Optimizing the Internal Reuse of Wireless Network Equipment

by

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Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degrees of
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Abstract

Reusing high-value wireless network equipment can allow telecommunications providers to achieve both financial and environmental benefits. However, without standardized processes and tools to reuse equipment, the reuse process can be highly inefficient and a significant amount of reusable equipment may remain in inventory. This thesis examines the reuse of wireless network equipment at Verizon Wireless (VzW) and presents tools and processes to increase the amount and efficiency of network equipment reuse within VzW. An analytical model is presented to differentiate between items that can be reused and items that should be immediately resold or scrapped. Once a pool of reusable items is identified, incentives to promote equipment sharing across internal VzW regions are discussed. A web-based tool and process to increase the ease and speed of identifying and requesting equipment is then examined. Finally, a framework by which reuse metrics can be evaluated is presented.

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1 Overview and Background

1.1 Verizon Wireless Background

Verizon Wireless (VzW) was formed as a joint venture between Verizon and Vodafone Group Plc in April 2000 with Verizon owning a 55% interest in VzW and Vodafone owning the remaining 45%. Just 13 years later, VzW is one of the largest telecommunications providers in the United States with the largest 3G CDMA and 4G LTE networks in the U.S. [1]. In addition to the wireless network services (e.g. voice and data plans on its 3G and 4G LTE network), VzW also offers its customers wireless devices, such as smart phones, basic phones, and tablets.

The wireless service industry is highly competitive with national wireless service providers like Verizon Wireless, AT&T, and Sprint Nextel Corporation as well as regional providers like Metro PCS and US Cellular. Furthermore, competition is expected to increase in the future as new products and services are introduced, additional spectrum becomes available, and even more people worldwide begin to use wireless services. As competition increases in the wireless telecommunications industry, providers are under pressure to charge lower prices and provide higher discounts to attract customers. The predominantly negative effects on earnings before interest, taxes, depreciation, and amortization (EBITDA) and revenue margins can be seen in Figure 1. The pressure on pricing has led some wireless service providers to assess opportunities to lower costs in order to maintain profits.

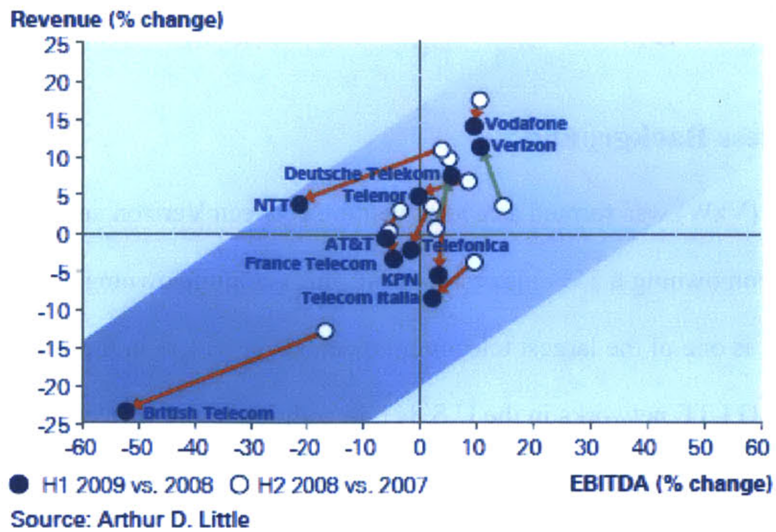

Figure 1. Percent change in revenues and EBITDA of various telecommunications providers [2]

While Verizon Wireless has assessed opportunities to cut costs, its primary goal, as stated in the February 2012 10-K, is to "provide the highest network reliability for the provision of data and voice services." Furthermore, the network at Verizon Wireless has consistently won awards for network reliability and speed as well as for customer satisfaction. Thus, any cost saving measures that are taken must not impact the reliability of the network and, ultimately, customer satisfaction. Fortunately, VzW has been able to achieve cost savings while maintaining high customer satisfaction through supply chain improvements on the device side. Given the successes of the device supply chain, there has been growing interest in applying supply chain principles to the network services side as well. It is believed that network supply chain improvements can reduce working capital requirements and improve return on invested capital while maintaining the quality and reliability of VzW's network.

1.2 Wireless Network Background

Verizon Wireless spends approximately $6 billion a year to maintain and expand its nationwide network. This network includes tens of thousands of cell sites, which are often called cell towers or base transceiver stations (BTSs). As seen in Figure 2, a BTS communicates with a user's cellphone, tablet, or other device by receiving and transmitting radio signals. A base station controller (BSC) then controls multiple BTSs and allocates radio resources on the BTSs. Finally, a mobile switching center (MSC) connects to multiple BSCs and acts as a central hub for the wireless networks. All of this equipment must be put in place and maintained properly in order to allow customers to place calls, to stay on calls even as they move past one cell tower and towards another, and to ensure appropriate billing.

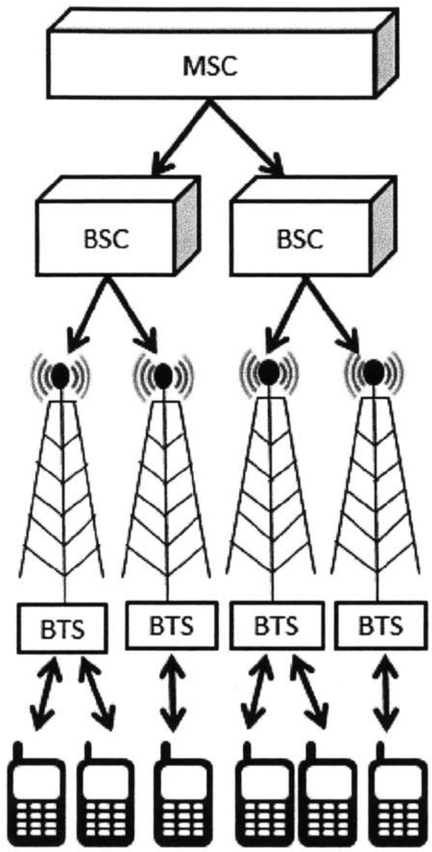

Figure 2. Wireless Network Communication Pathway

VzW has two primary network technology platforms: 3G CDMA and 4G LTE. 3G CDMA was launched in January 2002 while 4GLTE was launched in December 2010 [3]. Even with the launch of 4G LTE, the 3G network is still in service and is expected to remain in service until approximately the year 2021 [4].

Managing wireless network equipment can be difficult for telecommunications providers due to the quantity and complexity of the equipment, the need to maintain network reliability even when natural disasters occur, the speed at which equipment evolves within the industry, as well as many other factors. Telecommunications providers must ensure that they order the right quantity of wireless network equipment and place this equipment in optimal locations in order to best serve the growing number of cell phone and tablet users. Furthermore, telecommunications providers must ensure that there are enough spare parts in the right locations to ensure that the network is maintained when parts fail, which is especially challenging during natural disasters or other large-scale calamities. Finally, the fast-paced evolution within the telecommunications industry means that multiple generations of network equipment (e.g. 3G and 4G LTE) coexist. VzW must maintain and optimally place multiple generations of equipment through the United States. These are all major considerations when optimizing a telecommunications provider's network supply chain.

1.3 Excess Equipment

High-value wireless network equipment that was previously installed and functional is removed from a cell site or other in-service location and placed in a warehouse for many reasons. For instance, as Verizon Wireless and other telecommunications providers expand their 4G LTE network, much of the nearby 3G equipment can be removed from service when the 4G equipment is installed. The removed 3G equipment may then be placed into a warehouse and classified as "Excess" equipment. However, the 3G equipment may still be utilized at other locations with growing 3G traffic. Ideally, when a need for the equipment is identified, the Excess[1] equipment can be transferred from the warehouse and put back into service.

Excess equipment can also arise through acquisitions. In addition to organic growth, Verizon Wireless has also expanded through strategic acquisitions of other wireless network companies. After an

[1] The word "Excess" will be capitalized in this study when referring to equipment that has been or will be labeled as Excess in VzW's inventory management system. The word will not be capitalized when used to describe something that follows the dictionary definition of the word "excess."

acquisition, there may be redundant network equipment in certain geographic areas where both Verizon Wireless as well as the acquired company have network equipment and coverage. Thus, the redundant network equipment can be removed from service and brought to a warehouse for later use when a need for that equipment is identified.

Capacity changes are also a source of Excess equipment. For instance, if an area previously had significant cellular traffic flowing through its network but now has much lower traffic, then some of the network equipment can be removed from this area and placed into a warehouse as Excess equipment.

There are many other sources of Excess equipment, but the previous examples illustrate some of the primary sources.

1.4 Reusable Equipment

Once the Excess equipment comes back to the warehouse, this equipment can be reused or "retired." Transferring the equipment to a cell site or cell switch and putting the equipment back in service is termed "reuse." It is desirable to reuse Excess equipment within Verizon Wireless in order to capture return on capital that has already been invested in the equipment. Furthermore, reusing equipment instead of buying new equipment decreases the amount of working capital that is needed or frees up capital that can then be used for other network requirements. Lastly, reusing equipment offers environmental benefits because old equipment can be used in lieu of manufacturing new equipment. If an item[2] is not reusable at VzW, the item will be either sold to a third party if it has market value or scrapped if it has no market value. An item is said to be "retired" if it is dispositioned outside of VzW through sale or scrapping.

While VzW seeks to improve its reuse, resale, and scrapping efforts, this thesis focuses on optimizing only the reuse of wireless network equipment. The objective is to develop standardized

[2] An item is defined as a specific product, such as a particular type of antenna.

analytical tools and processes to make the reuse of wireless network equipment a more streamlined and efficient process.

Prior to the author's engagement with Verizon Wireless, VzW's individual regions and areas[3] had already developed their own approaches to reusing equipment. While some regions have been successful at reusing equipment both within their own regions as well as within their own area and sometimes even across areas, a significant amount of Excess equipment remains in warehouses instead of being reused as seen in Figure 3. It is expected that implementing standardized reuse processes and tools will enable VzW to reuse more equipment and to do so more efficiently.

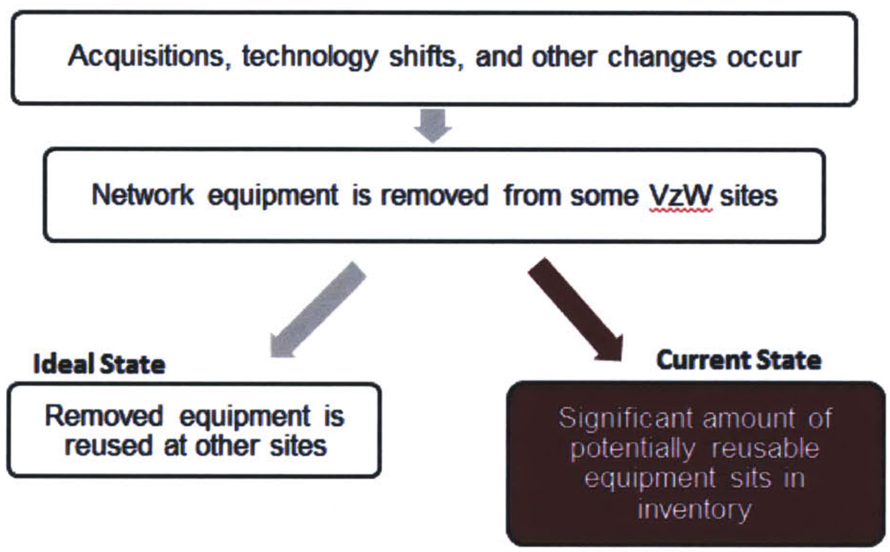

Figure 3. Flow of Excess Network Equipment

All regions, including the ones that have reused equipment in the past, face many challenges when attempting to reuse equipment. The primary challenges are as follows, and each challenge will be examined in further detail in the following chapters:

[3] Please see Figure 5 for a map of VzW's definition of regions and areas.

Challenge/Root Cause	Symptoms
Regions do not know when equipment can be reused and when it should be retired.	Warehouses become too full and hold equipment that cannot be reused. Regions waste money if they retire reusable equipment that can be reused.
No clear incentive for regions to share reuse parts with other regions.	Regions hold onto equipment for "just in case" situations and other regions that could have reused another region's equipment are forced to unnecessarily buy new equipment.
Current systems do not provide nationwide visibility, are difficult to search, and do not allow users to quickly request equipment.	Identifying and requesting reusable equipment can be very time consuming. Employees may choose to buy new equipment instead of reuse equipment due to the time consuming process.

Table 1. Primary challenges of reusing network equipment at VzW.

1.5 Hypothesis

It is hypothesized that standardized processes and analytical tools will make the reuse of wireless network equipment more efficient and more frequent, resulting in greater return on invested capital, lower working capital requirements, and reduced carbon emissions.

1.6 Research Methodology

The DMAIC (Define, Measure, Analyze, Improve, Control) framework [5] was used in this engagement with VzW. The DMAIC framework is a data-driven process that drives the improvement and optimization of business processes in Six Sigma projects. This framework can be leveraged in other types of projects due to the methodical approach to problem definition, analysis, improvement, and measurement.

During the Define phase, stakeholders were identified and interviewed at VzW in order to better understand VzW and the reuse of wireless network equipment. These interviews were then helpful in determining the goals of the project.

During the Measure phase of the project, four different regions within Verizon Wireless (one region in each of VzW's four areas) were visited to document current reuse processes, best practices, and challenges. In addition, the amount of network equipment that was reused by each region prior to this study was estimated by examining internal data. The amount of Excess equipment that was not reused (i.e. the missed opportunity for reuse) was also determined. This quantitative data provided a baseline for the amount of reuse and the opportunity for reuse.

The Analyze phase allowed VzW to understand some of the root causes for inefficient or low levels of reuse. The lack of standardized processes and analytical tools is believed to be the major root cause. For instance, regions may reuse less equipment because of the time-consuming tasks that are necessary to identify and request equipment. Without knowing what equipment is available in other regions and whom to contact in other regions, an employee will likely buy new equipment instead of reusing equipment from another region.

In the Improve phase, standardized tools and processes were identified to streamline the reuse process. These processes and analytical tools will be discussed later. Some of these improvements are being piloted while others are still being refined. Once these proposed improvements are validated through pilots and other testing, they can be implemented and monitored in the Control phase.

2 Excess Equipment: Reuse or Retire?

2.1 Background

As stated in Chapter 1, reusing Excess equipment has both financial and environmental benefits, but, unfortunately, not all Excess equipment can be reused. Excess equipment that cannot be reused will be retired (i.e. resold to an organization outside of VzW or discarded). Thus, before we can reuse equipment, we must first determine what equipment can actually be reused and what equipment should be retired.[4]

We originally believed that the problem was binary: wireless network equipment is either reusable or obsolete. We then put together an internal VzW subject matter expert (SME) group to identify obsolete equipment and to send this equipment down the retirement path. At this point, we thought that all other equipment that was not identified as obsolete should be kept and reused. However, a significant amount of inventory falls in a grey zone: the equipment is indeed reusable, but VzW is holding more units of these reusable items than it will ever use. As Rosenfield notes, "The real question in the treatment of excess inventory is not necessarily whether to salvage or dispose of an entire lot of merchandise, but what number of units (or batches of units) to keep." [6]

Excess inventory, or overstocking, occurs for a variety of reasons in many companies and across many industries. As mentioned in Chapter 1.3, when a telecommunications provider acquires or merges with another provider, they will likely have cell sites that are very close together, which become excess inventory after the merger. As Angelus [7] found, many other industries experience similar challenges with excess inventory due to volatility in demand, inadequate information and forecasting ability, and the bullwhip effect.

[4] Although the thesis focuses on reuse, the decision of whether to reuse or retire equipment falls under the purview of the reuse team at VzW. Because reusing equipment is ideal for VzW both financially and environmentally, the reuse team first determines whether equipment can be reused, and equipment is diverted down the retirement path only if it cannot be reused.

Fortunately, VzW can reduce its Excess equipment by identifying equipment that should be immediately retired and selling this unneeded Excess equipment to secondary markets. The size of the secondary market for electronic components was estimated to be $15 billion in 2008, and secondary markets are becoming even larger [8]. Even in cases in which the equipment cannot be sold and must be discarded, it might still be better to discard the equipment now rather than keep it due to holding costs. Before VzW can begin to sell or discard unneeded Excess equipment, however, it must first determine how many units to sell or discard now. Excess equipment can also be sold at a later date, but it is ideal to sell unneeded units as soon as possible due to holding costs, cost of capital, and potentially higher resale values before the equipment becomes outdated.

The end goal is to determine what equipment can actually be reused and to quickly retire units that are not reusable to avoid unnecessary holding costs and to capture high resale values. As seen in Figure 4, items that are not reusable can be retired with the help of SME groups and unneeded units of reusable items can be retired with the help of an analytical model, which we will discuss in the next section. This will leave us with a pool of reusable equipment.

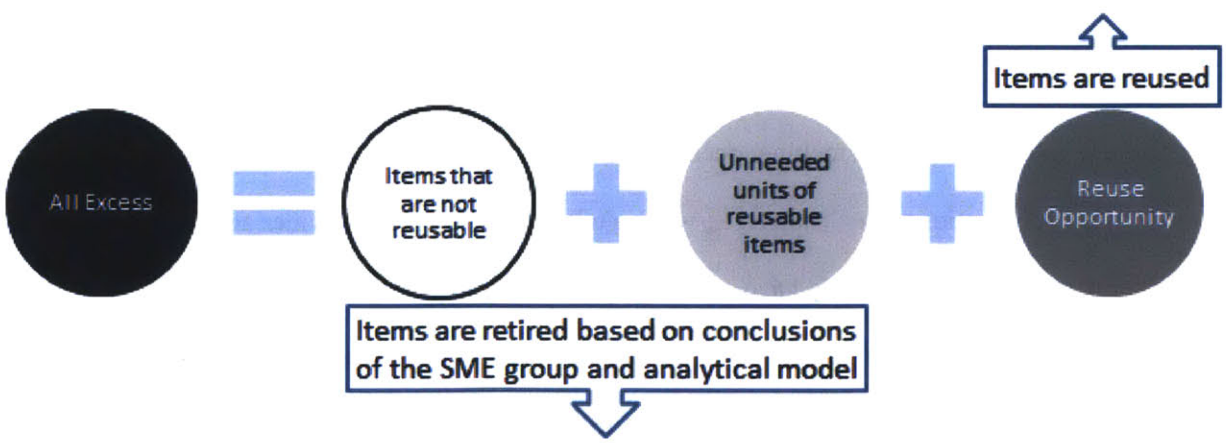

Figure 4. Pathways for the Disposition of Excess Equipment

2.2 Analytical Model for Excess Inventory

To address the challenge of Excess inventory, Rosenfield [6] developed an analytical model to determine the number of units of an item to dispose or keep, or in the case of VzW, to immediately retire or to keep for reuse/resale at a later time, respectively. The number of units to keep, n*, can be calculated using equation 1.

Equation 1:

$$n^* = \frac{\log(\frac{V+r/i}{A+r/i})}{\log(M(i))} \text{ in which } M(i) = e^{(-ix)}f(x)dx$$

where

n* = optimal number of units to be kept/reused

V = salvage value at present time as a percent of current value

A = cost to replace retired equipment that is later needed as a percent of current value

r = non-capital holding costs per unit time as a percent of current value

i = discount rate per unit time

f(x) = distribution of time between demand episodes, x [5]

As one can infer through equation 1, a unit should be retired if VzW can obtain a higher value by selling the item to a third party now than by waiting and either reusing the item or selling it to a third party at its expected discounted sales value minus holding costs. It is important to note that if there are 100 units of the same type of antenna, for example, not all 100 units are worth the same amount of money even if all 100 units of the antennas are identical. This is because the first unit will be reused first and will incur a small holding cost and a small discount on the current value of its future sales price. The 100th unit

[5] Assume that the times between demand episodes are independent and identically distributed. Furthermore, the model assumes a Poisson process for demand episodes, and the validity of such an assumption for demand episodes has been argued by Ehrenberg [9].

will be reused last, if it is reused at all, and will incur the highest holding cost and the highest discount on the current value of its future sales price.

Using this model, one can help balance the tradeoffs of managing Excess inventory. For instance, holding more units than a company will ever reuse requires unnecessary holding costs and prevents companies from obtaining generally higher resale values by selling now versus in the future. Furthermore, in space-constrained warehouses, holding a large number of units might not even be possible and, when it is possible, an opportunity cost arises because that space could be used to hold equipment that can actually be reused. On the other hand, retiring units too early can be costly if those units are needed later on and the company is forced to buy back used or even new equipment to replace the equipment that it once had.

Equation 1 can be applied to equipment at VzW to determine how many units to hold and how many to retire immediately. Although VzW's data will not be shown in order to protect confidential information, an example using fictitious inputs can illustrate the applications of the model. Imagine an item for which the current value is $1000 per unit.[6] The salvage value at present time is 25% of the current value. The cost to replace retired equipment that is later needed is 100% of the current value. Non-capital holding costs per year as a percentage of current value are 2% and the discount rate is 8% per year. Currently, 6000 units sit in Excess, and an average of 500 units will be used internally at VzW each year. In this case, equation 1 indicates that n*=5727 units, so 5727 units should be kept while the remaining 273 units can be sold to secondary markets. This will allow us to capture a high resale value, incur fewer holding costs by holding approximately 5% less inventory, and make space for other items that are more likely to be reused..

However, if the salvage value decreases to 0% of the current value, n* becomes 10059 units. Because there are only 6000 units in Excess, VzW obviously does not have 10059 units to keep, so the

[6] In order to protect confidential information, all inputs in the models do NOT arise from actual VzW data. However, the examples appropriately illustrate the analysis and benefits that can be generated from this model.

model's results can be interpreted to mean that all 6000 units that are currently in Excess should be kept. When V decreases, n* increases. This makes sense intuitively because when VzW derives no value or very little value from selling an item now, more units should be kept on the off chance that they can be reused or sold for a higher price later. However, it is important to note that even when the current salvage value is zero, there are still instances when the model will suggest that some units be discarded immediately. This is because there are costs, such as holding costs, which are required to hold Excess equipment, so it is better to discard items now for zero dollars if they likely will not be used rather than to discard them later when they are still worth zero dollars and have incurred holding costs.

2.2.1 Analytical Model with Obsolescence

Equation 1 does not consider that items might become obsolete or deteriorate before they are sold (referred to as perishing). Technology changes in the wireless telecommunications industry occur quite often, and hence this is a concern for VzW. Although 3G equipment is still being used even with the availability of 4G equipment, certain 3G parts may become completely obsolete or may deteriorate before they are sold or reused.

Rosenfield [6] notes that equipment can perish in many ways:

1. All units of an item can perish together at a random, unknown time period
2. All units of an item can perish together at one known time period
3. Each unit can perish at a random, unknown time

Case 1 and 2 represent situations in which product substitution or the phasing out of certain technologies occurs, so all units of an item are affected at the same time. Case 3 represents the deterioration of equipment, which affects each unit of an item at separate times.

For Verizon Wireless, all three options can apply. When the model was first developed, it was unclear when 3G equipment would become obsolete. Thus, our original model was based on Case 1. However, in October 2012, VzW announced that 3G equipment would be phased out by 2021, so Case 2 is now the most appropriate model for 3G equipment at Verizon Wireless because the 3G technology will be phased out on a known timeline.

It is important to note that this analytical model currently does not apply to 4G LTE equipment because, as the newest platform, 4G LTE equipment is being actively deployed and is not typically sitting in warehouses as Excess equipment. When a new platform (perhaps 5G) emerges in the future, however, 4G LTE equipment will likely be brought back to warehouses as Excess equipment. At first, the phase out date of 4G LTE equipment will not be known, and Case 1 can then be applied to 4G LTE equipment. Once the phase out date of 4G LTE equipment is known, Case 2 can be applied.

Lastly, we evaluated the application of Case 3 at VzW. Excess equipment does deteriorate over time, and this deterioration causes individual units to fail instead of causing all units to fail at the same time. However, VzW's equipment suppliers typically replace equipment that is no longer functioning, so Excess inventory levels would remain the same once a working unit from the supplier replaces a malfunctioning unit. Thus, Case 1 and 2 seems most relevant to the VzW Excess inventory model, and we will ignore Case 3.

2.2.1.1 Modeling Obsolescence under Case 1

Under Case 1, we must model situations in which equipment becomes obsolete together at an unknown time period. Because equipment obsolescence is often memoryless, we will assume that exponential perishing is applicable and thus the perish episodes are characterized by a Poisson process. The distribution of the time that a unit perishes can be modeled as 1 – exp(-ht), where h is the hazard rate and t is time. We can then revise equation 1 to include obsolescence as seen in equation 2.

Equation 2:

$$n^* = \frac{\log(\frac{V+r/(i+h)}{A+r/(i+h)})}{\log(M(i+h))} \text{ in which } M(i+h) = e^{(-(i+h)x)}f(x)dx$$

where

n^* = optimal number of units to be kept/reused

V = salvage value at present time as a percent of current value

A = cost to replace retired equipment that is later needed as a percent of current value

r = non-capital holding costs per unit time as a percent of current value

i = discount rate per unit time

h = hazard rate

f(x) = distribution of time between demand episodes, x

We can apply the same inputs as we did in Chapter 2.2, in which the current value is $1000 per unit. The salvage value at present time is 25% of the current value. The cost to replace retired equipment that is later needed is 100% of the current value. Non-capital holding costs per year as a percentage of current value are 2% and the discount rate is 8% per year. Currently, 6000 units sit in Excess, and an average of 500 units will be used internally at VzW each year. However, in this case, equipment does not last forever, and the hazard rate is assumed to be 0.05. Thus, n^* in this model is 4038 units instead of 5727 units, and fewer units are kept when we consider obsolescence. We see the decrease in n^* because now that items do not last forever, VzW sells more items now and keeps fewer items for reuse or resale in the future because they might become obsolete before they are reused or resold.

2.2.1.2 Modeling Obsolescence under Case 2

In case 2, we model the situation in which equipment becomes obsolete together at a known time period. We introduce variable p, which is the time period at which the equipment will all perish. The optimal number of units to be kept, or n^*, is then modeled by equation 3.

Equation 3:

n^* is the maximum k such that:

$$V < E\{\left(A + \frac{r}{i}\right)\left(\frac{\lambda}{\lambda + i}\right)^k \times \sum_{l=k}^{\infty} \frac{[(\lambda + i)p]^l e^{-(\lambda+i)p}}{l!} - \frac{r}{i} + \frac{r}{i} e^{-ip} \sum_{l=0}^{k-1} \frac{[\lambda p]^l e^{-\lambda p}}{l!}\}$$

where

n^* = optimal number of units to be kept/reused

V = salvage value at present time as a percent of current value

A = cost to replace retired equipment that is later needed as a percent of current value

r = non-capital holding costs per unit time as a percent of current value

i = discount rate per unit time

p = time period at which the equipment will all perish

k = unit of equipment

λ = average number of units demanded of an item per unit time

As stated in Chapter 2.2, a Poisson process for the demand episodes is assumed. Thus, the summations in equation 3 can be estimated through a normal approximation to the Poisson.[7]

Using the same inputs as we used in Chapter 2.2 for no obsolescence and in Chapter 2.2.1.1 for Case 1, we find that $n^* = 3980$ units when the perish time is set to eight years.[8] For Case 2, just as for Case 1, n^* is smaller than in the scenario with no obsolescence because fewer units should be held if some units will become valueless. Furthermore, we find that n^* in Case 2 is slightly less than 4000 units, which is the total expected demand from now until the item becomes obsolete in eight years.

2.3 Challenges

Several challenges exist for this model. First of all, availability of data is limited. For example, the current market value of equipment is difficult to determine. Building relationships with third party resellers in the secondary market may help us to determine this information, but resellers may be

[7] The normal approximation should hold for equation 3 when $(\lambda+i)p$ and λp are both greater than 10. In this example, λ is 500 units per year, i is 8% per year, and p is eight years, so $(\lambda+i)p$ and λp are both greater than 10.
[8] A perish time of eight years was used in order to simulate 3G equipment that will be phased out in the year 2021, which is eight years from now (2013).

incentivized to provide a low estimate for the current market value. Given that the current market value is difficult to determine, future prices, such as the cost to replace a unit that is retired now but needed later on, is even more difficult to predict.

Secondly, scaling up the model may be challenging. We applied the model to three different items in two of Verizon Wireless' 21 regions (see Figure 5), but applying the model to thousands of products in all 21 regions will likely be much more complex and time consuming. Nevertheless, as seen in the examples, the models may provide financial benefits even when applied to a few items.

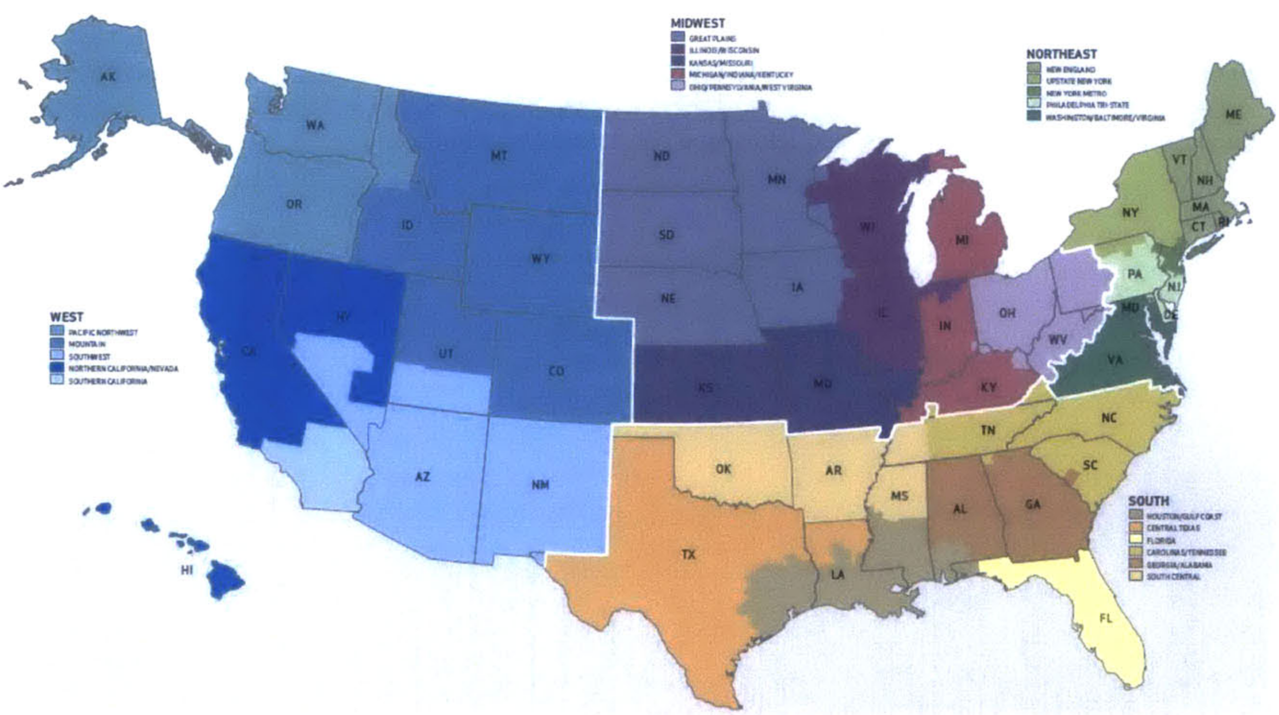

Figure 5. Map of Verizon Wireless' U.S. Areas and Regions. VzW is divided into four areas: the West, Midwest, Northeast, and South Areas. Each area is then divided into five to six regions, for a total of 21 regions.

Finally, it may also be challenging to train VzW employees to utilize the models. The model for the scenario with no obsolescence and the model for the scenario with obsolescence under Case 1 can be simplified in a way that allows an output to be generated in a tool like Microsoft Excel. The user would simply enter the inputs, such as yearly demand or current market value, in a spreadsheet or another user interface. The model for the scenario with Case 2 obsolescence, however, is much more complex.

Employees would require more training, including some knowledge of basic statistics in order to use the normal approximation to the Poisson, and the added steps could result in errors.

2.4 Benefits of Reuse vs Retire Models

As seen in the examples, the models may provide financial benefits to VzW even when applied to a few items. Furthermore, the models provide a data-driven approach that considers factors, such as holding costs, which were not analyzed during reuse versus retirement decisions prior to this research. While much work still needs to be done to overcome the aforementioned challenges and to implement the analytical model at VzW, giving employees a data-driven tool to balance the tradeoffs of holding too much or too little Excess inventory may lead to lower working capital requirements, greater return on invested capital, lower holding costs, and less space constrained warehouses.

3 Incentivizing Inter-regional Transfers of Reusable Equipment

3.1 Background

Once VzW retires unneeded Excess equipment, we are left with a pool of reusable equipment. Although equipment from one region is often reused internally within the same region, sharing of reusable equipment across different regions is not as prevalent. Logistical challenges associated with transferring equipment from one region to another likely play a role in limiting equipment transfer across regions, and this will be discussed in Chapter 4. However, another challenge lies in aligning the incentives at the regional level and the corporate level. Successfully aligning these incentives will likely increase the amount of inter-regional transfers of reusable equipment.

As indicated in Figure 5, Verizon Wireless is divided into 21 regions. Regions typically cooperate to do what is in the best interest of Verizon Wireless as a whole. The collaborative efforts at Verizon Wireless are especially evident when natural disasters occur, and all of Verizon Wireless' regions come together to ensure that affected regions have the equipment and personnel necessary to keep the wireless network running.

In spite of this collaborative spirit, the amount of equipment that is reused would likely increase significantly if incentives for inter-regional transfers of reusable equipment were put in place. Under the current system, each region acquires its own equipment and is responsible for ensuring that the purchased equipment is used efficiently within the region. If Region A believes that it will not reuse a particular piece of equipment, Region A will likely give up this equipment to any region that requests that equipment. However, if Region A is unsure of whether or not it will need a particular piece of equipment in the future, Region A will justifiably be hesitant to give this equipment to other regions that request it even though this is not in the best interests of VzW as a whole. In this case, other regions would be forced to buy new units of the equipment that Region A already owns, and Region A's equipment will be wasted if it never has the opportunity to reuse it.

As Chatterjee et al [10] have shown, business decisions in a variety of functions, including operations, strategy, and organizational design, can be modeled and analyzed using game theory. Game theory is applicable because it studies rational behavior in situations where there is interdependence (i.e. where one player's actions affect other players). Reusing equipment involves interdependence. It is not enough for one region to request equipment. The region that owns the equipment must be willing to give up the equipment before it can be reused. Game theory is based on a simplified model of a real-life strategic business situation, so like all models, it has its limitations. However, as McMillan [11] shows, game theory is helpful when thinking through issues in a systematic way to better understand how strategic decisions are made when two stakeholders' decisions affect one another.

3.2 Game Theory Analysis of Current State

Under the current incentive system, game theory suggests that a region that needs equipment will not request reusable equipment and a region that has reusable equipment in Excess will not send it to another region. For example, imagine that Region A has equipment that it can sell to a third-party buyer for $50,000. Region B needs this equipment and can buy it for $100,000 from a third-party vendor. It is in Verizon Wireless' interest for Region A to transfer the equipment to Region B so that expensive new equipment is not purchased externally. However, the Nash equilibrium suggests that this transfer will not occur under current conditions. Under VzW's current incentive system, regions do not pay other regions for reusable equipment. Current protocol dictates that if Region B were to convince Region A to send this equipment, Region B would only pay for shipping and for the time it takes an employee to identify and request equipment. Region A would give up the equipment at no cost and would have to pay for the time it takes an employee to confirm that the equipment is not needed within its own region and to ship the equipment.

Inputs for Sending Region	
Expected sales price to third-party buyer	$50,000
Cost to check if reusable equipment is available	$50
Cost to find and offer reusable equipment	$200
Cost to sell equipment to third-party	$50

Inputs for Receiving Region	
Price to buy item from third-party vendor	$100,000
Cost to find and request reusable equipment	$100
Cost to check if equipment is needed	$25
Cost to ship equipment	$500
Cost to buy equipment from third-party	$50

Table 2. Game theory inputs for sending and receiving regions

		Region B: Receiving Region	
		Request	Don't Request
Region A: Sending Region	Send	-$600 -$50	-$525 -$200
	Don't Send	-$100,650 $49,900	-$100,550 $49,950

Figure 6. Game theory analysis indicating that Region B will not request reusable equipment and Region A will not send reusable equipment at the Nash equilibrium. Within each box, numbers under the diagonal line represent the transaction value for Region A while numbers above the diagonal line represent the cost for Region B. For example, if Region B requests equipment and Region A sends the requested equipment, it will cost Region B $600 ($100 to find and request the equipment plus $500 to ship the equipment as shown in Table 2). It will cost Region A $50 to confirm that the equipment is available.

This analysis indicates that VzW's regions are not doing what is in the best interests of VzW as a whole. As seen in Table 3, the lowest cost method of obtaining needed equipment is for Region B to request the equipment and for Region A to send the equipment. Thus, the goal is to determine how to change the Nash equilibrium to an outcome that is more financially beneficial to VzW.

	Region B requests equipment	Region B does not request equipment
Region A sends equipment	-$650	-$725
Region A does not send equipment	$-50,750	$-50,600

Table 3. Total cost incurred by VzW to transfer reusable equipment and/or buy new equipment. These costs are calculated by summing the values above and below the diagonal line for each box in Figure 6.

3.3 Game Theory Analysis for Future State

Given that Region A currently receives no compensation for transferring reusable equipment to Region B, Region A's dominant strategy is not to send equipment. However, it is possible to change Region A's dominant strategy by incentivizing and compensating Region A for sharing equipment. If Region A could receive $50,000 by selling a piece of equipment to a third-party vendor but Region B offers $51,000, then Region A's dominant strategy will change as seen in Figure 7. In this example, Region B will also benefit from this internal equipment transfer because as depicted in Table 2, Region B would have had to pay a third-party seller $100,000 for the same equipment. When Region A receives more total compensation (with shipping and labor costs taken into account) by selling the equipment internally than by selling externally, Region A's dominant strategy changes; it will send equipment when asked, and it will even take the initiative and offer to send equipment to Region B when Region B does not request equipment. (Note: it is realistic for Region A to offer equipment to other regions who did not request equipment. This generally happens when a region has a space-constrained warehouse and takes the initiative to offer equipment to other regions.)

Although we can change the dominant strategy for Region A by compensating Region A for sharing equipment, we have not yet changed the dominant strategy for Region B, whose dominant strategy is still not to request equipment. At the Nash equilibrium shown in Figure 7, equipment is being reused, but the total cost of this reuse has not yet been minimized: as seen in Table 3, Verizon Wireless as a whole incurs the lowest cost when Region B requests equipment and Region A sends equipment. Region B chooses not to request equipment because it requires higher labor costs to search for and request equipment than to simply accept equipment that is offered to them. To change Region B's dominant strategy, we must change the process to search for and request equipment, which we will discuss in the next chapter.

		Region B: Receiving Region	
		Request	Don't Request
Region A: Sending Region	Send	-$51,600 / $50,950	-$51,525 / $50,800
	Don't Send	-$100,650 / $49,900	-$100,550 / $49,950

Figure 7. Game theory analysis of a scenario in which Region A is financially compensated for transferring equipment to Region B. Region A will send reusable equipment even though Region B will not request equipment at the Nash equilibrium.

4 Visibility and Access to Reusable Equipment Nationwide

4.1 Background

As described in Chapter 3, the process of finding and requesting reusable equipment must be less time intensive than it currently is in order to incentivize regions to request reusable equipment. Otherwise, regions will simply wait for other regions to offer equipment or they may even buy new equipment if reusable equipment is not offered.

The current process of identifying and requesting reusable equipment poses many challenges. The major challenges are that regions may not know what equipment is available in other regions and regions also may not know who to contact in other regions in order to request this equipment.

While many inventory tools exist to manage enterprise-wide resources, these inventory tools are currently not designed to facilitate the efficient reuse of network equipment. For instance, searches were conducted on just one item within the enterprise-wide inventory system using various search criteria (e.g. part number or part name), and the search process using each criteria took 13 minutes on average. However, putting together a cell site, for example, requires hundreds of different parts. Performing hundreds of searches for different parts and requesting these items from various regions in the US would likely take days using current tools, so regions might understandably skip the laborious reuse process and simply buy new equipment. Thus, a more efficient process and tool must be put in place to facilitate the identification and request of network equipment from region to region.

Although VzW's regions are part of a single entity, the dearth of information sharing and the misaligned incentives create a situation in which regions that have reusable equipment may be compared to external suppliers while regions that request equipment may be compared to buyers. A wealth of research examines process efficiency between suppliers and buyers and argues the importance of web-based tools to facilitate data transfer and procurement. As Grieger et al. argue [12], internet-based electronic marketplaces are "the most promising interorganizational information systems allowing firms to integrate with suppliers and customers." Saeed et al. [13] also contend that interorganizational systems (IOS), which include electronic data interchange (EDI) systems, electronic trading systems, and web-based procurement systems, provide the tools necessary to forge collaborative relationships and enhance process efficiencies. Coordination costs are lower and response times are shorter and more reliable with the use of IOS. Consequently, we began to explore various IOS solutions that would enable us to achieve these process efficiencies when transferring equipment across regions.

Saeed et al. assert that the type of relationship between supplier and buyer should be considered when structuring IOS processes. In competitive supplier-buyer relationships, a buyer requires an IOS system that allows him or her to examine the market and find the best price. In a long-term cooperative relationship, however, the buyer and supplier require extensive information sharing in order to maximize efficiency. It is hoped that VzW's regions will have a long-term cooperative relationship with one another in order to reach common objectives that benefit VzW as a whole. Given that we seek to have a long-term cooperative relationship between VzW's regions, efficiency gains can be achieved by sharing information with other regions and by automating the ordering process.

4.2 Reuse Marketplace Tool

After identifying business requirements for an internet-based electronic marketplace, we worked with a third-party vendor to design an internet-based tool, which we will call the Reuse Marketplace Tool. These business requirements will not be discussed in detail in order to protect proprietary information at VzW.

As previously mentioned, identifying reusable network equipment can be the most challenging step for regions that have little visibility regarding the availability of reusable equipment in other regions. The Reuse Marketplace Tool addresses this challenge by pulling in inventory data from existing inventory databases at Verizon Wireless and providing a fast and intuitive search capability by which users can quickly and easily search for and identify reusable equipment using a variety of search criteria.

The process by which equipment is requested is also more efficient when using the Reuse Marketplace Tool and the embedded workflow capability. Each region enters a designated approver in the system, so when other regions request items from that region, a request is automatically routed to the appropriate approver.

The Reuse Marketplace Tool was piloted in Verizon Wireless' South Area (refer to Figure 5 for geographic boundaries of the South Area) during the author's engagement with VzW. Since the pilot began, hundreds of thousands of dollars of equipment have been identified and requested in the South Area alone. Once buy-in from headquarters and the other three Areas is obtained, it is anticipated that the Reuse Marketplace Tool will be expanded nationwide.

5 Metrics

5.1 Background

While certain regions at Verizon Wireless began tracking the amount of equipment that was reused prior to the author's engagement with VzW, there is currently no agreed upon metric for reuse that is tracked nationwide for all regions. Reuse metrics are desirable for many reasons. Properly designed metrics can create accountability, drive behavior, help identify problem areas, guide improvement efforts, and enable the implementation of some incentive systems.

There is much research on the qualities of effective metrics. For instance, Eckerson [14] argues that effective metrics have 12 characteristics. Effective metrics are:

1. Strategic: Metrics embody a strategic objective and help the organization determine whether it is on track to achieve goals or outcomes.
2. Simple: Employees should be able to understand how metrics are measured and calculated, how incentives are affected by metrics, and how they can move the metric in a positive direction.
3. Owned: Metrics should have an owner who is accountable for the outcome of the metric.
4. Actionable: Employees should be able to take corrective action to improve the performance of a metric.
5. Timely: Metrics should be updated often enough for accountable metric owners to improve metrics when necessary.
6. Referenceable: Employees should be able to trust the data, know where the data came from, and how it was calculated.
7. Accurate: Metrics must accurately measure an activity. A metric that tracks worker productivity, for example, as calculated by the ratio of revenue to the number of workers

may be inaccurate because a rise in the inflation rate, which boosts revenue, will increase the metric even if worker productivity does not increase.

8. Correlated: Metrics must drive desired outcomes.
9. Game-proof: Employees must not be able to "game" the metric by making their numbers appear better than they actually are.
10. Aligned: Metrics should be aligned with one another to ensure that doing better in one metric does not undermine another metric.
11. Standardized: Employees across the company must agree on terms that affect the metric so that metrics in different geographies or other groups can be accurately compared or rolled-up.
12. Relevant: While metrics may be effective when first established, they should be revised or discarded over time with changes in processes, goals, etcetera.

This chapter examines literature on metrics to establish guidelines that should be examined when determining appropriate metrics to use. We then evaluate several metrics based on these guidelines.

5.2 Evaluation of Reuse Metrics

Initially, we considered using the amount of equipment reused per region as the primary metric. This metric was already measured by several regions, and it fulfilled several of Eckerson's criteria for an effective metric. The 'amount of equipment reused' metric is **strategic** and **correlated**[9]: it embodies the strategic objective of reusing more network equipment and drives the desired outcome of decreased working capital needs and decreased carbon footprint.

While this metric may seem to fulfill the requirement for **simplicity**, it is not as simple as it appears. Due to limited data regarding reuse, there is no easy way to determine how much equipment a region has reused. The amount of reuse can be estimated using data that does exist (e.g. by examining the transfer of

[9] The twelve characteristics of an effective metric will be written in **bold** so that readers can better track which effective characteristics are or are not met.

equipment from one location to another), but this method is highly complex. While some regions have tried to quantify the amount of equipment that has been reused by manually adding up the dollar value of the equipment (for example, in terms of purchase price) that they reuse, this process is time consuming and the data is not **referenceable**; there is no auditable record that allows others to trust the data or even to know where it came from.

Furthermore, tracking the amount of reused equipment is a metric that is difficult to **standardize**. Regions do not have the same amount of Excess or reusable equipment. As an example, if VzW were to acquire another wireless service provider that only served the Northeast, then VzW regions in the Northeast may be left with the majority of the acquired wireless service provider's network assets. These VzW regions would then have immense amounts of equipment in Excess that can be reused while other regions would not have as much. In this case, it would be unfair to compare the reuse of regions with a lot of equipment in Excess to regions without a lot of equipment in Excess.

Measuring the amount of reuse as a metric may also be **inaccurate**. While there is a tremendous amount of 3G equipment in Excess currently, there may not be as much in a few years. Thus, regions are concerned that they will be unfairly evaluated in the future if they reuse a large amount of equipment now but reuse only a small amount later on.

Finally, there are many ways to game the system when using the amount of reuse as a metric. For instance, regions that transfer equipment from one cell site to another cell site within the same region are reusing equipment internally. However, regions could shuffle equipment from one cell site to another to increase the metric for the amount of reuse. While regions likely would not game the system, it is still important to ensure that the metric system cannot be gamed, especially when incentives are involved.

In lieu of examining the amount of reused equipment, a reuse metric that could be used is the percentage of equipment aged greater than 365 days,[10] which we can refer to as the aging metric. As mentioned in Chapter 2, Verizon Wireless' objective is not only to reuse equipment but also to retire unneeded equipment in order to reduce holding costs and allow space-constrained warehouses to free-up room. Aging metrics would incentivize regions to move equipment out of Excess either by allocating equipment to a project within their region, by sharing equipment with another region that needs the equipment, or by retiring equipment that has not been allocated internally or requested by other regions after one year.

This metric would be **strategic** and **relevant** and would help VzW determine whether it is on track to meet its goals. It would be **simple** to measure, **timely,** and **referenceable** given that aging data is already tracked by an enterprise-wide electronic system as soon as equipment enters the warehouse and is scanned into the Excess category. The metric would also be **owned** by each region, **actionable**, and **correlated** with desired outcomes. It would be **accurate** and **standardized** because the data could be compared across regions and over time even as the amount of Excess equipment changes. For instance, a region that owns very little Excess equipment could still achieve high performance under this reuse metric as long as it reuses, shares with other regions, or retires what little Excess equipment it has.

The only characteristic of a good metric that is not met is the characteristic of being **game-proof**. There are unfortunately many ways to game the aging metric. For instance, a region could quickly retire equipment that their own region cannot use without offering the equipment to other regions. This would quickly decrease the percentage of equipment aged greater than 365 days. Furthermore, although equipment that enters the warehouse will be electronically classified as Excess, regions could game the metric simply by leaving equipment in the field (e.g. at a cell site) so that it appears that they have no Excess. They could then achieve "perfect" performance on the aging metric because they would have 0%

[10] VzW headquarters recommends that its region retire equipment after a certain number of days. The exact number is not disclosed in this thesis in order to protect proprietary information, but 365 days is used for illustrative purposes in this thesis.

of equipment aged greater than 365 days in Excess in the extreme case where they bring no Excess equipment back to the warehouse.

Fortunately, there are many ways to prevent or reduce gaming of the aging metric. VzW could set a minimum time that equipment must be kept in Excess[11]. Coupled with the Reuse Marketplace Tool (or any other nationwide visibility tool), other regions would be able to find and request equipment within this minimum time frame. If other regions have not requested the item within the minimum time, the region that owns this equipment can retire the item without gaming the system because no one appears to need it.

In terms of the second loophole, regions can always choose not to label their equipment as Excess. While most regions likely would not game the metric, the easiest way to game the metric is to keep equipment at the cell site or other in-service location instead of bringing equipment back to the warehouse, where it will then be labeled as Excess. However, cell sites are relatively space-constrained, so "hiding" equipment in a cell site instead of correctly categorizing items as Excess will likely occur infrequently, especially since there simply is not very much space to "hide" equipment.

When we compare the aging metric to the amount of reuse metric, we find that the aging metric possesses many of the characteristics of a good metric, as seen in Table 4, while the metric that tracks the amount of reused equipment possesses less than half of the characteristics of an effective metric.

Eckerson noted the importance of **aligning** proposed metrics with other existing metrics. It is still too soon to tell whether any metric that encourages the reuse of network equipment will be aligned with other goals such as network quality. The primary concern is that reusing equipment could undermine the renowned reliability of VzW's network services, so it is highly recommended that network quality metrics, such as number of dropped calls, be tracked in a way that allows VzW to compare network

[11] A subject matter expert (SME) group periodically reviews Excess equipment to determine what is obsolete and needs to be retired immediately. These obsolete items identified by the SME group can be immediately retired, so regions would not be forced to hold these items for a minimum number of days.

quality in areas with reused network equipment and areas without reused network equipment. Given that the effects of reuse on other metrics such as network reliability are not yet known, we will leave the "aligned" characteristic unrated, as depicted in Table 4.

Qualities for Effective Metrics	Metrics to Evaluate	
	Amount of Equipment that is Reused	% of Equipment Aged Greater than 365 Days
Strategic	1	1
Simple	0	1
Owned	1	1
Actionable	1	1
Timely	0	1
Referenceable	0	1
Accurate	0	1
Correlated	1	1
Game-proof	0	0
Aligned	?	?
Standardize	0	1
Relevant	1	1
Sum	5	10

Table 4. Evaluation of two metrics to determine whether they possess Eckerson's 12 characteristics of effective metrics. A score of "1" indicates that the characteristic is met while a score of "0" indicates that the characteristic is not met.

In summary, we have compared two possible metrics for the reuse initiative. Neither metric meets all the criteria for effective metrics as defined by Eckerson, but the aging metric meets 10 of the 11 characteristics (alignment cannot be evaluated as discussed in the previous paragraph). It is possible that more effective reuse metrics may exist, and this chapter provides a framework and criteria to evaluate other reuse metrics.

6 Conclusion

6.1 Key Findings

At the start of this research, three primary challenges that limit reuse at VzW were identified. This thesis addresses these challenges. First, we examined a method of determining how many units of equipment can actually be reused. We present a model that will allow VzW to balance the tradeoff between holding too many units, which leads to high holding costs and unnecessary space constraints, and holding too few units, which forces VzW to unnecessarily pay to reacquire equipment that it previously owned but retired.

Once a pool of reusable equipment is identified, we examined game theory models to determine how regions can be incentivized to not only request equipment but also to share equipment with regions that request equipment. This model suggests that regions that own reusable equipment can be incentivized to share equipment if they are monetarily compensated for transferring equipment to other regions. Furthermore, regions can be incentivized to request reusable equipment by implementing simpler processes to identify and request reusable equipment.

We then explored tools and processes to simplify the identification and request of reusable equipment through the design of an internet-based electronic marketplace, called the Reuse Marketplace Tool. This tool leverages existing inventory data and allows users to find and request reusable equipment quickly and easily. Furthermore, the Reuse Marketplace Tool has already contributed to the reuse of hundreds of thousands of dollars worth of equipment in the South Area since its initial pilot in December 2012, and it is anticipated that the tool will facilitate even more reuse if it is implemented nationwide.

6.2 Areas for Future Study

Although we have addressed a few of the challenges associated with reusing wireless network equipment, remaining challenges are also important to address. As Byrd et al [15] found, addressing multiple challenges often has synergistic effects where the positive effect achieved through improvements in multiple challenge areas will be greater than the sum of the separate effects of each individual challenge area.

First, there are still many processes left to standardize. Current de-installation and transportation procedures, or a lack thereof, can lead to damaged equipment and ultimately limit the amount of reuse. While some equipment malfunctions, such as deterioration of equipment over time, cannot be prevented, there are many equipment malfunctions that are preventable. Proper de-installation and transportation of equipment can reduce damage to reusable network equipment. When regions receive malfunctioning equipment that they intended to reuse, the ramifications can be long-term. Regions that receive damaged "reusable" equipment are hesitant to reuse equipment in the future and will be more likely to buy new parts from a supplier instead of requesting old "reusable" equipment that may or may not function properly when it arrives.

Properly de-installing and transporting equipment requires process standardization, and different types of equipment may require different handling methods, which might be time intensive at first. Once the appropriate processes for different types of equipment or for different suppliers' equipment are identified, standardization of de-installation and transportation processes should require very little capital expenditure. For instance, in many cases, adding inexpensive anti-static wraps and cushioning can protect sensitive electronics from damage.

A more capital intensive improvement involves the acquisition of testing equipment. This will ensure that equipment leaving one region is working before it sent to another region and might boost the regions' confidence in receiving undamaged reusable equipment. However, acquiring this testing equipment might be expensive, and further analysis will need to be conducted on whether such an investment will be worthwhile.

Further process standardization in addition to the tools and processes that have been discussed in this thesis will help enable Verizon Wireless to reuse its wireless network equipment more efficiently and minimize working capital requirements, improve return on invested capital, and decrease VzW's carbon footprint.

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