Enhancing Service Providers Reliability by Mitigating Supply Chain Risk: The Case of Telecommunication Networks

by

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Abstract

Service providers rely on the continuity of their service to sustain their businesses. While at first glance it may seem that service providers are not as dependent on their supply chain as product companies are, a closer look of some relevant systems shows that a stable and resilient supply chain is a key for both maintaining service and growing it. A wireless network provider which does not have spare parts in place to maintain existing cell sites will see an increase in outage duration and, thereby, customer churn. A cable/satellite service provider which does not have the equipment at the right place and in time to expand to a new market will see competitors capturing customers. In order to eliminate or at least mitigate these types of business risks for service providers, a transformation of the Time to Recovery (TTR) / Time to Survive (TTS) framework is shown to fit the service domain. TTR represents the time it takes for a supply chain system to recover from a disrupted supplier. TTS represents the time a supply chain system can continue to operate while its sources of supply are disrupted. The key metric which is introduced is *value of service*, which allows us to measure the actual lost value as a result of service disruptions.

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1 Introduction

On Friday night, March 17, 2000 a fire hit a Phillips Fabricator in Albuquerque, New Mexico and disrupted production at that site for nine months. At that time, two major cellular device manufacturers, Nokia and Ericsson, were dependent on the New Mexico fabricator to supply critical parts for their hand-sets. By the time the smoked cleared, Nokia was able to avoid disruption to its customers by capturing alternative sources for their critical parts. Ericsson on the other hand, wasn't able to obtain secondary supplies as they were all captured by Nokia. As a result, Ericsson had to report losses of $500M for that quarter (Sheffi 2005).

On October 8, 2011, during the Thailand flooding, the 10-meter-high water blockage in the Nikom Rojna industrial estate collapsed, flooding many manufacturing plants, including 75% of Western Digital (WD) Hard Drive production. WD's biggest competitor, Seagate, was barely affected by the flooding because of the location of its productions sites. As a result, Seagate captured the market lead and has held it ever since the event- See Figure 1 - HDD market share before and after the Thai flooding (Taylor 2012).

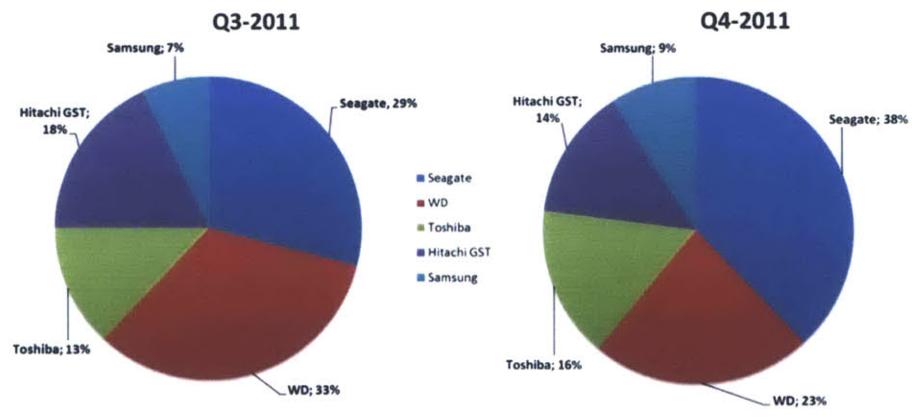

Figure 1 - HDD market share before and after the Thai flooding[1] (Taylor 2012)

In the aftermath of Japan's earthquake, top mobile telecom equipment manufacturers Ericsson and Alcatel Lucent (telecom 1st tier suppliers) raised a concern about supply of components in a sector which was already hampered by shortages[2] (Pollard and Virki 2011). In the Thai

[1] http://news.techeye.net/business/hdd-business-to-become-mexican-standoff
[2] http://www.balkans.com/open-news.php?uniquenumber=97732

flooding in 2011, 2nd and 3rd tier service suppliers such as Flextronics suffered $100M of extra costs, creating an immediate impact on the downstream supply chain[3] (JOC Staff 2012). These events showcase the impact of supply chain disruptions on the business operations and the underscore the need to mitigate the vulnerability of the business to such risk. Service providers procure items and components from similar sources and are exposed to the same type of risk. The following article builds upon the Time to Recovery (TTR) method presented in HBR "from superstorms to factory fires" (Simchi-Levi, Schmidt, and Wei 2014) and combines it with the Time to Survive (TTS) methodology (Simchi-Levi, Wang, and Wei 2013). TTR represents the time it takes for a supply chain system to recover from a disrupted supplier. TTS represents the time a supply chain system can continue to operate while its sources of supply are disrupted. On top of that, this paper explores for the first time the effect such disruptions have on service providers, where the direct impact of lost service is not as clear as lost sales. In order to evaluate the effect of such disruption on the business, a new term is defined – *Value of Service* - which represents the dollar value of having the service provided operational and available at a given time period.

1.1 Project Objectives

The objective of this article is to present a reusable methodology which allows any service provider to evaluate vulnerabilities in its supply chain and facilitates development of mitigation plans. The model is built upon a comprehensive Time to Recovery (TTR) / Time to Survive (TTS) analysis of the Network SC and is designed to be robust to any type of supply disruption. In addition, the project was intended to gain important insights in the 2nd and 3rd tier supplier network and to mitigate risks, if any were discovered.

1.2 Problem Statement

The company is the largest mobile network operator in the US, currently serving over 100 million retail customers and continuing to expand its coverage and technology. With this

[3] http://www.joc.com/international-logistics/global-sourcing/thailand-floods-cost-flextronics-100-million_20120121.html

intensive growth, the Network Supply Chain (SC) is becoming more globally extensive. The growing complexity raises the need to evaluate the vulnerability of the SC to possible supply disruptions, the time to recover from these disruptions, and the effect on end consumers.

1.3 Project Scope

The project focuses on developing a reusable model which can be applied on any modular service system. The TTS model is built in a method which allows straight forward expansion to any type of service system configuration and the TTR analysis follows the same methodology for any supply chain map. Yet, in order to focus the project explored only the supply chain of a single technology. Thus, the case study presented as part of the project represents a breakdown of a single technology.

1.4 Project Approach

The methodology consists of four stages:

1. Identify critical items in the service system.
2. Evaluate the *Value of Service* for each item
3. Calculate TTS for each item.
4. Identify the most critical items and calculate their TTR.

For each critical item, if $TTS \geq TTR$ there is currently no immediate risk[4] due to a supply disruption. If $TTS < TTR$ then the difference between the two values is the time the service system is exposed. This is where the Value of Service comes into play:

$$Financial\ Impact = MAX[0, (TTR - TTS)] \times Value\ of\ Service$$

[4] This might indicate that the current inventory levels are too high

1.5 Thesis Overview

This document starts by giving an overview of risk assessment and mitigation literature up to date. From there the research follows the four step methodology presented in the project approach and builds upon the data discovered. The thesis concludes with two implementations of the analysis, one for a demand simulator and one for a thorough TTR/TTS analysis of a service provider.

2 Verizon Wireless Network Supply Chain

Verizon Wireless has two major and independent supply chain operations:

1) Supply chain for its retail products – Mobile phones, Tablets and Accessories and etc.
2) Supply chain for network infrastructure – Cell Towers, Data Centers, Switch locations and etc.

The retail goods such as mobile phones and accessories react as traditional consumer products when analyzing their risk and resiliency. This paper is concerned with the network infrastructure supply chain which is as large and globally extensive as the retail products supply chain.

2.1 Background of the Company

In 2000, Vodafone AirTouch and Bell Atlantic Corp. received regulatory approval to combine their U.S. wireless assets, Bell Atlantic Mobile and AirTouch Communications. This $90-billion joint venture began operations as Verizon Wireless on April 4, 2000[5]. Until 2014, Verizon Wireless operated as a joint venture between Verizon communications (55%) and Vodafone (45%). The company has over 101.2 Million retail connections, 71,852 employees, $75.9B Annual revenue in 2012 and the largest deployed 4G LTE network in the US. On September 2nd, 2013 Verizon Communications announced that an agreement had been made to buy Vodafone 45% holdings for $130B; this transaction closed in the first quarter of 2014[6].

2.2 The - Network Supply Chain

Operationally the company is separated into regions with each region fulfilling its own demand for network infrastructure. The two main sources of inventory usage are either for new projects or for maintenance. In new projects the following steps occur:

1) Ad-Hoc forecasts sent to vendors monthly
2) Purchase orders are sent to vendors
3) 1st tier Vendor Manufactures / Assembles parts in Factory

[5] http://www.verizonwireless.com/aboutus/company/story.html
[6] http://www.reuters.com/article/2013/09/02/us-vodafone-verizon-idUSBRE97S08C20130902

4) Parts are delivered to vendor DC (generally managed by a 3rd party)
5) Parts stay in the Vendor DC until they are pulled according to project needs
6) Projects pull Inventory from the regional staging facilities according to project progress

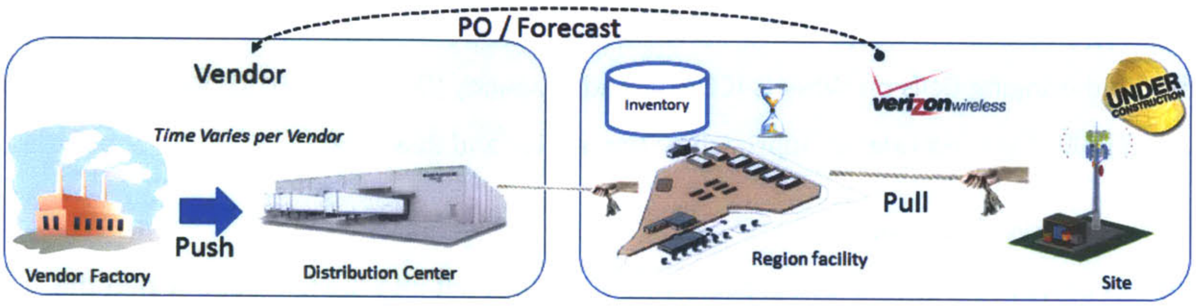

Figure 2 - Supply chain for new projects

For maintenance items the following steps occur:

1) Purchase orders are sent to vendor according to forecast or project requirements which include spare parts
2) 1st tier Vendor Manufactures/assembles parts in factory
3) Spare Parts are delivered to vendor DC (run by a 3rd party)
4) Spare parts are sent to the regions
5) Spare parts then remain in the regional facilities or stored in operational sites
6) Operational sites pull spare parts from their own inventory or from the regional facilities upon need

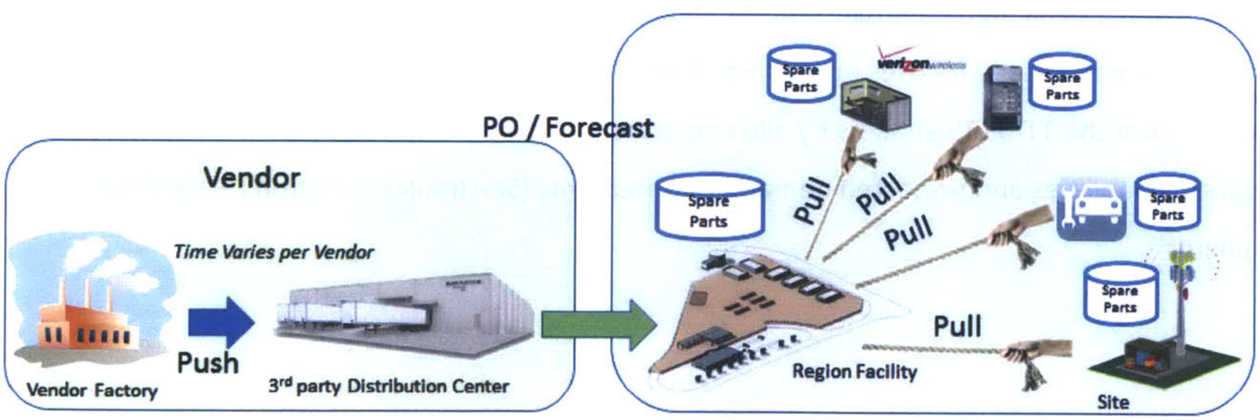

Figure 3 - Supply chain for maintenance items

2.3 The Company's Current and Future Risk Mitigation Process

The most recent major environmental disruption which Verizon had to deal with was Hurricane Sandy which impacted the Northeast and disrupted 25% of cell towers in its path (Svensson 2012). Verizon reacted immediately to the crisis and was able to recover its wireless network back to 100% capacity in less than two days (Svensson 2012) by fixing cell towers where possible, and bringing Cells on Wheels (COW) to add capacity (DeGrasse 2012). Verizon has two types of supply chain risk related approaches: Preventive and Reactive.

2.3.1 Preventive Process

Prior to this project, the preventive process was primarily built into the language within the contracts with suppliers and was managed by the sourcing team which was responsible for the contracts. This project allowed the company to enhance its preventive process leveraging the Value of Service and TTR/TTS methodologies established from the analysis and the findings in this article. Following the recommendations presented at the end of this article, it appears that Verizon is well positioned to roll-out an even more comprehensive risk mitigation process.

2.3.2 Reactive Process

Verizon's reactive process is very effective as seen during Hurricane Sandy. For example, when the storm hit the East Coast the entire organization focused on restoring wireless service and was able to minimize disruption and customer impact. The decision hierarchy in the organization for the reactive process is operationally executed by each region while receiving support from a dedicated command center which coordinates between the different regions. While this article mostly focuses on a comprehensive preventive process, the reactive process benefits from the TTR/TTS analysis by allowing a clear picture of current available inventory, supplier capabilities and projected demand requirements (See Implementation I – Demand Simulator)

3 Literature Review

With off-shoring and lean operations becoming more and more popular in the early 1990's, supply chain risks have become a much higher concern for global operations. Inventory and production models like Toyota's TPS and Just-In-Time require holding minimal amounts of inventory on hand, thus increasing the impact of a major supply chain disruption. Several models aimed at addressing these risks have been published in operations research literature in recent years. These models typically quantify the probabilities of events and assess their potential financial impact. The classical view of risk analysis seeks to separate the risk into categories such as environmental, geopolitical, financial, etc. Then using probabilities, financial impact values and weights, the models try to quantify the risk in each category. Finally, a supply chain map is required in order to find the expected risks and vulnerabilities according to the risk model.

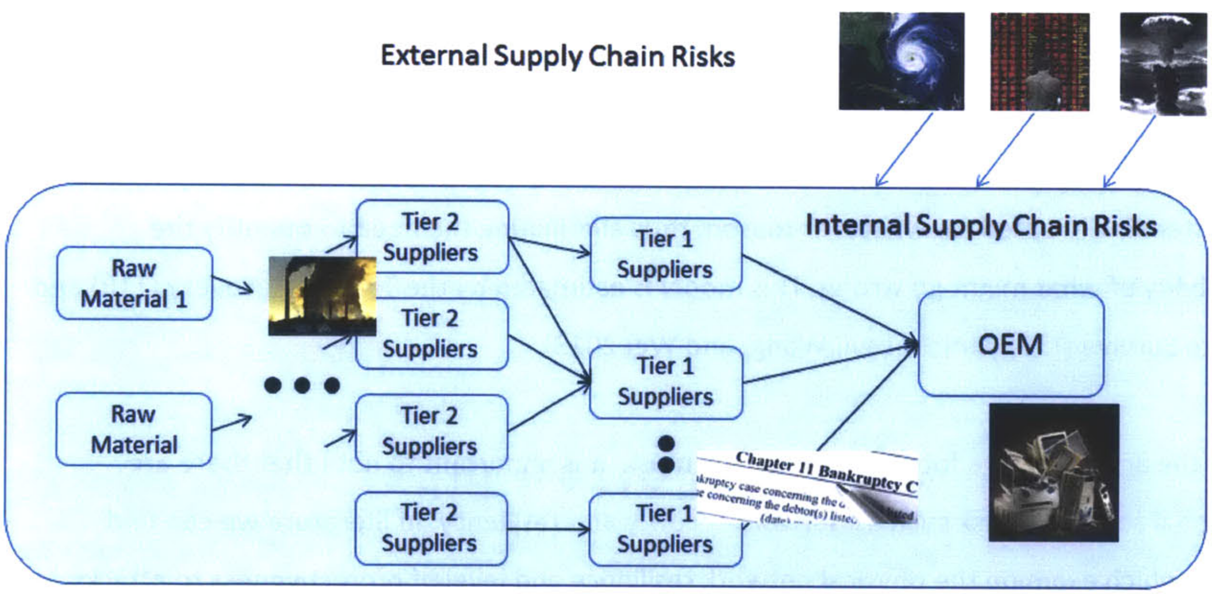

Figure 4 - Potential supply chain risks

3.1 Risk Assessment and Mitigation Frameworks in the Literature

The literature defines risk as "The potential for unwanted or negative consequences of an event or activity" (Rowe 1977). When assessing risk, threats are usually categorized into groups such as business risk, environmental, political, etc. The literature includes models and definitions which try to quantify the risks in terms of what can happen, what is the probability that certain

events will happen and what is the potential impact, severity or consequences. (Kaplan and Garrick 1981). This type of analysis is further developed into sub-classification of the risks and individual assessment and then aggregation to a full risk profile. (Fiksel and Rosenfield 1982).
A comprehensive risk analysis model for global strategic sourcing which brings the quantitative models into practice is presented by Brian Feller LGO/LFM 2008 (Feller 2008). Several risk mitigation methodologies have been researched and implemented in industry – such as demand-responsive supply chain, reduction of likelihood of disruptions, vertical supply chain collaboration for resiliency, detection methods, redundancy and flexibility approaches (Sheffi 2005).
A major challenge that is not addressed well by classical (probability and impact) risk models is the ability to handle rare events which are highly unlikely to happen, but have a potentially drastic impact. Such events are referred in literature as unknown - unknowns (David Simchi-Levi 2011) or Black Swans (Taleb 2007). In order to overcome this problem, a risk analysis which tries to eliminate the assumption-over-assumption approach for event probabilities is presented as the risk exposure index (Simchi-Levi et al. 2012). The model which this project is based upon views the supply system as a whole and asks what the financial impact is, if part of the system is disrupted for whatever reason, thus eliminating the need to quantify the probability of what might go wrong. This model is estimated by the Time to Recovery (TTR) and Time to Survive (TTS) (Simchi-Levi, Wang, and Wei 2013).

While the articles above focus on supply chain risk, it is important to note that there are additional sources of risk such as network security and resiliency. In literature we can find articles which examine the physical network resilience and level of protectiveness to attacks. For example, Hsin-Yi Tsai and Yu-Lun Huang present a wireless network risk assessment method (Tsai and Huang 2011). On a more rigorous aspect, NIST – the National Institute of Standards and Technology which works under the US Department of Commerce publishes specific guides for conducting risk assessments on network security (Blank and Gallagher 2012). These network security risks are not in scope for this project.

3.2 Case Studies and Risk Mitigation Practices in Industry

In practice, only a few companies adopted the new approaches for risk and resiliency assessment and have developed internal models, programs and disciplines to handle risk challenges. For example, Cisco has developed a Supply Chain risk management (SCRM) group which created an internal system to understand and manage risk associated with the supply of its products (Miklovic and Roberta J. Witty 2010). As part of this analysis, Cisco developed a crisis management map based dashboard that helps it handle crisis events in real time. The data for the dashboard is derived from an in-depth analysis of Cisco's supply chain and by identifying key nodes with potential high impact such as single source location or a single supplier with a relatively large footprint. In addition Cisco is focusing on critical components when narrowing down supplier sites to look at. Finally Cisco uses audit and reviews of suppliers as a tool to identify the potential time to recovery (TTR) (Miklovic and Roberta J. Witty 2010).

Another important aspect which was highlighted in a recent case study that was done in Ford Motor Company is that low-cost commodities are often overlooked by risk managers (Simchi-Levi, Schmidt, and Wei 2014). An extensive risk analysis was performed on Ford's supply chain, building on the Time to Recovery (TTR) approach. The research covered over 1000 of Ford's supply chain nodes and while most of the supplier sites were found to have no risk impact on Ford's profit, the "supplier sites whose disruption would cause the greatest damage are those from which Ford's annual purchases are relatively small" (Simchi-Levi, Schmidt, and Wei 2014). The TTR analysis allowed Ford to rebalance the risk mitigation efforts according to potential financial impact and not according to item cost.

Both Cisco and Ford are product based companies as are other similar examples that were reported in the literature. The financial impact analysis of the risk exposure in such companies is made possible by accounting for the potential lost sales of their product. This is the first challenge the present project had to overcome - how to quantify a financial impact of lost service as a result of a supply chain disruption.

4 Methodology

A service system, unlike a supply chain of consumer products, is more difficult to analyze. In the case of consumer products, the direct sales reflect accurately which items are material to revenue and profit and which are not. In service systems, the cause and effect relationship between certain disruptions and bottom-line financial results are not always obvious. The need to identify new ways to measure the risk of supply chain disruptions and their effects in service systems is the main motivation for the present project. The following methodology consists of four stages:

1. Identify critical items in the service system.
2. Evaluate the *Value of Service* for each item
3. Calculate TTS for each item.
4. Identify the most critical items and calculate their TTR.

4.1 Identifying Critical Items in the Service System

To identify the critical items for a system to operate, involvement of subject matter experts (SME's) is required. The SME's are typically engineers that designed, deployed or maintain the service system. Following the data acquired form the SME's, the items in the service system should be categorized in the following criticalities: (1-The most critical)

1) Critical to continue service – A back-up system/component doesn't exist (single point of failure)
2) Critical to continue service – A built-in back-up system/component exists
3) A back-up system/component
4) A component which is not critical but improves performance
5) A "nice to have" component (Helps in maintenance / monitoring the system)

4.2 Quantifying the Value of Service

In a regular risk analysis for off-the-shelf products, the financial impact of a supply chain disruption can be directly measured by the value of lost sales. For a service system such as a telecommunications provider this measurement is not so clear. This calls for a new term, which is defined here as *"Value of Service"*. This term encapsulates all the sources of revenue loss or costs that might occur as a result of a service disruption.

4.2.1 Setting up the Value of Service for a Network Provider

In order to evaluate the lost value caused by a service disruption we first need to understand the possible business implications that might be caused by such disruption.

A supply chain disruption for a service provider can lead to lost value such as:

- **Cost / Loss of Revenue as a result of network service disruption to existing customers.**
    - **Direct Loss of Sales** - Less revenue on pay-by-usage or refund to customers with monthly plans
    - **Higher Call Center Cost** - Higher volume of calls / complaints to call centers as a result of the networks' service disruption
    - **Brand Value** – Negative public relations implications that might drive away potential new customers
    - **Customer Churn** - Lost customers who decide to switch to a different service provider due to lack of service
- **Loss of revenue as a result of inability to expand to new markets or add capacity to existing markets.**
    - **Loss in Market Share** – Allowing competitors to gain new customers in new markets
    - **Customer Churn** – Customers who want to upgrade to new technology will go to competitors

- **Brand Image** - Not being in the right place at the right with the right technology will hurt the overall image of the company

Some of the metrics for Value of Service are hard to quantify, such as Brand Value. To overcome this, the following equation is introduced:

$$Value\ of\ Serivce = \#\ of\ Customers\ affected\ \times ARPU$$

The average revenue per user (ARPU) is the income an average subscriber generates in a given unit in time. The ARPU is typically calculated as the total revenue in a given time frame divided by the number of users[7] (Rouse 2007). Because ARPU is a straight forward calculation and it can be customized per service provider, the paper focuses on the potential number of customers per supply disruption. The number of customers represents all the implications of lost service:

Brand Value – The higher the number of customers affected the higher the buzz of the disruption

Customer Churn - Only customers who are affected by the disruption will potentially leave terminate the service

Loss of Sales – The customers who are impacted will be the one who will generate less revenue and we can assume that they represent potential new customers whom the company can't extend service to.

Call Center – Only a subset of the customers impacted are potential additional callers to the call centers.

[7] http://searchtelecom.techtarget.com/definition/average-revenue-per-user

4.2.2 Analyzing the Value of Service

A supply disruption can potentially lead to a shortage in items required for the ongoing operations of the service system. In order to identify the link between a supply chain disruption and the number of customers affected we need to look at the *critical items* in the service system, this can be done in the following 4 steps:

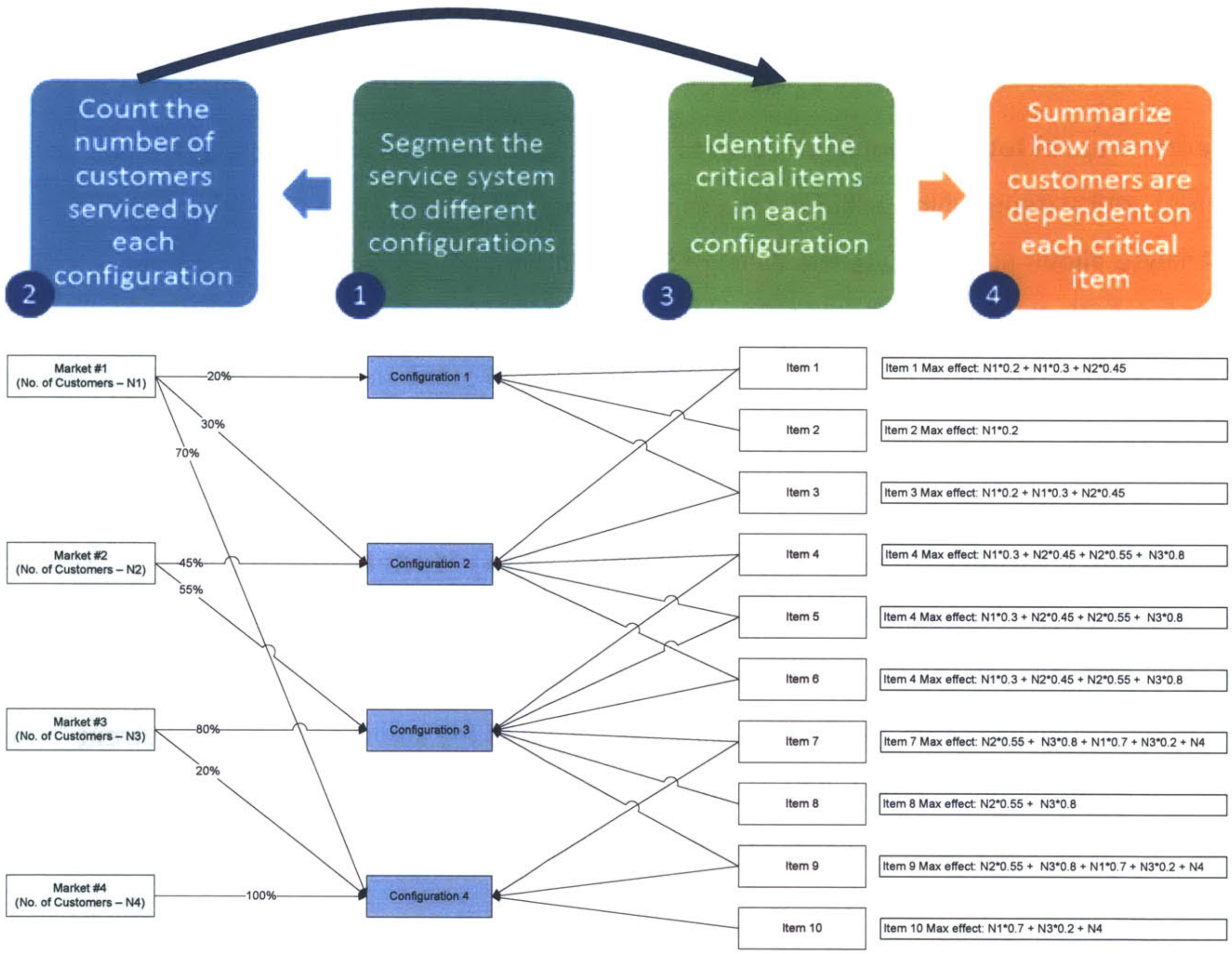

Figure 5 - Calculating the number of customers affected

These four steps allow us to tie the number of customers and critical items. We now know the potential "Value of Service" of each critical item in terms of the number of users and the financial impact by factoring in ARPU.

An illustration of the output of this 4 step process is given below: (All numbers in the table below are for illustration purposes and don't represent actual data)

Critical Item	No. of Customers (Thousands)	% of Total Customers
Critical Item 23	4,454	11%
Critical Item 29	15,868	39%
Critical Item 81	6,489	16%
Critical Item 101	32,658	80%
...	...	...

Table 1 - Number of customers affected by Item

The percentage of total customers will sum to beyond 100% since we are expecting to have different critical items which will affect the same customers and vice versa. The conclusion of this analysis allows us to capture the Value of Service in terms of percent of total customers who are potentially impacted by each item. For example, if the supply chain of item 101 from Table 1 is disrupted, the potential result can affect up to 80% of the service provider's customers.

4.3 Network Supply Chain – Time to Survive (TTS) Model and Analysis

Time to survive (TTS) is defined as the maximum time that the service system can operate during a supply disruption with no customer impact regardless of which supplier is disrupted (Simchi-Levi, Wang, and Wei 2013). In our case, we treat it as the amount of time the current usage levels can continue to be fulfilled from existing inventory, assuming the supply chain is disrupted. For service providers usage can come from several sources, but in general it can be clustered into two major sources:

- Maintaining existing service systems (**spare parts**): With Supply cut-off, spare parts may run out. This may cause a service disruption to existing users as cell towers can't be maintained at the same rate.
- Building new systems or upgrading existing systems to increase coverage and services (**new projects**): The rate at which new projects are constructed can be affected by a supply chain disruption leading to a decrease in on-boarding new customers or providing enhanced service to existing customers and impacting future revenue.

Thus, TTS can be calculated in the following way, per Item:

$$TTS = \frac{Average\ Inventory\ level}{Spare\ Usage\ Rate + New\ Projects\ Usage\ Rate}$$

4.3.1 Model Design

The model allows calculating TTS for each type of item in the service system. The simplicity of the model allows the user to focus on three figures:

1) The rate which the item is being replaced in the service system (Spare Usage)
2) The rate the item is needed for new projects
3) The average inventory level of the item in-house

Calculation of spares usage rate – The theoretical usage of each item is calculated according to the expected Mean Time between Failures (MTBF) of that item:

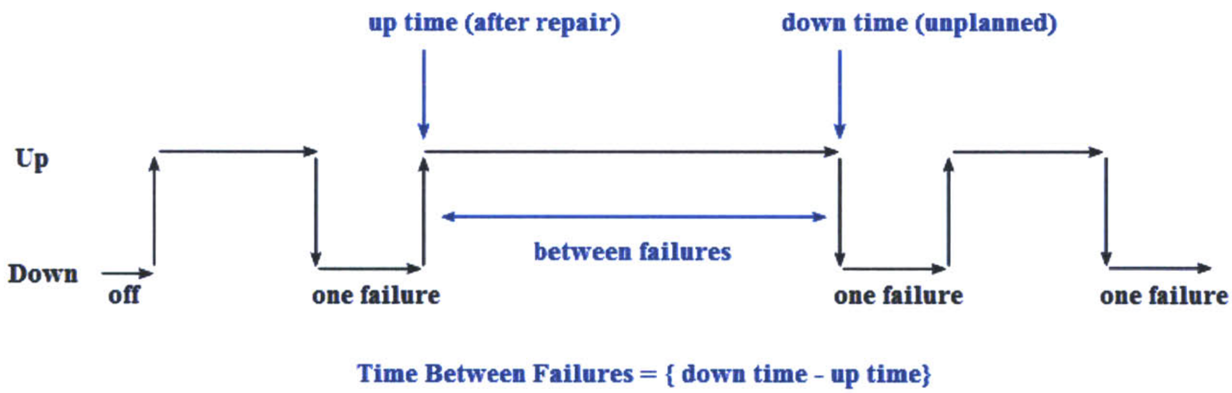

Figure 6 - MTBF[8]

The formal definition of MTBF is:

$$MTBF = \frac{\sum(Start\ of\ Downtime - Start\ of\ Uptime)}{Number\ of\ Failures}$$

MTBF is the expected value of a function$f(t)$, where $f(t)$ is the density function of the time until failure of a certain item. In our case, MTBF is used to predict the expected rate of failure of an item.

[8] http://en.wikipedia.org/wiki/Mean_time_between_failures

$$Spare\ usage\ rate\ (itemA, Weekly) = \frac{1}{MTBF(weeks)} \times Num\ of\ itemA\ deployed$$

If the system has been running for some time, an empirical approach can be taken, and instead of MTBF, we can use the actual number of items which were sent for repair on average per week as the usage rate per item.

Calculation of usage rate for new projects – Since the resolution of TTS is per item, additional work will be required to translate building new systems to single item usage rate. Yet, this work is similar to the one presented for the "Number of customers affected" calculation. In order to determine the usage rate per item we look at the different system configurations (CFG) and the demand forecast for each CFG. From there we cross-reference the configuration of items with the system demand. An example is provided in the following demand matrix:

	CFG - 1	CFG - 2	CFG - 3	CFG - 4	Demand for Item
Item 1	1	0	1	0	7 + 29 = 36
Item 2	1	1	0	0	7 + 12 = 19
Item 3	0	0	1	1	29 + 2 = 31
Item 4	0	1	0	1	12 + 2 = 14
Item 5	1	1	1	0	7 + 12 + 29 = 48
Item 6	0	0	0	1	= 2
...	..	..	..	..	..
Demand for Configuration	7	12	29	2	

Table 2 - Configurations and items weekly demand matrix

Because the demand forecast only represents a projected figure we need to take into account variability. A correct use of the TTS model allows the user to insert a percentile of expected demand. For example, if the user chooses to go with an average demand forecast he can insert a value of 0.5, while a value of 0.997 $(+3\sigma)$ will represent an extreme case of demand forecast where the rate of projected consumption of items for new projects is 3σ above the projected mean.

Calculation of Average Inventory – Because Inventory levels tend to fluctuate between orders (see Figure 7 - A typical inventory level annual behavior), just taking a snapshot of the inventory level might provide a misleading view of inventory status – for example, just after or before a replenishment the inventory level will either be artificially low or artificially high, thus biasing the TTS model results accordingly.

Figure 7 - A typical inventory level annual behavior

Therefore, the inventory level for the TTS Model should be calculated as the average inventory from several snapshots[9] taken from inventory reports. Observe the inventory levels at various points to ensure average inventory is not biased (Cachon 2013). For example in Figure 7 - A typical inventory level annual behavior where the lead time is about 4 weeks, so by choosing four continuous snapshots which are 2 weeks apart the result is likely to be a reliable average inventory value.

Figure 7 - A typical inventory level annual behavior also illustrates important phenomena regarding the timing of the supply disruption. If the supply disruption occurs in week 7,13,23,32 or 48 (just before replenishment) the impact will be much greater than in week's 9, 15, and etc.

[9] If an information system exists in the organization that allows continuous monitoring of the inventory levels, then taking the average inventory out of it is the best practice.

(just after replenishment). In order to plan for these worst case scenarios, the TTS model is adjustable to calculate the TTS according to a configurable inventory level projection which includes values other than average. Specifically, the TTS model presented allows the user to choose a specific percentile of inventory level to include in the calculation. For example, setting the percentile to be 0.003 (-3σ) then the model assumes that with a 99.7% confidence the inventory level required to survive at the time of disruption will be higher than the actual inventory → TTS will be equal or higher with 99.7% probability.

Once we have the following values for each item – *Spare Usage, New Project Usage and Average Inventory level,* TTS can be calculated.

4.3.2 Data Collection and Analysis

Reliable and periodic data collection for the TTS analysis is key for continuous monitoring of the in-house inventory risk. The TTS data should be updated on a monthly basis as inventory levels change, new projects arrive, and forecasts change. For the data collection stage, the following sources should be monitored when collecting data:

Configurations (CFG's) of the service systems – Service systems are composed of several items which are sourced from a wide range of suppliers (either from the 1st or 2nd tier). A complete list of configurations and number of items per configuration is required. Furthermore, as technology changes, substitute items should be updated in the model when a configuration change occurs. The configuration data may be found in the following units in service organizations: Sourcing, Technical Maintenance, and Engineering. If the data is not captured in the organization, it can usually be found in Purchase Orders (PO).

Forecast per configuration – The forecast of new projects and the configurations which will be used is continuously updated as time progresses. The data can be found in an infrastructure planning department and from actual operational units. It is important to look not only at the amount of new projects planned, but also at the expected *ratio* of configurations designated to be built in the new projects.

Inventory levels – The inventory levels are monitored in most organizations via a designated enterprise information system. Yet, most of the information systems capture a current snapshot of the inventory and not historical data. Therefore, a bi-weekly snapshot of the data is recommended to perform a relevant the average inventory analyses.

Failure rate of items in service – MTBF of items can be either taken from the engineering unit of the organization or directly from the vendor of the item. Actual failure rates should be captured from the technical maintenance teams which monitor the items sent for replacement.

4.3.3 Model Results and Conclusions

The following table is an example of TTS model results: (All numbers and items in the table below are for illustration purposes and don't represent actual data or actual products)

Item ID	Item Name	Average Inventory level (Spares)	Average Inventory level (New projects)	MTBF Usage Rate (Weeks)	Spare Usage (Weeks)	New Project usage (Weeks)	TTS (Weeks)
ABX001	Analog display	45	88	27	52	37	**2**
ABN002	Analog circuit	65	214	12	23	37	**5**
GHY456	Grounding unit	234	243	14	14	39	**9**
KJU879	Circuit Breaker	654	532	20	20	28	**25**
PFR934	Power Filter Unit	34	125	8	8	28	**5**
JKI984	Connector J984	23	311	12	12	27	**9**
JKI990	Connector J990	432	122	17	17	57	**8**
JKI768	Connector J768	54	111	20	20	69	**2**

Table 3 - Example of a TTS model results

Table 3 represents a typical result of a periodic TTS analysis results. The TTS result defines the length of time the service system can continue to operate and grow at the same rate it is currently operating when a supply chain of a certain item is disrupted. For example, the Power Filter Unit – PFR934 has a TTS of 5 weeks, thus if the vendor who supplies PFR934 will not be able to supply this item for whatever reason, the service system can continue to operate as-is up to 5 weeks.

While we see relatively high (25 weeks) and low (2 weeks) TTS results, this data on its own is not sufficient to understand the risk factor. The complementary data we need in order to actually assess the risk of the item is how many potential customers may be impacted (Value of service), how critical the item is to the system, and the Time to Recovery (TTR) of this item. For example, the TTS of item ABX001 (Analog display) in our case is 2 weeks, yet, an analog display might only be a technician user interface which is only used in rare cases and has no direct effect on the end customer. On The other hand, item JKI990 (Connector J990) might be a critical connector which is essential for the system to continue to operate and it exists in almost all service systems configurations. Thus, even though item JK990 has a comparably higher TTS, we will still continue our risk analysis with this item before we look at item ABX001.

An additional important note which needs to be taken into account is the bundling of inventory dedicated to projects with inventory dedicated to spares. Assuming a supply chain disruption is temporary, the impact of an immediate service disruption as a result of lack of spare parts far outweighs the immediate impact of a delayed project. Furthermore, in practice at the time of crisis, new project inventory becomes available for spare replacement. Therefore, the model assumes that it will deplete new project inventory when it runs out of spare inventory.

4.4 Network Supply Chain – Time to Recovery (TTR) analysis

Time to Recovery is defined as the time it takes for a supply chain node to fully recover after a disruption (Simchi-Levi et al. 2012). The recovery time can either be the time it will take the supplier which was disrupted to recover on its own (i.e. moving production to another site) or by finding an alternative supplier to source compatible items.

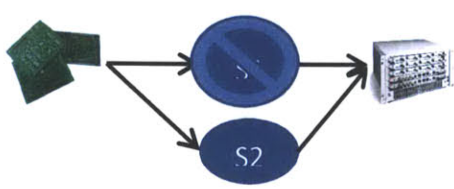

Figure 8 - Replacing a disrupted supplier

TTR requires a comprehensive analysis of an item's Bill of Material, 1st, 2nd and 3rd tier supplier's data, and transportation routes. Therefore it is suggested narrowing the TTR analysis and focusing only on items that have the following attributes:

- **High Impact** – Percentage of customers potentially affected
- **Critical to the System** – An item that will impact service levels if not available
- **Low TTS** – An item that doesn't have comparable redundant inventory levels

It is important to note that cost of the item is a significantly less important factor in the risk analysis in comparison to the three mentioned above. Furthermore, any item that is either *High Impact* or *Critical to the System* and has *Low TTS* presents a considerable potential risk and should be further explored in a TTR analysis.

The TTR analysis is composed of the following stages:

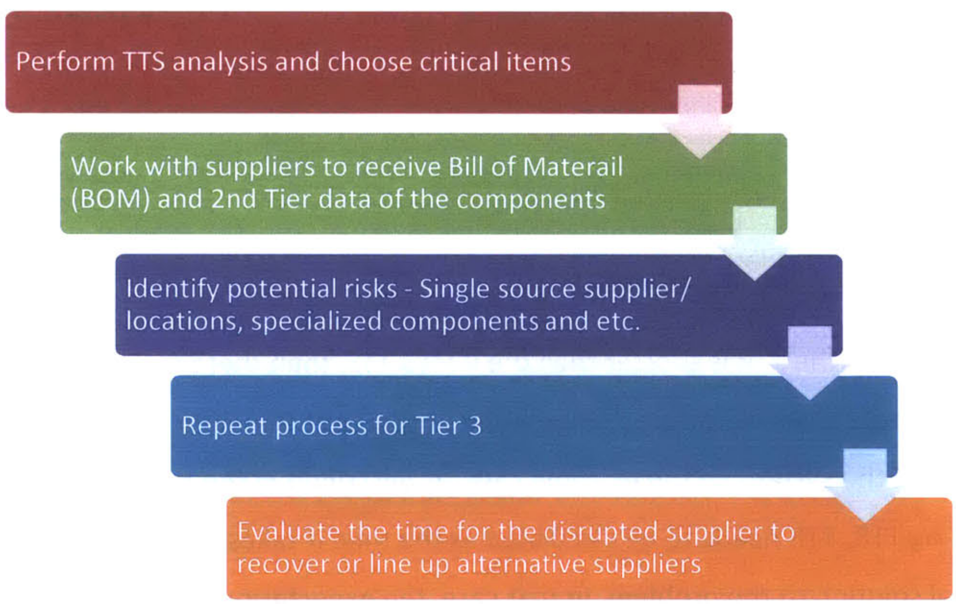

Figure 9 - TTR stages

The TTR of each supplier will be determined by the time measurement evaluated in the final stage of Figure 9 - TTR stages. In order to reach a time measurement for TTR the following methodology should be performed:

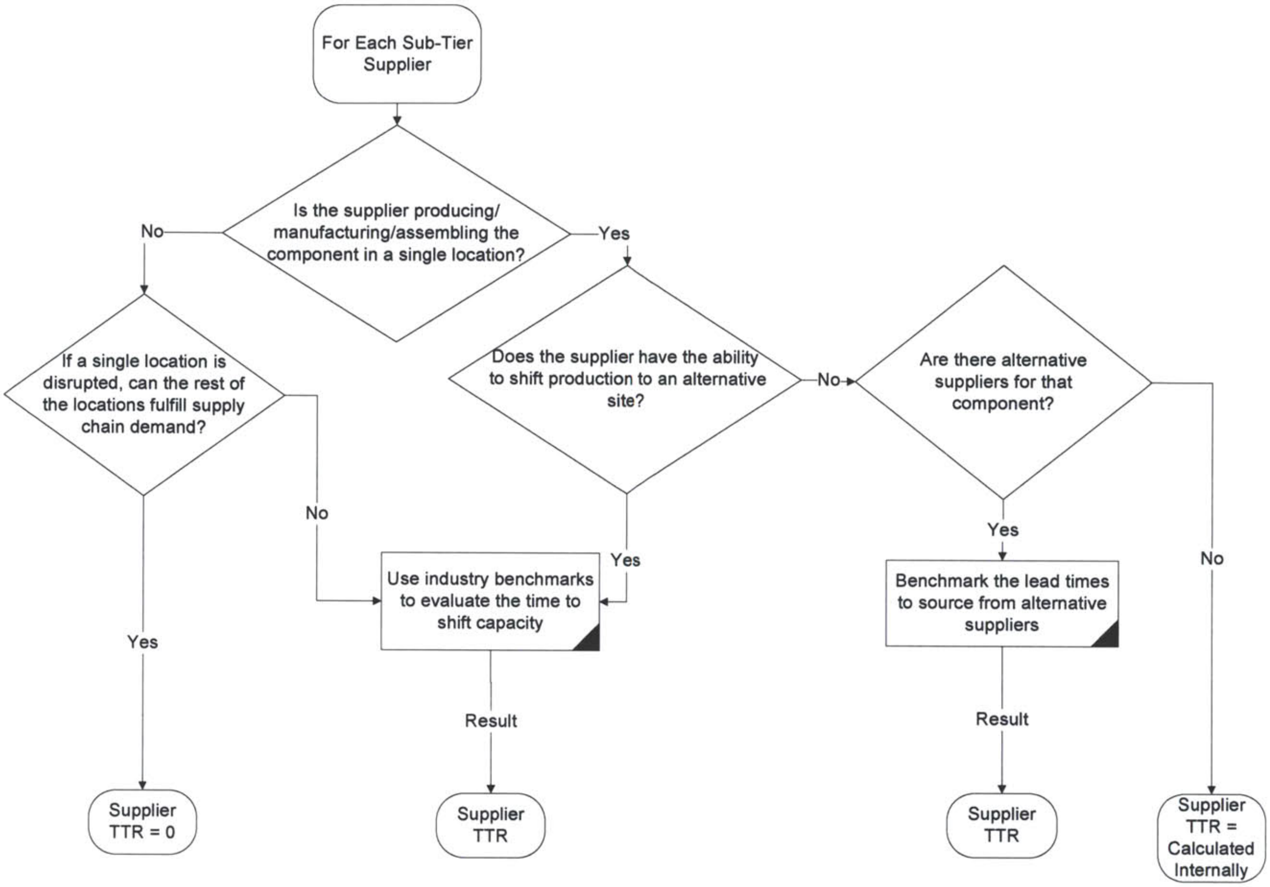

Figure 10 - Evaluating TTR

In case the supplier TTR is zero, or the TTR is shorter than the item's TTS, then there is no issue. If the TTR of any supplier is longer than TTS of the item, then the difference between the two is the potential exposure time of the system. In the extreme case, as described in the bottom right in Figure 10 - Evaluating TTR, TTR needs to be calculated as the time it takes the supplier to come up with an internal solution to the problem. In that case, the expectation is that the item's TTR will be comparably high, and entail a serious risk concern which needs to be specifically addressed.

4.4.1 Data Collection and Analysis

Data collection for a TTR analysis is a challenging task as it requires suppliers to share information about their internal operations. The approach to gather the data can be done by building trust and cooperation between the organizations and ensuring the supplier that there is no intention to vertically integrate into its business, thus sourcing directly from upstream suppliers. The following questionnaire was presented in the HBR article From Superstorms to Factory Fires(Simchi-Levi, Schmidt, and Wei 2014) and demonstrates the type of questions that need to be queried from suppliers to evaluate their TTR:

Assessing Impact? Use a Simple Questionnaire

The first step in assessing the risk associated with a particular supplier is to calculate time to recovery (TTR) for each of its sites under various disruption scenarios. Companies can develop a simple survey to collect key data, including:

1 SUPPLIER
- Site location (city, region, country)

2 PARTS FROM THIS SITE
- Part number and description
- Part cost
- Annual volume for this part
- Inventory information (days of supply) for this part
- Total spend (per year) from this site

3 END PRODUCT
- OEM's end product(s) that uses this part
- Profit margin for the end product(s)

4 LEAD TIMES FROM SUPPLIER SITE TO OEM SITES
- Days

5 TIME TO RECOVERY (TTR)
The time it would take for the site to be restored to full functionality
- if the supplier site is down, but the tooling is not damaged
- if the tooling is lost

6 COST OF LOSS
- Is expediting components from other locations possible? If so, what is the cost?
- Can additional resources (overtime, more shifts, alter-nate capacity) be organized to satisfy demand? If so, what is the cost?

7 SUPPLIER RISK ASSESSMENT
- Does the supplier produce only from a single source?
- Could alternate vendors supply the part?
- Is the supplier financially stable?
- Is there variability in perfor-mance (lead time, fill rate, quality)?

8 MITIGATION STRATEGIES FOR THIS SUPPLIER-PART COMBINATION
- Alternate suppliers
- Excess inventory
- Other

Figure 11 - Questionnaire to assess supplier's TTR (Simchi-Levi, Schmidt, and Wei 2014)

The data should be collected, captured, and updated in a per item basis. The TTR analysis is performed per item, according to the portfolio of suppliers and sub-tier suppliers of the item's BOM.

4.4.2 Results and Conclusions

The result of a TTR analysis is the time it will take a supplier to recover from a disruption in a single site. The result is compared directly with the TTS of the item this supplier is supplying (or a component which belongs to an item).

$$Exposure\ time = \ MAX[0, (TTR_A - TTS_A)]$$

If the result of this exposure time is zero then from a risk perspective this item is safe for the time being. If the exposure time is greater than zero then the result is the time which any type of potential disruption for this specific supplier can cause a service failure and potentially impact end customers.

In order to understand the full impact of such a disruption, the value of service should be added to the equation, resulting with the following financial impact:

$$Financial\ Impact = MAX[0, (TTR_A - TTS_A)] \times Value\ of\ Service_A$$

$$\downarrow$$

$$Financial\ Impact = MAX[0, (TTR_A - TTS_A)] \times \#\ of\ Customers\ affected_A \times ARPU_A$$

5 Implementation I – Demand Disruption Simulator

We define two major types of business disruptions:

Supply disruption – In this kind of disruption the supply of an item or a component is limited due to an internal or external event. For example, the Thai flooding created a major shortage in the personal hard drive market as 40% of all hard drives worldwide are produced in Thailand (Lefkow 2011).

Demand disruption – A demand disruption unlike a supply disruption happens when the service system itself is affected by an internal or external event. When such an event occurs, the usage rates of items in the service system can significantly increase and inventory levels are depleted. For example, Hurricane Sandy impacted 25% of cell towers in its path, causing a massive requirement for spare parts to be sourced (Svensson 2012).

A slight expansion to the TTS analysis as presented in Section 4 allows a service provider to plan for such a disruption prior to it occurring and pre-estimate the amount of items that need to be sourced.

The method to achieve a pre-estimate is the following:

1) According to the disaster type, estimate the number of Cell sites which will be impacted according to either benchmarks or actual data
2) Using the cross matrix of configurations vs. items developed for the TTS model and the ratio between configurations let the model calculate the impact per item based on the estimate from step 1
3) Adjust the average inventory levels in the TTS model according to the results from step 2

These three steps will results in two types of Items:

Items Type A - Inventory levels remain positive after the adjustment – For items of type A, there is no need for immediate sourcing, as the current inventory can fulfill the additional need.

Yet, internal transportation will be required for these items, TTS is impacted and will require reevaluation of future risk for new projects and infrastructure expansions.

Items Type B – Inventory levels become negative after the adjustment – these items are a major risk as we can expect that competitors are seeking to source them as well. Here the competitive advantage the demand simulator creates comes into play – the service provider will have knowledge about estimated shortage of these items even before the event hits. Instead of waiting to check the results in the field, the service provider can secure its supplier's inventory and capacity of items B, before its competitors react.

The following figure represents a user interface for the simulator as developed as part of this project. The simulator allows the user to simply enter the model estimates of cell sites impacted as a result of an anticipated natural disaster:

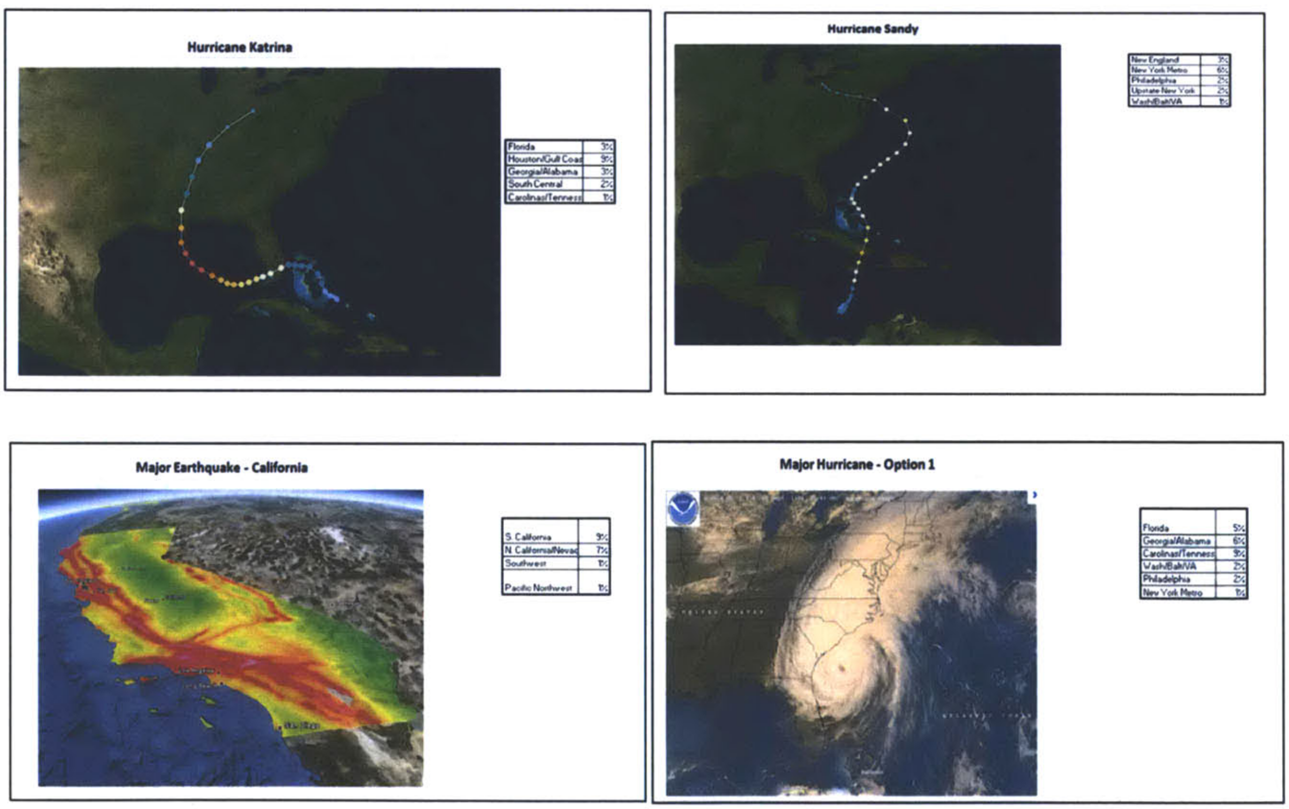

Figure 12 - Demand Simulator

The implementation of the demand simulator allows the service provider to plan not only for service or demand disruption, but also for both. For example, if a natural disaster is expected to impact an area which contains both suppliers and customers the demand simulator will allow planning for both. Specifically, the model will generate the updated TTS values of the items sourced from the disrupted supplier adjusted for the peak in demand; then a regular TTR analysis can be performed on the supplier as described in Part 4.3.

To summarize, the Demand simulator allows the service provider to plan ahead for a potential crisis, either before it happens or as an immediate response.

6 Implementation II – Case Study – Risk Analysis for – ISP-A

The following implementation is a practical example of the usage of a TTS/TTR analysis for a service provider; the data in the example does not represent actual information and is solely for illustration purposes.

ISP-A is a large Internet Service Provider in the US, serving over 20 million households in 5 different markets (Appendix I - Figure 19 - Number of households per market) and continuing to expand in coverage and technology. With this intensive growth, the Supply Chain (SC) for network items is becoming more globally extensive. The growing complexity raises the need to evaluate the vulnerability of the SC to possible supply disruptions, the time to recover from these disruptions, and the effect on end consumers.

While ISP-A's network technology and reliability is best-in-class, a shortage in network equipment can create a situation where either ISP-A won't have the ability to continue expanding coverage and upgrading bandwidth for its customers, or would be missing spare parts to maintain the existing network sites, switch locations, and data centers. By understanding the potential constraints and having mitigation strategies in place, ISP-A can be the first to respond at a time of crisis and protect its network from SC disruptions.
To evaluate ISP-A's vulnerability to supply chain disruptions, the TTR/TTS methodology was applied. In order to focus the effort, the part of the network which was explored was only the **Customer Access Switches (CAS)**:

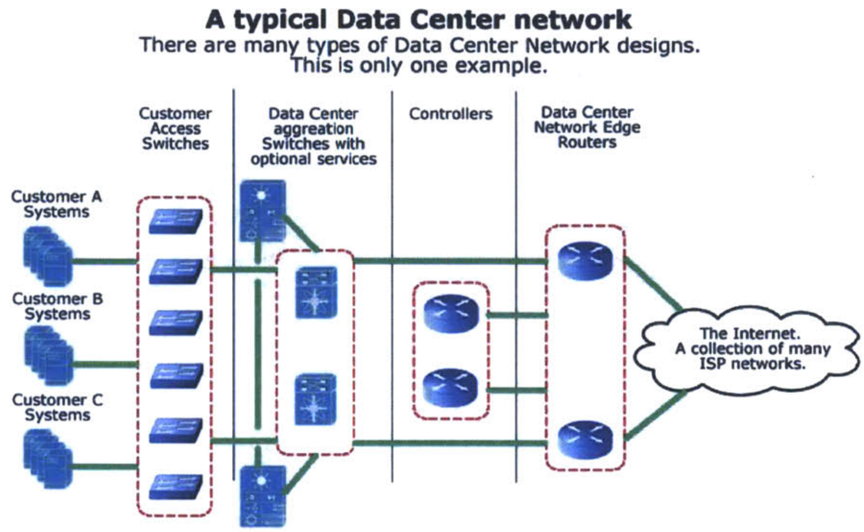

Figure 13 - A typical data center network[10] (Franks 2012)

The first step in the analysis was to determine *the value of service*. The metric to evaluate it was defined as the potential impact of each item on the customer base. In order to do calculate this, the following information was gathered:

- Data about CAS items (Figure 16 - List of CAS items data)
- ISP-A CAS item configuration breakdown (Figure 17 - Number of items per CAS configuration)
- The current amount of deployed CAS configurations and forecast for future CAS projects (Figure 18 – Deployed CAS configurations and forecast for new CAS projects)
- The number of households per market (Figure 19 - Number of households per market)
- The allocation of different CAS configurations in different regions/market (Figure 20 - Number of CAS CFG per market)

What is the Value of Service of each item?

Following the method described in Figure 5 - Calculating the number of customers affected, we were able to map out the number of customers dependent on each Item. The first step is to combine the data in Figure 19 - Number of households per market and Figure 20 - Number of

[10] How do you know who is qualified to design, build, and maintain your network?
May 30, 2012. By Justin Franks

CAS CFG per market and find the percentage of each configuration per market and the number of customers that are potentially impacted by each configuration:

	Percentage of customers per configuration			
	CFG1	**CFG2**	**CFG3**	**CFG4**
Market 1	71%	27%	2%	0%
Market 2	76%	24%	0%	0%
Market 3	69%	28%	2%	1%
Market 4	59%	30%	1%	10%
Market 5	60%	29%	11%	0%
No. of Customers	14,985,784	6,129,943	630,148	339,061

Table 4 - Number of customers per configuration

Once this data is generated, we can go back to Figure 17 - Number of items per CAS configuration and populate the number of customers per CFG. Cross-matrix between the product and the configuration gives us the number of customers per item, thus the *value of service*. See Below:

Item ID	Item Name	CFG1	CFG2	CFG3	CFG4	No. of Customers	Percentage of total customers
ABX001	Analog display	1	1	1	0	21,745,875	98%
ABN002	Analog circuit	1	1	1	0	21,745,875	98%
GHY456	Grounding unit	1	1	1	1	22,084,936	100%
KJU879	Circuit Breaker	1	0	1	0	15,615,932	71%
PFR934	Power Filter Unit	1	0	1	0	15,615,932	71%
JKI984	Connector J984	0	3	0	0	6,129,943	28%
JKI990	Connector J990	3	0	0	0	14,985,784	68%
JKI768	Connector J768	2	0	3	2	15,954,993	72%
BNT172	Switchboard	1	1	1	1	22,084,936	100%
PRT847	Power supply Unit	1	1	1	1	22,084,936	100%
NDH563	Padmount Transformer	1	1	1	0	21,745,875	98%
MBR034	Fuse unit	1	1	1	1	22,084,936	100%
KTY476	Fusible Switch	1	0	0	0	14,985,784	68%
NMU839	Bus Material	2	0	1	0	15,615,932	71%
RTV213	Power Distribution Panel	1	1	1	1	22,084,936	100%
BLY283	Battery unit	0	1	0	0	6,129,943	28%
TTN332	Timer unit	1	1	1	1	22,084,936	100%
FBT937	SB1	6	0	0	6	15,324,845	69%
YRE374	SB2	0	6	6	0	6,760,091	31%

MNA923	SB3	0	0	6	0	630,148	3%
YTH789	Adjuster 789	2	0	2	0	15,615,932	71%
YTH934	Adjuster 934	0	2	0	0	6,129,943	28%
YTH478	Adjuster 478	0	0	0	2	339,061	2%
ZVY568	Front Panel	1	1	1	1	22,084,936	100%
TYN932	Transmitter	1	1	1	1	22,084,936	100%
RVN493	Receiver	1	1	1	1	22,084,936	100%
BBR474	Back-Up Receiver	1	0	0	0	14,985,784	68%

Table 5 - Number of customers per item

What is the TTS of each item?

$$TTS = \frac{Average\ Inventory\ level}{Spare\ Usage\ Rate + New\ Projects\ Usage\ Rate}$$

In order to calculate the TTS of each item we need to determine three values:

Average inventory of each item: Taken directly from Figure 16 - List of CAS items data sum of columns "Average inventory level (Spares)" and "Average inventory level (New Projects) for Example the total average inventory for $GHY456 = 234 + 243 = 477$

Usage rate for spares: From Figure 16 - List of CAS items data we have two pieces of data – Replacement rate per week (If known) and Theoretical MTBF. If we know the replacement rate of an item (e.g. ABX001) that value is exactly the spare usage rate. If we don't know the replacement rate (e.g. GHY456) we need to calculate the expected failure rate and the replacement rate. First we need to figure out how many items of GHY456 are deployed. We can achieve that by cross-referencing Figure 18 – Deployed CAS configurations and forecast for new CAS projects and Figure 17 - Number of items per CAS configuration.

For example the GHY456 appears once in each of the four configurations. So the number of GHY456 deployed is:

$$GHY456_{Deployed} = 1 \times 540 + 1 \times 220 + 1 \times 21 + 1 \times 11 = 792$$

From there we know that $GHY456_{MTTF} = 10{,}000\ Hours = \sim 60\ Weeks$

Hence, the expected weekly replacement of GHY456 is:

$$Spare\ usage\ rate\ (GHY456, Weekly) = \frac{1}{GHY456_{MTTF}} \times Num\ of\ GHY456\ deployed$$

$$= \frac{1}{60} \times 792 = \sim 14\ per\ week$$

Usage rate for new projects: By cross multiplying the forecast of configurations from Figure 18 – Deployed CAS configurations and forecast for new CAS projects (After transforming it to weeks) and the items per configuration in Figure 17 - Number of items per CAS configuration. We can find the expected usage per week of each item. For example, Item YTH789 appears twice in CFG1 and twice in CFG3.

$$CFG1_{Average\ forecast} = 74.5\ per\ month = \sim 19\ per\ week$$

$$CFG3_{Average\ forecast} = 35.5\ per\ month = \sim 9\ per\ week$$

$$YTH789_{Demand\ per\ week} = 2 \times 19 + 2 \times 9 = 56\ per\ week$$

In the same method we can calculate:

$$GHY456_{Demand\ per\ week} = 1 \times 19 + 1 \times 9 + 1 \times 9 + 1 \times 2 = 39$$

$$\boldsymbol{TTS_{GHY456} = \frac{Average\ Inventory\ level}{Spare\ Usage\ Rate + New\ Projects\ Usage\ Rate} = \frac{477}{14 + 39} = 9\ weeks}$$

See TTS results for additional items:

Item ID	Item Name	Vendor	Cost	Critical to system (1 - Highest)	TTS (Weeks)
ABX001	Analog display	S1	$ 158.00	3	2
ABN002	Analog circuit	S1	$ 56.00	2	5
GHY456	Grounding unit	S2	$ 3.00	1	9
KJU879	Circuit Breaker	S3	$ 44.00	2	25
PFR934	Power Filter Unit	S4	$ 17.00	2	5
JKI984	Connector J984	S5	$ 0.20	1	9
JKI990	Connector J990	S5	$ 0.10	3	8
JKI768	Connector J768	S5	$ 0.10	3	2

BNT172	Switchboard	S6	$ 99.00	1	8
PRT847	Power supply Unit	S7	$ 7.00	1	16
NDH563	Padmount Transformer	S8	$ 85.00	2	16
MBR034	Fuse unit	S9	$ 0.10	1	6
KTY476	Fusible Switch	S10	$ 1.00	2	27
NMU839	Bus Material	S11	$ 0.10	2	11
RTV213	Power Distribution Panel	S12	$ 10.00	2	3
BLY283	Battery unit	S13	$ 15.00	2	38
TTN332	Timer unit	S14	$ 12.00	1	33
FBT937	SB1	S15	$ 45.00	3	7
...	...	...	...	...	...

Table 6 - TTS results

What are the top 3 items we would want to explore regarding their TTR?

The metrics to evaluate in order to determine which items should be selected for a more thorough TTR analysis are:

- **High Impact** – Percentage of customers potentially affected
- **Critical to the System** – An item that will impact service levels if not available
- **Low TTS** – An item that doesn't have comparable redundant inventory levels

The top 3 items that fit this criteria's are:

1) MBR034 - Fuse Unit (100% of Customers, Critical-1 and TTS = 6 weeks)
2) BNT172 - Switchboard (100% of Customers, Critical-1 and TTS = 8 weeks)
3) GHY465 - Grounding Unit (100% of Customers, Critical-1 and TTS = 9 weeks)

Assume that Figure 21 - Supply chain map of item 1 describes the Supplier map and the recovery time of the MBR034 – Fuse Unit, what will be the impact in service if Sub-tier supplier 3C is disrupted?

Supplier 3C has the following data in the supplier map:

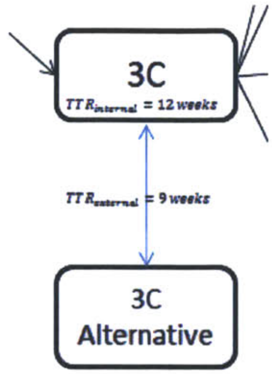

Figure 14 - Supplier 3C recovery time

We can see an internal TTR of 12 weeks (time to recover on its own) and an external TTR of 9 weeks (time to shift capacity to an alternative supplier). Given a TTS of 6 weeks for MBR034 – Fuse Unit, the time of exposure will be the following:

$$Exposure\ time_{3C} = MAX[0, (TTR_{3C} - TTS_{MBR034})]$$
$$Exposure\ time_{3C} = MAX[0, (9-6)] = 3\ weeks$$

7 Project Results

The analysis allows Verizon to gain valuable insights to its 2nd and 3rd tier supplier network. In addition, it paves the road for a meaningful risk and resiliency partnership with one of its major suppliers. Thus, adding another layer of reliability to its robust LTE network.

Multi-tier supply chain analysis:

Through a comprehensive analysis of the supply chain, Verizon discovered suppliers with both TTR > TTS and TTR < TTS. This information allowed Verizon to plan, balance, and mitigate as required. The analysis explored 3rd tier suppliers which are supplying to the Contract Manufacturer (CM), who are supplying to an Original Equipment Manufacturer (OEM) who then supplies to Verizon (Service Provider). See Figure 15 - Supply Chain Visibility:

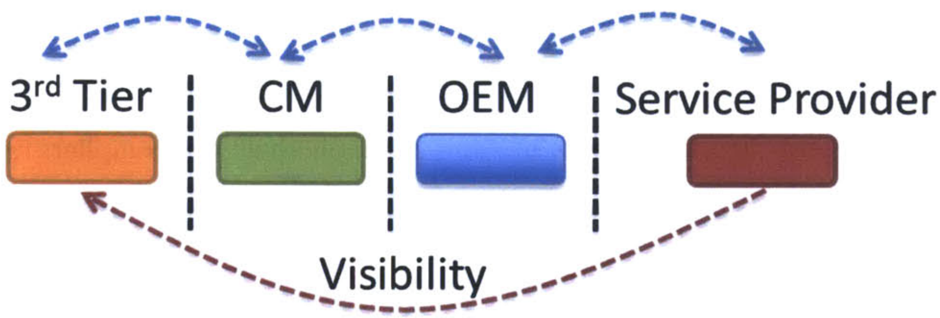

Figure 15 - Supply Chain Visibility

For example, a component sourced from a 3rd tier supplier was identified as driving significant risk as TTR > TTS. In response, an alternative source was found and sourcing volume was rebalanced for this 3rd tier supplier. This created a more robust supply chain for the service provider, but also the 1st and 2nd tier suppliers.

Risk and Resiliency partnership:

A key achievement of the project was the inception of a meaningful partnership between Verizon and one of its key vendors on risk and resiliency. As part of the partnership, important information was shared on critical components. On top of that, mutual frameworks, models, and best practices were reviewed. Furthermore, a joint task force from both parties was established to mitigate risk vulnerabilities in the combined supply chain network.

8 Recommendations and Conclusions

Risk can and should be measured within a service firm. A TTS model which is routinely updated with recent data represents actual exposure of items to supply chain risk. Suppliers need to be continuously observed as part of a regular process to identify single sourcing locations or suppliers and to evaluate TTR.

The major implementation recommendations for a successful Risk and Resiliency practice within a service provider include the following:

Ownership: Risk and resiliency is a task which requires full ownership. The methods in which this ownership is handled can vary between different organizations. Yet, it should be clear who owns each part of the risk and resiliency program in the company, otherwise day-to-day operations will always become a priority and sideline meaningful risk and resiliency efforts. Collecting the data for the TTS model and keeping it up-to-date, exploring the supplier's supply bases, and evaluating their TTR is a task which needs a *designated driver*. The *driver* in the organization who owns the risk and resiliency program can be a supply chain manager, a sourcing/procurement manger, or even a dedicated Risk and Resiliency analyst. The importance is that risk and resiliency will be included in the role's job description and not fall between the cracks.

Partnership: Risk and resiliency can't be fully explored solely within a company's internal supply chain. A real partnership must be established with strategic vendors. The partnership includes sharing crucial supply chain information between the companies in order to have actual estimation of TTS and TTR. Trust is essential for success of the partnership to succeed; both companies in the partnership need to be confident that the shared data will be used for legitimate risk and resiliency purposes and not to gain leverage and that the information shared will create a synergistic effect were the combined supply chain system is more robust and protected to vulnerabilities..

Continuity: Every company tends to regress towards its core business of day-to-day operations and the upcoming quarterly results. Evaluating risk is a strategic long-term investment and not a short-term goal. Furthermore, a risk manager will not be praised if nothing happened (a great outcome from a risk perspective), but he will be the first to be called to the corner office if something does go wrong. The challenges above are hard to neglect and can easily push aside the risk and resiliency efforts making them a lower priority. Only a continuous attention to the subject will allow a company to be fully capable to deal with an unknown crisis in supply or demand when it occurs.

To conclude, a strong risk and resiliency program will not only create a competitive advantage at the time of crisis, but also add another layer of reliability to any service provider – creating an even better service and value to the end customers.

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10 Appendix I

The following tables describe the data used for the ISP-A case study. This data is a representation of the data which should be gathered as part of a TTR/TTS analysis does not represent actual data.

Item ID	Item Name	Vendor	Cost	Critical to system (1 - Highest)	Theoretical MTBF(Hours)	Replacement Rate Per week (If known)	Average Inventory level (Spares)	Average Inventory level (New projects)
ABX001	Analog display	S1	$ 158.00	3	5000	52	45	88
ABN002	Analog circuit	S1	$ 56.00	2	12000	23	65	214
GHY456	Grounding unit	S2	$ 3.00	1	10000	-	234	243
KJU879	Circuit Breaker	S3	$ 44.00	2	5000	-	654	532
PFR934	Power Filter Unit	S4	$ 17.00	2	14000	-	34	125
JKI984	Connector J984	S5	$ 0.20	1	10000	-	23	311
JKI990	Connector J990	S5	$ 0.10	3	17000	-	432	122
JKI768	Connector J768	S5	$ 0.10	3	10000	-	54	111
BNT172	Switch Board	S6	$ 99.00	1	10000	75	123	765
PRT847	Power supply Unit	S7	$ 7.00	1	10000	-	555	252
NDH563	Pad mount Transformer	S8	$ 85.00	2	10000	-	553	235
MBR034	Fuse unit	S9	$ 0.10	1	10000	45	112	353
KTY476	Fusible Switch	S10	$ 1.00	2	10000	-	457	324
NMU839	Bus Material	S11	$ 0.10	2	10000	-	22	642
RTV213	Power Distribution Panel	S12	$ 10.00	2	15000	-	12	124
BLY283	Battery unit	S13	$ 15.00	2	21300	-	12	435
TTN332	Timer unit	S14	$ 12.00	1	123000	12	432	1234
FBT937	SB1	S15	$ 45.00	3	45900	5	124	765
YRE374	SB2	S16	$ 44.00	3	23000	-	759	213
MNA923	SB3	S17	$ 35.00	3	12000	-	128	214
YTH789	Adjuster 789	S18	$ 0.01	4	54200	-	345	658
YTH934	Adjuster 934	S18	$ 0.01	4	23400	-	864	235
YTH478	Adjuster 478	S18	$ 0.01	4	12000	-	534	765
ZVY568	Front Panel	S19	$ 25.00	3	42300	4	523	123
TYN932	Transmitter	S20	$ 245.00	1	12000	24	231	654
RVN493	Receiver	S21	$ 235.00	1	43000	23	546	234
BBR474	Back-Up Receiver	S22	$ 125.00	3	53000	-	22	75

Figure 16 - List of CAS items data

Item ID	Item Name	CFG1	CFG2	CFG3	CFG4
ABX001	Analog display	1	1	1	0
ABN002	Analog circuit	1	1	1	0
GHY456	Grounding unit	1	1	1	1
KJU879	Circuit Breaker	1	0	1	0
PFR934	Power Filter Unit	1	0	1	0
JKI984	Connector J984	0	3	0	0
JKI990	Connector J990	3	0	0	0
JKI768	Connector J768	2	0	3	2
BNT172	Switch Board	1	1	1	1
PRT847	Power supply Unit	1	1	1	1
NDH563	Pad mount Transformer	1	1	1	0
MBR034	Fuse unit	1	1	1	1
KTY476	Fusible Switch	1	0	0	0
NMU839	Bus Material	2	0	1	0
RTV213	Power Distribution Panel	1	1	1	1
BLY283	Battery unit	0	1	0	0
TTN332	Timer unit	1	1	1	1
FBT937	SB1	6	0	0	6
YRE374	SB2	0	6	6	0
MNA923	SB3	0	0	6	0
YTH789	Adjuster 789	2	0	2	0
YTH934	Adjuster 934	0	2	0	0
YTH478	Adjuster 478	0	0	0	2
ZVY568	Front Panel	1	1	1	1
TYN932	Transmitter	1	1	1	1
RVN493	Receiver	1	1	1	1
BBR474	Back-Up Receiver	1	0	0	0

Figure 17 - Number of items per CAS configuration

		Forecast for Future Months			
	Currently Deployed	1	2	3	4
CFG1	540	82	72	69	75
CFG2	220	23	22	45	48
CFG3	21	54	34	32	22
CFG4	11	4	7	8	8

Figure 18 – Deployed CAS configurations and forecast for new CAS projects

	No. of Households
Market 1	4,569,895
Market 2	1,254,896
Market 3	11,254,263
Market 4	2,548,986
Market 5	2,456,896

Figure 19 - Number of households per market

Configuration per Market

	CFG1	CFG2	CFG3	CFG4
Market 1	86	33	2	0
Market 2	19	6	0	0
Market 3	356	142	11	4
Market 4	42	21	1	7
Market 5	37	18	7	0

Figure 20 - Number of CAS CFG per market

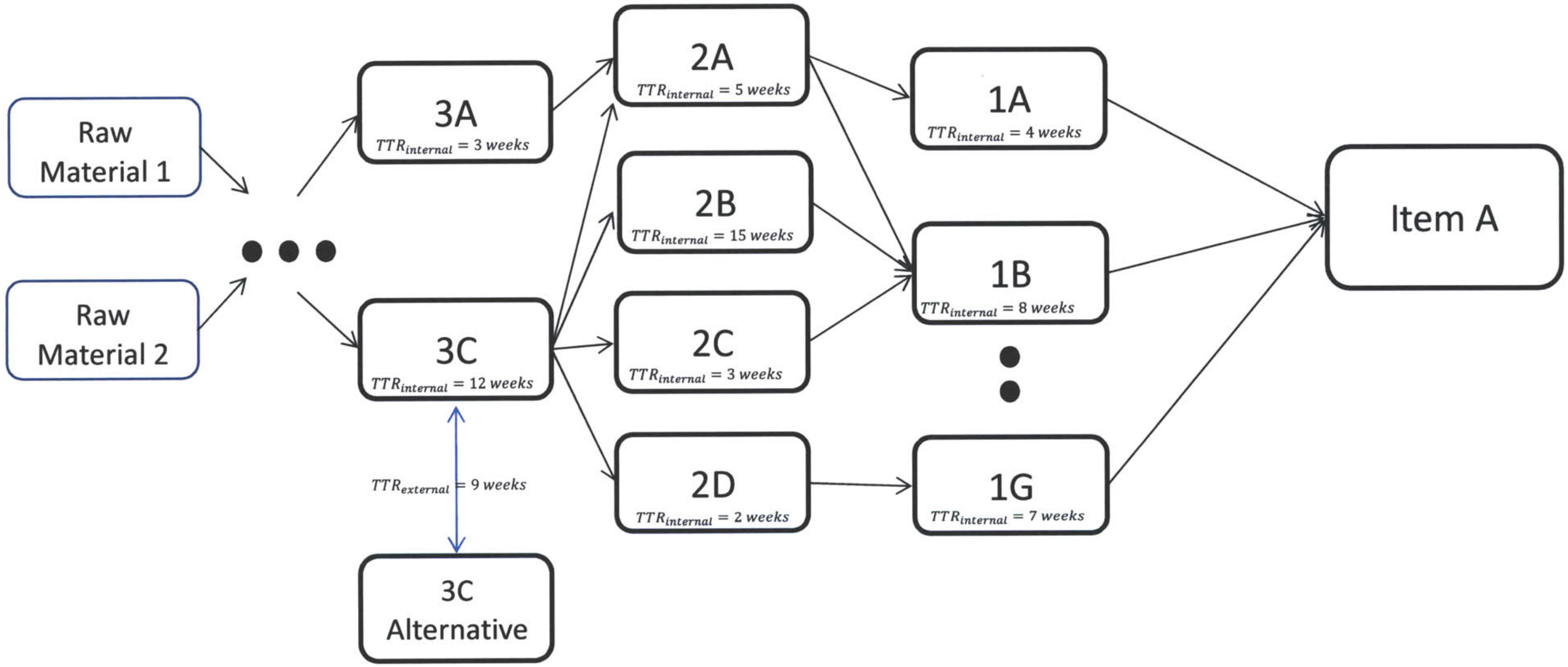

Figure 21 - Supply chain map of item 1