Analyzing Supply Chain Risk and Resiliency for Service Providers - Enhancing Network Reliability by Mitigating Supply Chain Risk

Yanai S. Golany[1], Prof. David Simchi-Levi[2]

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.

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.

[1] **Yanai S. Golany:** MIT Leaders for Global Operations (LGO) Fellow class of 2014

[2] **Prof. David Simchi-Levi**: Engineering Systems Division, Department of Civil and Environmental Engineering, and Operation Research Center, Massachusetts Institute of Technology

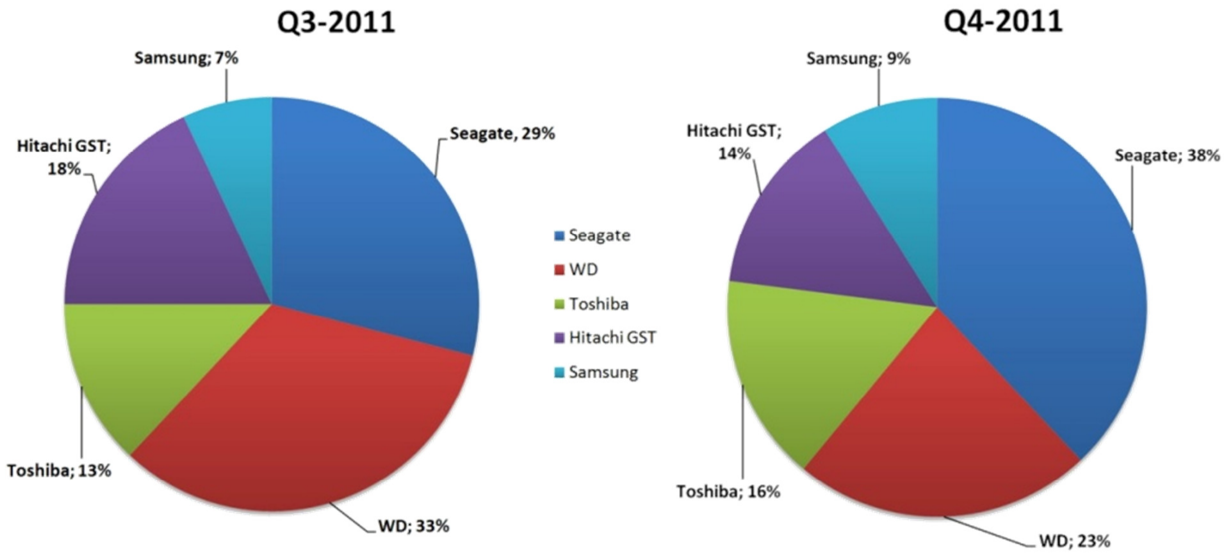


Figure 1 - HDD Market Share Before and After the Thai Flooding[3] (Taylor 2012)

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 (Pollard and Virki 2011). In the Thai 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 (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.

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

[3] http://news.techeye.net/business/hdd-business-to-become-mexican-standoff

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 ≥ TTR there is no risk at this time. 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:

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

2. 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.

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[4] (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:

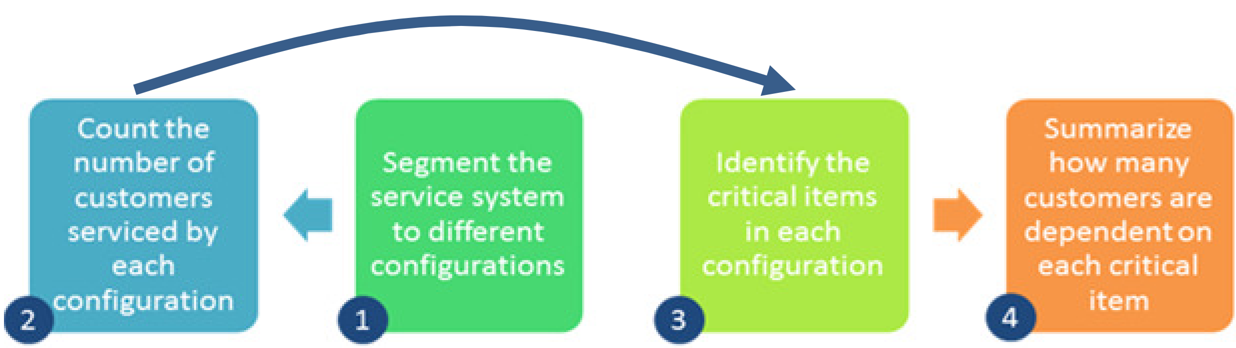
Brand Value – The higher the number of customers affected the higher the buzz of the disruption

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

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:



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

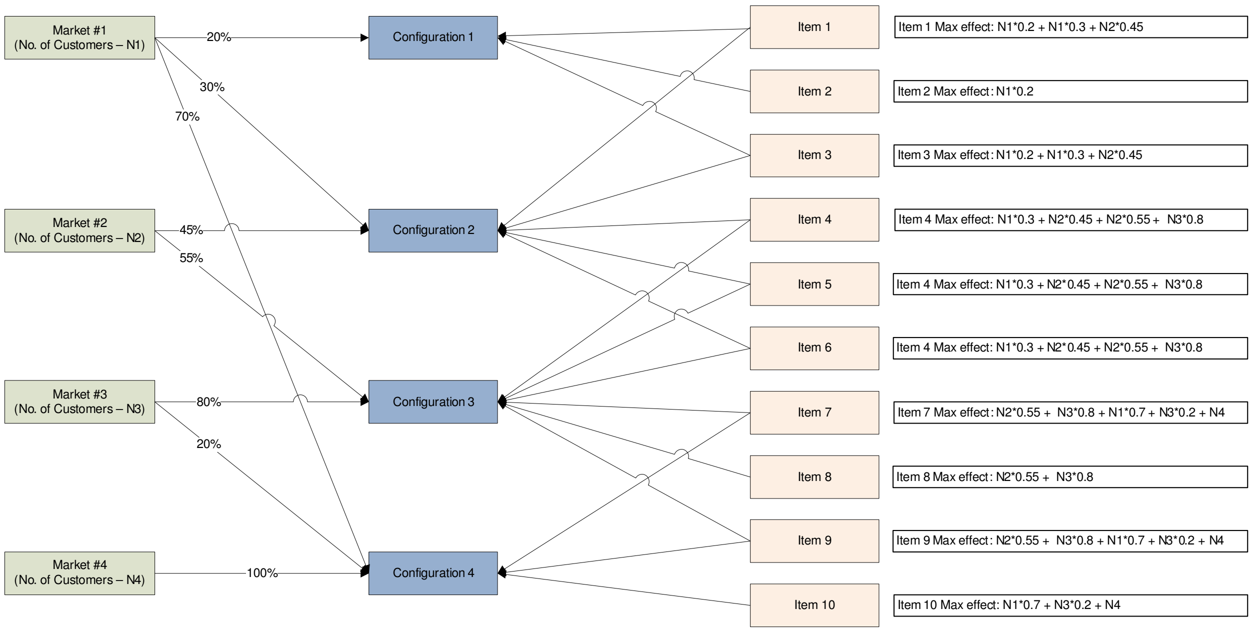


Figure 2 - Calculating the number of customers affected

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.

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3. The time to survive Model (TTS)

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:

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

Calculation of spare usage rate – The theoretical usage of each item is calculated according to the expected Mean Time Till Failure (MTTF) of that item:

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

If the system has been running for some time, an empirical approach can be taken, and instead of MTTF, 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 (+3σ) 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 Average Inventory – Because Inventory levels tend to fluctuate between orders (See Figure 3). Just taking a snapshot of the inventory level might provide a misleading view of inventory status – for example, just after or before replenishment the inventory level will either be artificially low or artificially high, thus biasing the TTS model results accordingly.

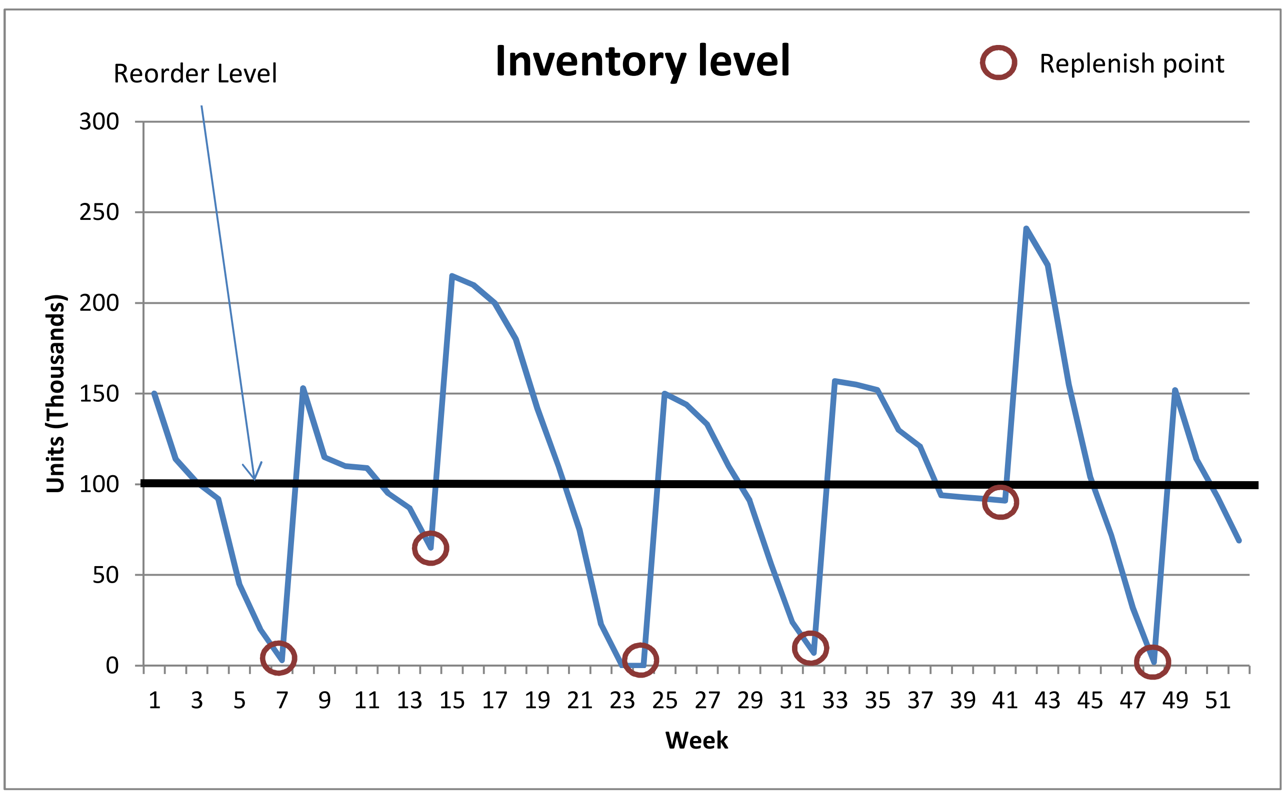

Figure 3 - A typical inventory level annual behavior

Therefore, the inventory level for the TTS Model should be calculated as the average inventory out of several snapshots[5] taken from inventory reports. Observe the inventory levels at a couple of random time points throughout the year to ensure that snapshots are taken both before and after replenishment (Cachon 2013). For example, in Figure 3, 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 3 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. (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. The time to recovery model (TTR)

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.

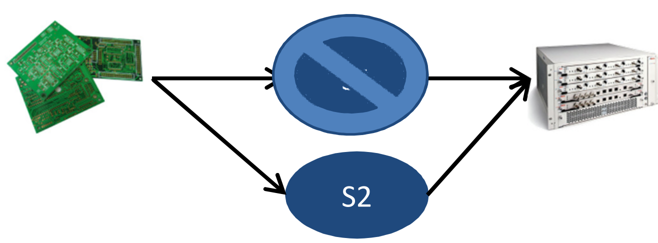

Figure 4 - Replacing a disrupted supplier

[5] 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.

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:

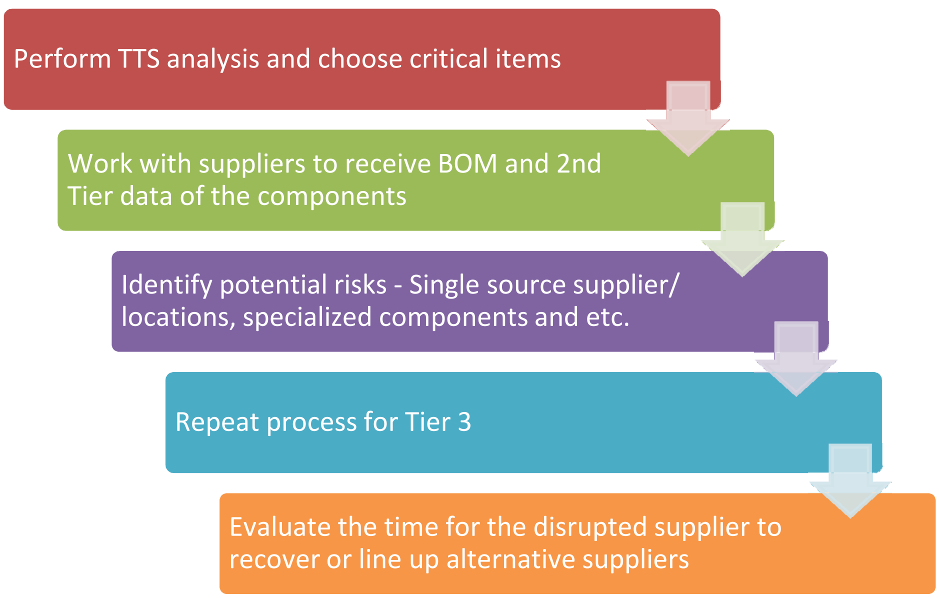

Figure 5 - TTR Stages

The TTR of each supplier will be determined by the time measurement evaluated in the final stage of Figure 5. In order to reach a time measurement for TTR the following methodology should be performed:

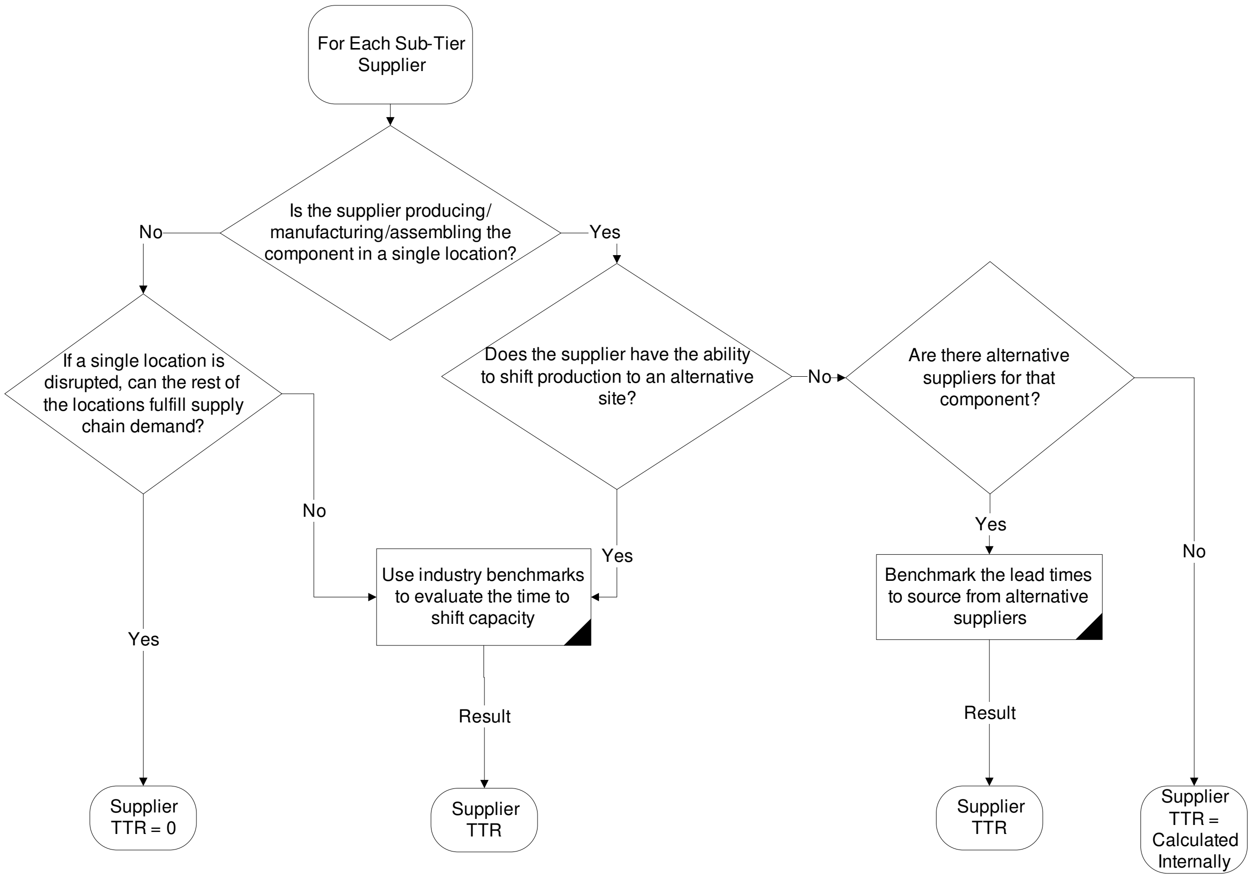

Figure 6 - Evaluating TTR

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 6 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.

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. Case Study – Internet Service Provider – ISP-A

ISP-A is a large Internet Service Provider in the US, currently serving over 20 million households in 5 different markets (Figure 12) and continuing to expand in coverage and technology. With 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)**:

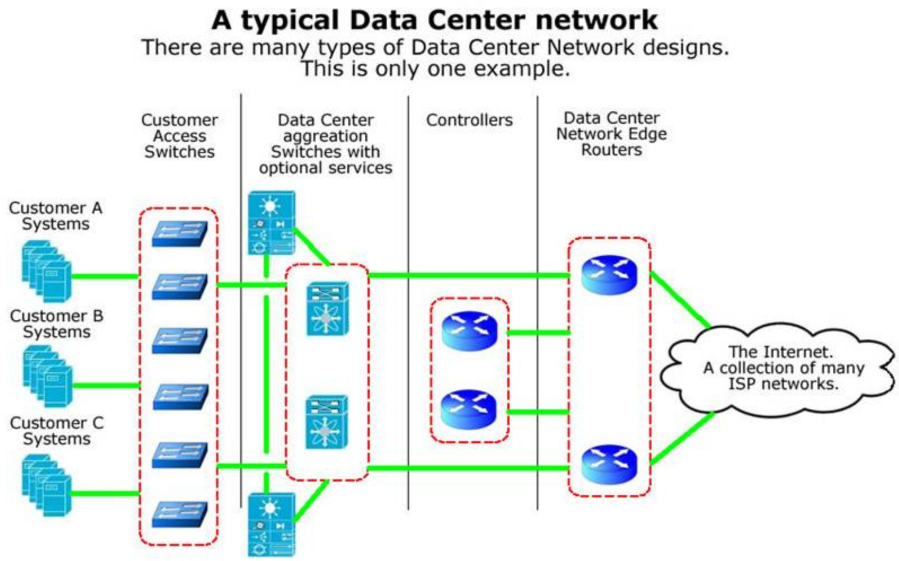

Figure 7 - A Typical Data Center Network[6] (Franks 2012)

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 calculate this the following information was gathered:

- Data about CAS items (Figure 8). You can assume that average inventory level = average inventory level of spare items + average inventory level of new project items.
- ISP-A CAS item configuration breakdown (Figure 9)
- The current amount of deployed CAS configurations and forecast for future CAS projects (Figure 10)
- The number of households per market (Figure 11)
- The allocation of different CAS configurations in different regions/market (Figure 12)

Following the method described in Figure 2, we were able to map out the number of customers dependent on each Item – See Table 1.

Answer the following questions according to the data gathered following the TTS/TTR methodology for service providers:

1) **Assume the average revenue per user (ARPU) is 200 dollars. What is the Values of Service of each item?**

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

2) **What is the TTS of each item?**
3) **Choose the top 3 items with TTR you would want to explore and explain why.**
4) **Assume that Figure 13 describes the assembly network of the top item you choose. What will be the impact in service if Sub-tier supplier 3C is disrupted? (Other facilities are not disrupted.) The recovery time of 3C is given by its internal and external TTR.**

Item ID	Item Name	Vendor	Cost	Critical to system (1 = Highest)	Theoretical MTTF(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 8 - 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 9 - 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 10 –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 11 - 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 12 - Number of CAS CFG per Market

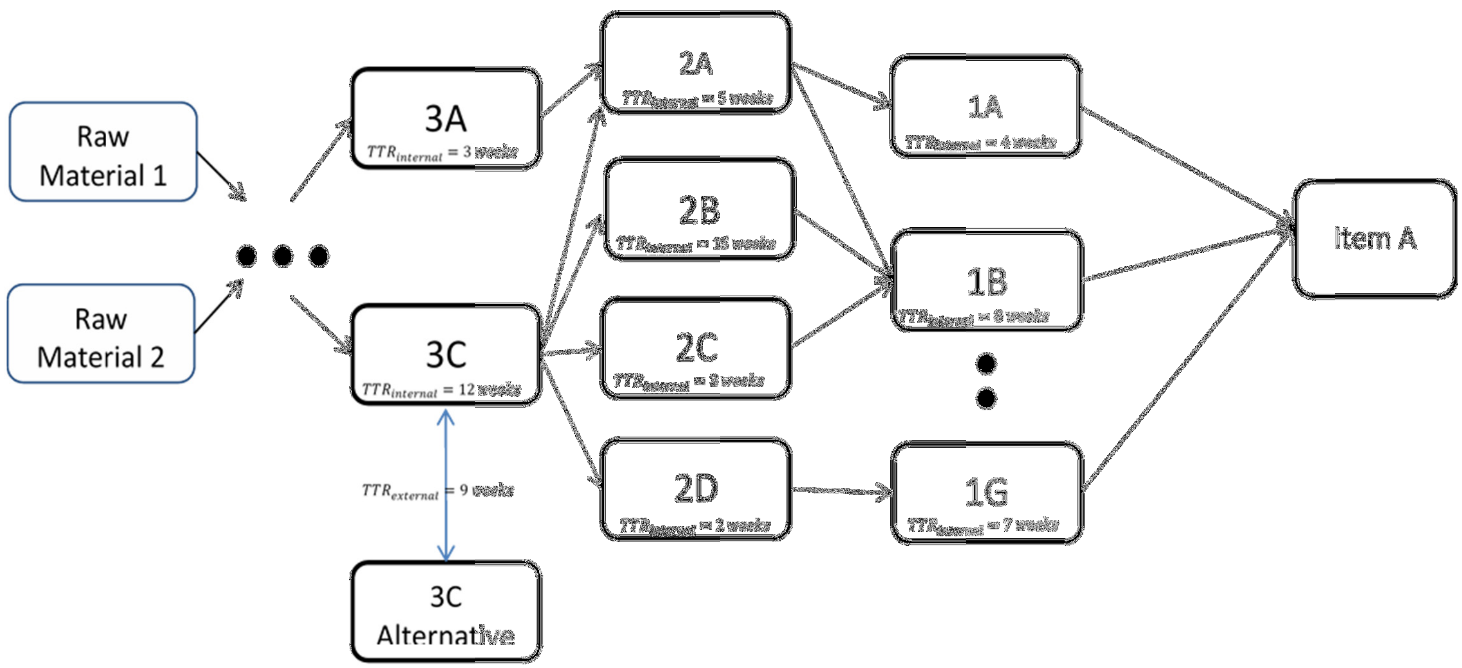

Figure 13 -Supply Chain Map of Item 1