MBS Issues

Proposition 3: Issues addressed in conducting the TCS MBS initiatives are typically encountered in other large-sized global manufacturing enterprises. According to Pang (2009), the design and implementation of telecommunications systems, including MBS, can be very similar across various industries, including manufacturing enterprises. The case study evidence revealed that TCS was similar to industry peers in terms of organizational structure, manufacturing footprint, and other trends in manufacturing technologies. The basic network design followed a core layer, distribution layer, and access layer methodology that was recommended by leading commercial network equipment vendors and resellers (ASBS, 2009).

The challenges in implementing an MBS strategy were similar to the challenges faced by ASD peer companies across the manufacturing industry (Pang, 2009). The results showed that ASD had a list of peer companies in the diversified industrials sector that are also global manufacturing companies used for financial benchmarking. Due to the competitive relationships between these companies, data focused on MBS are limited, but it was noted by the author that the industry peers also faced the same MBS challenges and were working with vendors to encourage maturation of commercial technology capable of resolving traffic survivability issues.

ASD expressed an interest in MBS technologies to assist in making the network user experience more reliable (ASD, 2009). Traffic classification, prioritization, and utilization reporting are key benefits (Pang, 2009). However, among IT management, there was concern about the reliability of MBS due to the complexity and granularity of the traffic control required on the WAN. Specifically, ASD did not want MBS to become a replacement for properly sized network connections and network capacity planning. IETF RFC 3272, the RFC that created principles of TE, creates a way to map traffic into classes and provide metrics for performance evaluation (Zhang & Bao, 2009). It was also noted by this RFC that MBS was not a replacement for network capacity planning, as fully utilized network connections demonstrate a much higher packet loss rate and slow delivery of packets (Zhang & Bao, 2009).

Proposition 4: Design, Planning, Configuration, and Implementation of MBS

Proposition 4: The MSDLC framework serves as a method for design, planning, configuration, and implementation of an MBS solution in a large global manufacturing enterprise (Whitten & Bentley, 2007). The MSDLC framework has been used as a basic method for design, planning, configuration, and implementation of several technologies across business, government, and education industries and is considered to be a foundational framework for information systems implementation (Whitten & Bentley, 2007). This framework was recognized by ASD as the framework for implementation of the MBS initiatives and is included in ASD's basic project management instructions to project participants and network team members.

The purpose of MSDLC is to organize the efforts necessary for design, planning, configuration, and implementation of information systems into phases, and each phase was implemented in succession by the project teams. By using the MSDLC framework, the project teams were able to actively identify project milestones, task dependencies, and resources needed to support the MBS solution prior to project implementation. The framework was tailored to the specific requirements of the MBS initiatives and refined to meet the specific requirements of MBS in a global manufacturing enterprise as a result of lessons learned during the case study.

Findings

MBS as implemented by TCS at ASD would contribute to greater resilience in the network, increased system availability, and greater manufacturing plant efficiency. The technology has made brief bursts in network traffic have less of an impact on ASD users by smoothing the peaks into more manageable flows that can be passed through the network without causing application delays or service outages. Two of the four MSDLC components identified by Whitten and Bentley (2007) as foundational elements of an information system include networks that allow system communications, and network components for capturing, storing, and manipulating data. At ASD, these two elements were incorporated into an overall MBS implementation.

The research questions that guided the investigation are as follows:

1. What types of traffic exist on a manufacturing enterprise network that are considered to be critical to business objectives? (Erbad, Najaran, & Krasic, 2010).
2. What specific factors must be considered in creating a framework for enterprise traffic management in a manufacturing organization? (Erbad et al., 2010).
3. How can a manufacturing enterprise ensure the availability of critical enterprise applications and services during periods of heavy network traffic? (Chi, Ravichandran, & Andrevski, 2010).
4. How can a manufacturing enterprise use the MSDLC framework to protect critical network-based business processes? (Pang, 2009).
5. How should a manufacturing enterprise prepare itself to ensure survivability of future VoIP traffic? (Pang, 2009).

During the planning phase, the CoS traffic classification was created, and six classes of service were defined: voice, video, mission critical, business data, bulk data, and general data. The voice traffic class contained IP telephony, voice, voicemail, call signaling, and VoIP applications. The video class was reserved for interactive video conferencing. The mission-critical traffic class included critical interactive applications that were sensitive to latency, including Citrix, SQLNet, AP Oracle, Telnet for MFGPRO software, routing updates, network management tools, and Light Weight Access Point Protocol (LWAPP). The business data traffic class was considered to be the default general traffic class and comprised key business applications, including Cincom, PeopleSoft, Human Resource Management Systems (HRMS), Product Lifecycle Management (PLM), Authentication, HTTPS, Internet Control Message Protocol

(ICMP), SNMP, Domain Name Services (DNS), and Dynamic Host Control Protocol (DHCP). The bulk data traffic class included file transfer protocol (FTP), batch traffic and file replication, data warehouse applications, and client updates. Finally, the general data traffic class was reserved for public Internet, e-mail, non-priority streaming video, and file-sharing classes (Figure 6).

6 Classes of Service	Applications
Voice	IP Telephony Implementation *(Voice, Voice-Mail, Call Signaling)*
Video	Interactive Video Conferencing
Mission Critical	Critical Interactive Applications: *Citrix, SQLNet, AP Oracle, Telnet (MFGPRO), Routing Updates, IR NetMan, LWAPP/CAPWAP*
Business Data (Default)	Business Applications examples: *Cincom, PeopleSoft, PBS, HRMS, PLM Interactive, Oracle, Intranet, Authentication, HTTPS, Ping (ICMP), SNMP, DNS, DHCP*
Bulk Data	File Transfer (FTP), PLM-Files, Pro-Intralink, Cincom Batch, ReplicatorX, Dataguard, TPS System i5, TCS Data Warehouse, Client Updates: *(SCCM, WSUS, Forefront,Altiris,Tivoli backups)*
General Data	Public Internet, E-mail (Exchange), Streaming Video (RTSP) File Sharing *(Microsoft-ds, NetBIOS, CIFS)*

Figure 6. ASD CoS application classification.

In addition to mapping applications into a six-class CoS structure, ASD modified a nine-class QoS model to interface with the MPLS network carrier's CoS and QoS implementation on the ASD MPLS WAN connections. This approach combined non-priority streaming video, a scavenger traffic class for Internet flows, and general data into a best-effort class, with 20% of the egress queue dedicated to the traffic class. Voice traffic and call signaling were provided a guarantee by the MPLS carrier with a Committed Access Rate (CAR) sized to match the site's need in an Expedited Forwarding (EF) MPLS CoS. Interactive video was mapped to a DSCP of Assured Forwarding (AF) 41, with 30% of the egress queue dedicated to the traffic class. Mission-critical data, including IP routing and interactive applications, were mapped to a DSCP of AF31, with 20% of the egress queue dedicated to the traffic class. Business data were mapped to the DSCP of AF21, with 20% of the queue dedicated to the traffic class, and bulk data, including client updates and antivirus updates, were mapped to DSCP AF11, with 10% of the egress queue dedicated to the traffic class (Figure 7).

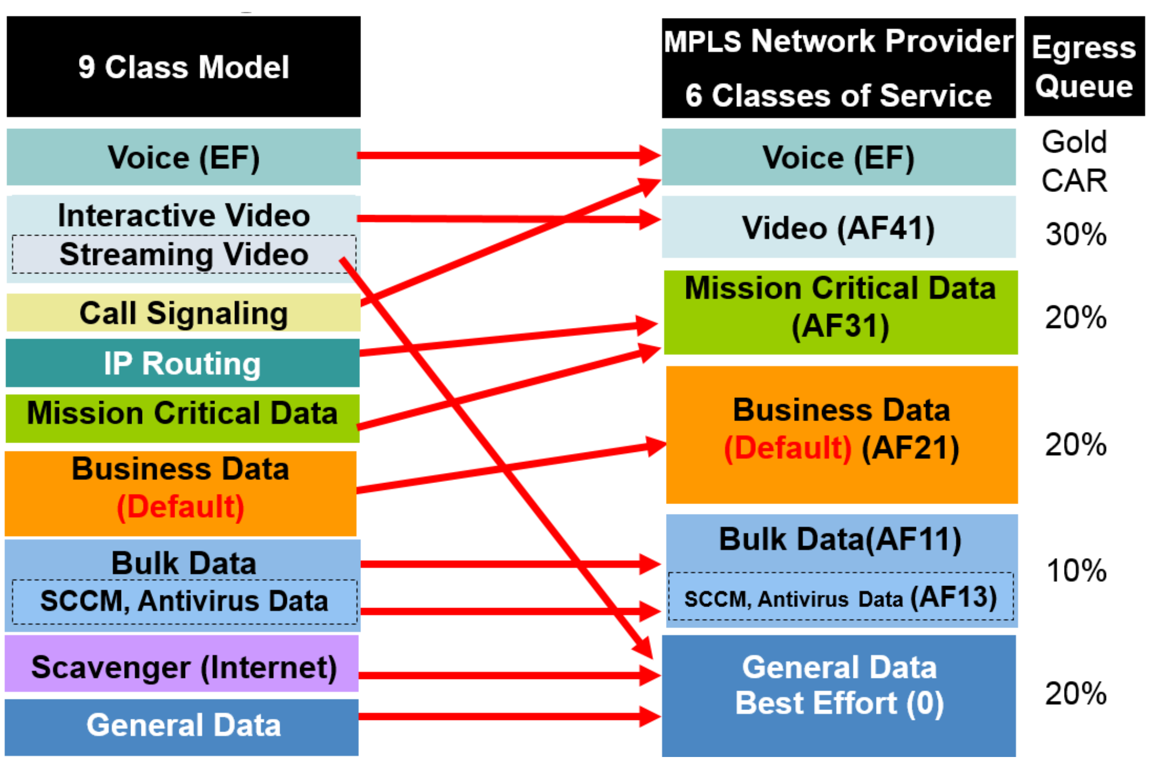

Figure 7. ASD QoS MPLS classification.

The case study evidence showed that the MBS initiatives successfully combined IT and MBS technologies, such as CoS, QoS, and high-speed data networks, with implementation practices supported in recent literature to support successful implementations. Whitten and Bentley (2007) provided a review of theories and successful system implementation approaches presented in recent literature. According to Whitten and Bentley's model of focuses for information systems implementation, there are three main focuses as business drivers: improving business knowledge, improving business processes, and improving business communications, all using network technologies as a technology driver.

Case study evidence also showed that the management of ASD recognized the growing interdependence between the data network and the continuity of manufacturing operations for the company. As implemented, the network is more reliable for ASD and TCS. ASD's strategic plan showed a strong commitment to the use of the network as a tool for increased manufacturing effectiveness and a greater ability to meet a growing product demand from customers.

There was a noted commitment from all levels of IT management and staff, including the CIO, technical director, network managers, and network engineers, to the success of the project. As a result of this commitment, the system implementation was successful, and management was able to navigate the risks of network outages during implementation. Network outages followed a strict change management process and required approvals from business leaders, IT leaders, and the technical team. By sharing the benefits of the MBS initiatives and including them in the IT strategic plan, management was able to create a strategic enablement approach to these projects. This approach aligned staff with the objectives and goals of the enterprise, executive management, IT department, and individual staff. The technical experts who carried out the system implementation itself formed strong working relationships with the key stakeholders within the business, as they were able to deliver on the technical promise of improved service.

Other case study evidence demonstrated that the equipment selected for the MBS initiatives was properly sized and specified in the planning phase of the MSDLC. The planning phase also included equipment that had been built based on IETF standards. Standards are a key part of technology management to ensure interoperability between components (Stallings, 2013). The project team ensured that all equipment would interface with equipment from WAN carriers, LAN hardware vendors, and computer operating system and software vendors, based on IETF standards for TE and MBS. During reviews of architecture designs, it was demonstrated that ASD selected components that followed interoperability standards. For example, the base network components supported TCP/IP as a protocol suite for the WAN and LAN.

A single network hardware vendor was chosen for all routers and switches to avoid QoS and CoS tagging issues that were prevalent with some switch manufacturers based on evolving industry standards. A single WAN carrier, with the ability to accept QoS markings from ASD into their network infrastructure's routing plan, was chosen. The configuration for traffic classification was standardized by ASD's network teams to avoid administrative network management complexities. This consistency in choosing components aligned to industry and internal standards provided ASD with greater ease of implementation and better service delivery across sites.

The mission statement of ASD is to "be the best in the eyes of our customers, employees, and shareowners," and the values of ASD include being customer-driven, delivering on promises, and striving for excellence (ASD, 2009). The implementation of the MBS initiatives achieved both the vision and mission by providing capabilities for the network to serve customer demands and successful implementation of the projects by IT as well as resulted in a more reliable network for daily use (ASD, 2009).

User satisfaction with the improved network performance was demonstrated by a reduction in reported incident tickets. Routine bursts of traffic did not prevent VoIP systems from completing critical calls, and key business systems that support manufacturing experienced less periods of slowness during operations. -The addition of MBS technology to the network created a huge advantage when network traffic was congested in non-critical traffic classes. There was a perception of increased productivity in the network based on the creation of the ability for sensitive traffic, such as VoIP, to be successfully delivered during traffic bursts.

Summary of Results

According to documentation, archival records, direct observations, and physical artifacts, IT and data networks are critical to the operation of ASD. The survivability of VoIP and critical business application traffic was a high priority within IT and was included in the IT catalog (ASBS, 2009). The enterprise quickly adopted the use of CoS, QoS, and high-speed networks to enable employees to communicate more effectively, increase productivity, and prevent manufacturing system outages. MBS enables these critical and fragile traffic types to be delivered during periods of network congestion, i.e., during the busiest times of the ASD work day. The MBS design positions ASD for the most efficient use of the corporate network infrastructure and enables the business to meet the increasing demands of customers for ASD products.

The IT management and employees of ASD value the relationship between technology, the ASD businesses, the MSDLC methodology, and communication with users (ASBS, 2009). The network managers encourage participation of the network engineers in decisions to improve systems and implement new technology. The author noted that ASD management recognized the three business drivers identified by Whitten and Bentley (2007) and aligned them to technology drivers, such as the database, software, interface, and network drivers, and that this alignment contributed to success in the project implementation.

Case study evidence showed certain benefits of the MBS initiatives as implemented by ASD. These benefits were enhanced survivability of key business system traffic, more reliable voice communications, fewer user perceptions of network problems, increased manufacturing uptime, better communication between employees through greater voice quality, enhanced traffic prioritization following a standard configuration, faster access to information across WAN, faster access to information across LAN, and a reduction in the number of user service complaints.

Information sharing is critical to the operations of a manufacturing organization in today’s competitive business environment (Chi et al., 2010). For businesses to rely on data networks and enterprise applications to meet customer demands and produce their projects, there must be a compatible technology environment with the design, capacity, support staff, and training that enables the maintenance of business operations while implementing technology improvements (Chi et al., 2010). Case study evidence demonstrated that ASD has done an excellent job improving its network infrastructure while taking into account user and technician needs. As a result, ASD is able to provide greater network performance to corporate users and enable higher productivity.

Chapter 5

Conclusions, Implications, Recommendations, and Summary

Conclusions

The successful project activities completed during the phases of MSDLC, specifically, the planning, analysis, design, implementation, and support phases identified by Whitten and Bentley (2007), demonstrate that the model is effective for the implementation of MBS in a global manufacturing enterprise. Although the author had to adjust the basic MSDLC model to align to the projects, the MSDLC model proved itself to be a proper and functional approach for deployment of MBS in the complex manufacturing organization. Based on these findings, described in Chapter 4, the author concluded that the Whitten and Bentley model is effective for MBS deployment in a global manufacturing enterprise.

The effective activities completed during the planning, analysis, design, implementation and support phases of the ASD MBS initiatives were aligned to the basic structure of the Whitten and Bentley (2007) MSDLC model. Other global manufacturing organizations can benefit by using the same methods when deploying MBS initiatives in their network infrastructure.

The goal of this study was to provide global manufacturing enterprises with a model for deployment of MBS services in corporate offices, manufacturing plants, and research laboratory environments. This goal has been met by the study, and, as stated, the framework follows the format of the MSDLC model with improvements to address the specialized needs of MBS implementations in global manufacturing enterprises.

Although a few exceptions were noted in Chapter 4, the Whitten and Bentley (2007) model was highly effective for deployment of MBS services at ASD. The overall effectiveness of the model for deployment of MBS across other global manufacturing enterprises has been validated through the case study research. The noted exceptions focus on the timing of the study and quickly maturing technologies, resulting in frequent technology reviews during the implementation phase of the project. These issues, noted during the ASD MBS initiatives, are representative of challenges faced by other global manufacturing enterprises. Many global manufacturing enterprises utilize common technology to build information systems and follow industry best practices to address common problems faced similarly across the manufacturing industry.

In the course of this investigation, the author focused on validity and reliability of the study. This was done by following the recommendations and case study research methods outlined by Yin (2009) and Woodside (2010). The deployment of MBS across office, manufacturing, and research laboratory environments is a strong point of the research study due to the standardization of the various needs of these types of locations. The results of this study are transferable, based on the comprehensive nature and scope of the research.

Implications

Documentation indicated that MBS technologies can be used to improve network performance and the overall user experience during times of congested network traffic in a global manufacturing enterprise. Case study evidence demonstrated the use of MBS technology development and implementation to improve network resilience, such as continued survivability of VoIP traffic in the event of high volumes of batch network traffic. This study also validates recent investigations that focus on the mission-critical nature of information systems and, specifically, data networks in global manufacturing enterprises.

The author has contributed to the body of knowledge by analyzing and demonstrating the use of the MSDLC model for implementation of MBS initiatives at ASD, an example of a global manufacturing enterprise. By using the MSDLC framework as defined by Whitten and Bentley (2007) and the single-case study methodology outlined by Yin (2009) and Woodside (2010), the author has conducted a repeatable case study of the implementation of MBS initiatives at a global manufacturing enterprise. The general phenomenon noted in the study, and implications noted through analysis of these phenomenon, support Yin's (2009) requirement for a single-case study report to provide knowledge through description and analysis. The case study provided a framework of specific steps that can be taken to implement MBS in a global manufacturing enterprise, an analysis of how MBS technology can be used to support better network performance at ASD, and research that can be used to develop MBS installations in manufacturing environments. The results of this study enhance MBS development in future implementations because the findings apply directly to global manufacturing organizations. This research is relevant to the MSDLC five-phase model, which requires technology managers to plan, analyze, design, implement, and support information systems in a prescribed approach, while aligning to the ASD mission and values to meet customer and employee demands for reliable and available IT resources (Whitten & Bentley, 2007).

Recommendations

This study identified current literature on MBS as technical in nature but as lacking in the area of application to global manufacturing enterprises. The implementation of MBS was viewed by ASD as constantly growing and evolving to meet customer and employee needs (ASD, 2009). Thus, technologies that help MBS to become more dynamic and flexible should be studied. Additional studies to further the flexibility of MBS technologies may further support the data presented in this case and the effectiveness of the Whitten and Bentley (2007) MSDLC model for the deployment of MBS technologies.

This study also focused on WAN and LAN MBS applications, but there are areas of opportunity in MBS for wireless and cellular networks. The emerging wireless and cellular network technologies, such as “Beyond 2020” or fifth-generation (5G) cellular technologies, carry greater capacity and potential for use in global manufacturing enterprises but will require MBS implementation to be used to full capacity. By researchers’ investigating companies with and without MBS implementations in the context of these emerging technologies, the functionality of MBS in high bandwidth wireless environments may become better understood.

Another recommendation for further inquiry involves the limitations of the QoS solution deployed during the ASD MBS initiatives. The QoS solution is static in nature and must be updated as the network changes and evolves. A study should be conducted to build or identify a technology that can make QoS implementation adaptable and that increases the effectiveness of the model for long-term implementation in dynamic networks based on the IETF TE model.

Summary of the Study

Global manufacturing enterprises face increasing demands for delivery of critical business processes and applications across data networks (Chi et al., 2010). MBS technologies provide these companies with a way to more efficiently deliver and prioritize traffic across high-speed networks. This study investigated a framework to effectively manage ASD network traffic to increase reliability, dependability, scalability, and availability. These enhancements are required by ASD for operations in support of the corporate mission of a converged network that carries voice traffic (Namee, 2009). MBS technology offers network capacity planning and management as distinct benefits (Pathak et al., 2011).

ASD is typical of a global manufacturing enterprise. Headquartered in Piscataway, New Jersey, ASD is a diversified global manufacturing enterprise with over 60,000 employees and business sectors, including TCS, RS, B&K, and WABCO, respectively focused on commercial and residential air conditioning, plumbing fixtures, and vehicle control systems. Manufacturing plants, corporate offices, sales offices, and research facilities compose the global footprint of the enterprise.

Communications equipment at ASD locations across the globe are not always capable of ensuring seamless traffic flows for dependable, reliable, scalable, and available network applications and services (ASBS, 2009). In periods of bursty network traffic, the mission-critical production environment at ASD is exposed to potential failures without the implementation of QoS and MBS. In addition the quality of voice traffic across the data network is limited by available bandwidth and bursty traffic classes.

In Chapter 1, the author presented a problem faced by many global manufacturing enterprises such as ASD in today's competitive business environment, namely, how to effectively manage ASD network traffic to accommodate ASD requirements for reliability, dependability, scalability, and availability. MBS technologies offer benefits such as ease of capacity planning and management, support for converged networks, and cost effectiveness (Namee, 2009). However, opportunities to improve the interoperability and adaptability of QoS must be taken by companies that implement MBS (Pathak et al., 2011).

The goal of this study was to provide a model for global manufacturing enterprises to use when deploying MBS in their facilities and offices. Chapter 1 presented the significance and relevance of the study and included an overview of barriers and issues. Limitations and delimitations of the study were discussed, and the problem statement and research questions were provided, along with the definition of key terms used in the study.

The extensive review of literature in Chapter 2 provided the background for this investigation and documented the role of MBS within ASD. A historical review of the literature was presented, followed by research on the design and implementation of MBS strategies in global manufacturing enterprises as well as research on bandwidth management and flow performance management technologies. The literature was organized into several areas of traffic management technologies, including QoS, IntServ, DiffServ, CBR, MPLS, hybrid architectures, GMLS, IETF RFC 3270, service-level metrics, delay, latency, jitter, throughput, loss, response time, utilization, bandwidth, MBS, network management, and VoIP. A summary of the body of knowledge was presented as well as a discussion of the contribution of the study to the field of information systems.

Chapter 3 presented the methodology used for this study. The case study format and the use of ASD's La Crosse, Tyler, and Piscataway offices as the unit of analysis were established. The author defined the implementation of the model utilized within this study, following the MSDLC method (Whitten & Bentley, 2007). This model was implemented using the five-phase approach of MSDLC, and specific procedures were covered. The validity and reliability of this study were preserved through the use of the literature review, case study format (Yin, 2009), and MSDLC framework.

Chapter 4 presented the results of the case study analysis. The chapter included a presentation of the information collection phase of the study and the key data sources. Through an analysis of the data, the author addressed the four propositions presented in Chapter 3:

1. The MSDLC method can be replicated and, as a result, supports the development of a design that other large global manufacturing enterprises can replicate and use in MBS initiatives (Whitten & Bentley, 2007).
2. The outcomes that result from the TCS MBS initiative will apply to MBS initiatives in other, similar enterprises.
3. Issues addressed in conducting the TCS MBS initiatives are typically encountered in other large-sized global manufacturing enterprises.
4. The MSDLC framework serves as a method for design, planning, configuration, and implementation of an MBS solution in a large global manufacturing enterprise (Whitten & Bentley, 2007).

The findings, presented in Chapter 4, demonstrate that MBS as implemented by TCS at ASD provides for greater network resilience, more efficient manufacturing, and increased system availability. Although the configuration for MBS services, such as QoS and CoS, can be complex in an enterprise environment, the author found that the project teams were willing to work within the complexities to provide increased performance for users, including benefits such as better VoIP quality, less delay and jitter in voice traffic, and improved reliability of critical applications. Whitten and Bentley's (2007) foundational information system elements for networking, including allowing system communications and network components for data capture, storage, and manipulation, were incorporated into the overall MBS implementation.

The conclusions of the case study research were presented in this final chapter. ASD documentation, archival records, direct observations, and physical artifacts all showed an IT staff and user population that were dedicated to service improvement. MBS technologies can increase the reliability, scalability, dependability, and availability of the ASD network. This research is timely because it aligns with an emphasis on QoS implementations by commercial WAN carriers to gain greater network efficiency from end to end. The implications of this research were presented, and the contributions of the study to the body of knowledge were discussed. Recommendations for future research were provided, along with specific suggestions, including the need for a study to make QoS implementation adaptable.

Appendix A

Letter of Permission from American Standard Companies

AMERICAN STANDARD COMPANIES

Business Services
3600 Pammell Creek Rd.
La Crosse, WI 54601

To Whom It May Concern:

This letter of permission certifies that Nate Melby, an American Standard (ASD) Employee and Ph.D. Student at Nova Southeastern University, may conduct a scientific case study using qualitative research methods at American Standard for use in his Ph.D. dissertation.

No information of a proprietary nature regarding ASD's products, or other sensitive information (vendors used, products, etc.) will be included. The scope of the dissertation work, for the purposes of this research, is outlined in the dissertation idea paper (copy attached).

The information that will be included pertaining to ASD will be as follows, with greater detail outlined in the idea paper itself:

- The survey instrument used to gather information (administered within ASD)
- A study defining specific types of network traffic existing on the network
- Prioritization and classification of these types of traffic
- Development of a model for traffic classification based upon study results
- Public information from financial statements
- Quality of Service (QoS) usage

At regular intervals during and upon completion of the study, the results of the study will be made freely available to ASD for its unrestricted use. These results will then be used by the researcher, along with additional research from the body of literature, to develop a higher-level bandwidth management framework for manufacturing organizations and developed into his full Ph.D. dissertation the content of which shall likewise be free for ASD to use on an unrestricted basis. The researcher agrees that ASD shall have the right to review his dissertation at reasonable intervals during its preparation and prior to its publication and further agrees that should such review result in ASD's belief that it contains information which is proprietary to ASD or information which is presented in a manner that is of concern to ASD, the researcher will remove such information from the dissertation or modify its presentation such that it resolves ASD's concerns. ASD, for its part, agrees not to exercise such right other than in good faith and with reasonable basis for doing so.

David C. Skrove 31/oct/05	31 OCT 05
American Standard Representative (Sign)	Nate Melby (Sign)
David C. Skrove	Nathaniel J. Melby
American Standard Representative (Print)	Nate Melby (Print)

Appendix B

Acronyms

ASBS	American Standard Business Services
ASD	American Standard Companies
ATM	Asynchronous Transfer Mode
B&K	American Standard Bath & Kitchen
BA	Behavior Aggregate
BGP	Border Gateway Protocol
CBR	Constraint-based Routing
CBWFQ	Class-based Weighted Fair Queuing
CIO	Chief Information Officer
CoS	Class of Service
COTS	Commercial Off-the-Shelf Software
CPU	Central Processing Unit
CRM	Customer Relationship Management
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
DDoS	Denial of Service
DiffServ	Differentiated Services
DLTP	Data-Link Transport Protocol
DSCP	DiffServ Code Point
DWDM	Dense Wavelength Division Multiplexing
E-1	European-1
EBGP	External Border Gateway Protocol
ERP	Enterprise Resource Planning

ETSI	European Telecommunications Standards Institute
EU	European Union
FR	Frame Relay
GMPLS	Generalized Multiprotocol Label Switching
GoS	Grade of Service
HVAC	Heating, Ventilation, and Air Conditioning
IBGP	Internal Border Gateway Protocol
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IntServ	Integrated Services
IP	Internet Protocol
IT	Information Technology
ITU	International Telecommunication Union
ITU-T	International Telecommunication Union-Telecommunication Standardization Sector
LERs	Label Edge Routers
LLQ	Low Latency Queuing
Mbps	Megabits per Second
MBSs	Managed Bandwidth Services
MCP	Multi-constrained Path
MIB	Management Information Base
MPLS	Multiprotocol Label Switching
MSDLC	Modern Systems Development Life Cycle
NREN	National Research Education Networks
OSI	Open Systems Interconnection

OSPF	Open Shortest Path First
PBM	Policy Based Management
PHB	Per-hop Behavior
PIB	Policy Information Base
QoS	Quality of Service
RFC	Request for Comments
ROI	Return on Investment
RS	Residential Systems
RSVP	Resource Reservation Protocol
RTP	Real-Time Transport Protocol
SLA	Service-level Agreement
SNMP	Simple Network Management Protocol
SPF	Shortest Path First
T-1	Terrestrial-1
TCS	Trane Commercial Systems
TEP	Traffic Engineering Process
ToS	Type of Service
VoIP	Voice-Over-Internet Protocol
VPN	Virtual Private Network
WABCO	Westinghouse Air Brake Company
WAN	Wide Area Network
WFQ	Weighted Fair Queuing

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