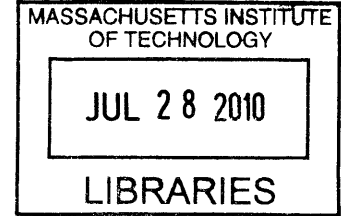# Aftermarket Vehicle Hybridization: Designing a Supply Network for a Startup Company

by

Marcus S. Causton

B.S. Chemical Engineering
Colorado School of Mines, 2000

and

Jianmin Wu

B.S. Chemical Engineering
Cornell University, 2009

Submitted to the Engineering Systems Division in Partial Fulfillment of the
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Massachusetts Institute of Technology

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Signature of Author....
Master of Engineering in Logistics Program, Engineering Systems Division
May 2010

Certified by......
Dr. Jarrod Goentzel
Executive Director, Masters of Engineering in Logistics Program
Thesis Supervisor

Accepted by......
Prof. Yossi Sheffi
Professor, Engineering Systems Division
Professor, Civil and Environmental Engineering Department
Director, Center for Transportation and Logistics
Director, Engineering Systems Division

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Aftermarket Vehicle Hybridization: Designing a Supply Network for a Startup Company

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Marcus S. Causton and Jianmin Wu

Abstract

Our thesis introduces a supply chain framework catered for startup companies. Startup companies face unique circumstances such as constraints on financial and human resources, and greater uncertainty in demand. From our work with XL Hybrids, a startup company that hybridizes aftermarket vehicles, as well as interviews and literature review, we have attempted to distill supply chain strategies that can be applied to startup companies.

To plan XL Hybrids' supply chain, we developed models for the following aspects of their supply chain: production scheduling, capacity planning, inventory policy, and component distribution. By running different demand and pricing scenarios, we gained an understanding of the impact of these variables on the four aspects of XL Hybrid's supply chain. Based on the scenario analysis and supply chain framework that we developed, we recommend that XL Hybrids be conservative with capacity expansion while strategically sourcing key components after considering volume discounts and different distribution methods.

Thesis Supervisor: Dr. Jarrod Goentzel
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1 INTRODUCTION

Planning an effective supply chain strategy for a company involves complex considerations such as sourcing, distribution, demand forecasting and capacity planning. Supply chain planning for a startup company involves similar complexities with the added challenge of demand uncertainty and financial and human resource constraints. For our thesis we worked with XL Hybrids, a new company founded by MIT alumni which converts existing vehicles into hybrids, to design its supply chain. XL Hybrids offered us the opportunity to study a startup company that is introducing a new technology into a market that does not exist. In addition to designing supply chain strategies to help XL Hybrids cope with extreme demand uncertainty and resource constraints typical of a startup, we also helped XL Hybrids identify the parts of its supply chain to outsource versus manage in-house.

Our thesis is divided into two parts. The first part describes our work with XL Hybrids to design its supply chain. The second part describes a broader supply chain framework for startup companies based on our lessons learnt from designing XL Hybrids' supply chain, interviews, and literature review. Typically, companies do not think about supply chain issues at the startup stage due to resource limitations. We believe our framework can help startup companies think about supply chain issues early on. Furthermore, it will enable startups to implement supply chain management strategies that will help them conserve cash, maximize internal resources, cope with uncertain demand, and decide outsourcing strategies.

Section 1.1 and Section 1.2 is dedicated to introducing the motivation and scope of the two parts of our thesis. The rest of Section 1 describes our literature review.

1.1 XL Hybrids

XL Hybrids is a startup company that converts conventional, gas-powered commercial vehicles into hybrids, allowing customers to improve fuel efficiency of their existing vehicles. Five converging factors are driving the business opportunity for hybridizing commercial vehicles: First, gas prices now exceed $2.50 per gallon and continue to rise. Second, hybrid vehicles have become accepted as a viable transportation solution with corporate and individual consumers beginning to adopt the technology. Third, the U.S. government is beginning to mandate the adoption of hybrids and fuel-efficient vehicles. Fourth, corporations are adopting carbon emission reduction policies for their vehicle fleets. Fifth, there are millions of low-MPG commercial vehicles in the U.S. This results in thousands of dollars being spent on fuel annually per vehicle. Owners of these types of inefficient commercial vehicles have been exposed to high gasoline prices since 2008 and are now seeking ways to reduce their fuel costs. Hybrid retrofits offer fleet owners lower fuel costs and lower carbon emissions on their existing vehicles. Aftermarket hybridization of these vehicles represents a multi-billion dollar market opportunity for XL Hybrids.

XL Hybrids' hybridization process uses three critical components which are sourced from external suppliers: a battery, a controller and an electric motor. XL Hybrids purchases these components and assembles them into a kit which is installed into vehicles. These components are sourced from overseas suppliers and will be shipped via a U.S. port. Since all the components are sourced externally, careful sourcing is required to ensure the conversion is reliable and of a high quality. The hybridization process involves quality control testing of the individual components before retrofitting them into the vehicle. This entire process takes approximately four hours. The conversion can take place in a XL Hybrids conversion center, or can be performed offsite at a customer's location by sending a XL Hybrids mobile van with the workers, components, and installation equipment. Mobile vans have a higher capital cost, but incur lower operating costs and

are more convenient for the customer. XL Hybrids is planning to open many conversion centers in urban markets over the next couple of years to complement its existing Boston area headquarters.

XL Hybrids' sales cycle lasts approximately six months. The process involves working with the customer to identify the number of vehicles that need to be converted and to schedule the conversions around availability of vehicles and conversion capacity. This allows XL Hybrids to negotiate customer contracts with flexible conversion deadlines and plan capacity around incoming orders. Additionally, since the sales cycle time exceeds both product delivery time and the time required to increase capacity, XL Hybrids is able to lower inventory levels and postpone capacity expansion. This is unique to XL Hybrids, since most startup companies will need to have product and capacity available in advance of confirmed sales.

From our consultations with XL Hybrids, we limit the scope of our thesis to the following four elements of supply chain planning:

- Production planning
- Capacity expansion
- Order quantity
- Warehousing versus transshipment decision

We built optimization models for production planning and capacity expansion, and built simulation models for order quantity and warehousing/transshipment decision to analyze these aspects quantitatively. Using these models, we stress-tested our results by analyzing multiple scenarios for XL Hybrids' supply chain based on demand projections, supplier locations and other operating conditions. This is especially important for a startup company since there is greater uncertainty in its business during the early stages. Our models focus on the three most important components from XL Hybrids' conversion kit- the battery, the controller, and the electric motor-

which are sourced from three separate specialty suppliers. Based on the results from our four models, we provided XL Hybrids with recommendations for planning its supply chain.

We introduce and explain our four models in Section 2. In Section 3, we summarize the results of our scenario analysis and provide recommendations for XL Hybrids.

1.2 Supply Chain Framework for Startup Companies

As mentioned previously, the second part of our thesis introduces a supply chain framework for startup companies. This framework is for startup companies that have a sellable product or a product at a later stage of development.

We began this project fully intending to find supply chain frameworks for startup companies that we could use. However, while our literature review uncovered supply chain frameworks that are industry specific, we did not find studies that are specific to a company's timeline. Consequently, our literature review did not uncover any supply chain frameworks focused on startup companies. Additionally, books for startup companies such as "Start Your Own Business" (R. Lesonsky, 2001) or online websites like entrepreneur.com do not approach the startup process from a supply chain viewpoint.

This lack of literature signaled an opportunity for us to contribute meaningful research to the subject of entrepreneurship and startup companies. This also indicates that perhaps most startup companies do not think hard enough about supply chain management and the importance it can play in the growth of a company. Startup companies are restricted in human and financial resources, thus they focus on issues that are core to their business, such as sales, operations, and raising funds. Supply chain is typically viewed as a support function for their core business rather than something that is managed in-house. However, based on our work with XL Hybrids, we

believe that there is value in startups thinking early about supply chain concepts, as these concepts will likely impact fundraising decisions *(How much money is needed to fund operations?)*, hiring decisions *(How many people do we need to hire?)*, expansion decisions *(When should we open additional facilities?)*, sourcing decisions *(When should my company begin using an RFP process?)*, as well as many other future operations.

Having identified the opportunity to contribute meaningful research on an increasingly important business topic, we decided to compile a framework that is angled towards helping startup companies design a supply chain strategy. Our framework is based on our work with XL Hybrids, literature review, and interviews with academics and other professionals in the field. We then distilled possible strategies in supply chain planning that can be applied to startup companies.

Our framework can be divided into two phases. In the first phase, the company has to define its market, customers, product, process, and competitive advantage. These factors are the core elements of a business plan that affect how the supply chain is designed. Before moving to the next phase, the company has to decide how much of its supply chain to outsource.

In the second phase, the company begins to look at different parts of the supply chain, such as production planning, capacity expansion, and network design. Although this list is similar to what an established company has to consider, a startup company will look at these concepts through a different lens. Startup companies face unique circumstances in planning their supply chain, such as financial constraints and greater uncertainty in demand. Our framework seeks to explain how these unique circumstances affect how startups plan the different parts of the supply chain.

Section 4 of our thesis describes this framework in detail. Finally, Section 5 discusses future steps to expand literature in this field.

1.3 Review of Literature

We looked at five supply chain concepts related to XL Hybrids' supply chain: capacity expansion and production scheduling, warehousing, transportation, distribution options, and assemble-to-order startups. To get a better understanding of these concepts, we surveyed case studies, journals, articles, and textbooks. The bulk of the literature we found focuses on optimizing supply chain networks for established companies, which have greater financial resources, more predictability in their supply chain, and can afford to be more risk-seeking. With little literature found on supply chain design for startups, we modified the concepts of established companies in order to apply them for a startup company such as XL Hybrids.

The literature review starts with an analysis of techniques to optimize production scheduling and capacity planning in Section 1.3.1. In Section 1.3.2 we look into inventory policies that provide background on inventory strategies. Section 1.3.3 then reviews warehousing logistics and basic cost structures to determine how these concepts could be incorporated in our distribution model for XL Hybrids. Section 1.3.4 looks at typical shipping options for freight transport. In Section 1.3.5 we researched startup companies with assemble-to-order production processes to see how they plan and develop their supply chain network.

1.3.1 Production Scheduling and Capacity Expansion

We classify XL Hybrids' service as an assemble-to-order system with few product varieties. This means they should follow a "lag and level" capacity planning strategy (Olhager, Rudberg & Wikner, 2001), which focuses on high utilization of working resources. Capacity expansion typically results in a large incremental step in capacity. A "lag" strategy means that capacity is added when there is enough demand to cover the gain in capacity. A "level" strategy takes a short time horizon

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for demand and averages the production to ensure that there is constant production in the short-term. This "lag and level" strategy means that capacity would always be lower than the demand, and results in high utilization of working resources. This concept was captured in the structure of our capacity planning model.

Rajagopalan & Swaminathan (2001) offers another way to optimize production scheduling by comparing inventory holding costs versus facility expansion costs while ensuring demand is met. The authors suggest that it is better to build inventory with current excess capacity in order to postpone the need to expand capacity. For XL Hybrids, this is analogous to converting vehicles in advance whenever there is excess capacity. However, this will most likely be infeasible since the vehicles may not be available for conversion. The model developed by Rajagopalan & Swaminathan combines production scheduling with capacity expansion, which we tried to duplicate. However, XL Hybrids' multiple options for expanding capacity, and its long time horizon, introduced too many decision variables which made solving the model infeasible using the Risk Solver Microsoft Excel add in. Thus we separated the model into a production planning and a capacity expansion model. Our approach was primarily focused on optimizing for the most cost effective way to expand the facility given an optimized production plan.

For capacity planning, Yuan and Ashayeri (2009) took a simulation approach using a control theory model to simulate the growth of a firm's supply chain as a function of price change, intercompany delays and sales effectiveness changes. Our thesis looks at achieving similar results using an optimization model under a fixed demand.

The "lag" strategy also means XL Hybrids has to postpone some of its demand. Current postponement models (Iyer, Deshpande & Wu, 1999) compare the cost between postponing a fraction of the demand versus adding capacity in a two period scenario. Chen (2001) also looks into how companies might fulfill demand differently for different consumers based on how much they

are willing to pay. We incorporated the use of postponement costs in our optimization model, and extended the time frame to consider a multi-period scenario.

1.3.2 Inventory Policy

Our focus of this section was to gain understanding on building a model to determine the order quantity for the three key parts involved in XL Hybrids' hybridization process. To optimize the order quantity, we used the modified Silver-Meal heuristic model (Hu, Munson, Silver, 2004) to determine the order quantity that minimizes the total costs related to lost opportunity cost of volume discounts, transportation costs, and carrying costs. Unlike the more simplistic periodic review and continuous review model, the Silver-Meal heuristic model allowed us to incorporate varying weekly demand as well as non-linear transportation and volume discount cost equations.

More complex models which account for variable lead time from suppliers (Pan & Yang, 2002), and analyze the benefits of Just-In-Time inventory management using lead time efficiency (Olhager, 2002) were also considered to determine the order quantity for XL Hybrids' key parts. However, the increased complexity of Pan's and Olhager's model that better account for lead time variability would not bring about any additional insights beyond the Silver-Meal heuristic model. This is because volume discounts drove the bulk of the total relevant costs, thus lead time had little effect on the inventory policy.

1.3.3 Warehousing

In this section we discuss the literature that helped us understand more about warehousing and how it could be applicable to XL Hybrids. The literature gave us insight into the type of warehousing that a startup company should be using due to limited cash constraints and uncertain demand.

Bolten (1997) states that warehouses can be operated as a private, public, contract, or leased facility. Private warehouses allow for responsiveness, but have high cost of capital. Managing a private warehouse requires the same expertise as running a public warehouse, but all the risk of damage and responsibility is borne by the company. Public warehousing allows for flexibility in inventory location so companies such as XL Hybrids are not tied long term to a private facility in a fixed location. The commitments are often short term monthly contracts. Public warehousing relieves companies of maintaining a professional operation and bearing the burden of safety, insurance, environmental, and legal responsibilities. Contract warehouses are similar to public warehouses however they involve long term contracts and thus have higher service and lower rates than a public warehouse.

One of the key decisions in deciding whether to set up a warehouse is whether to outsource warehousing operations by working with a 3rd party logistics provider (3PL) or whether to manage the warehousing internally. Feare (2000) highlights several large companies that spend a huge amount of money on 3PL services. For example, Nabisco, with annual revenues of $9 billion per year, spends more than $200 million on 3PL services. Feare discusses in his paper that using companies that work in a multi-client variable-cost environment allows for flexible contracts and "you pay only for the space and labor you use". This flexibility is ideal for a startup company, which should not be tied into long term contracts because its business is still very uncertain. Even Wal-Mart uses 3PL warehousing to supplant its distribution centers for seasonal demand. L.E Mason, a maker of electrical components, works with a 3PL which has allowed it to focus its investments on sales/marketing and on product development. This has enabled L.E Mason to focus on its core business and adapt with agility to marketplace changes and requirements. This flexibility is ideal for XL Hybrids because it is cash constrained, and it needs the ability to adjust to market demand.

Tompkins, Simonson, & Upchurch (2006) state that selecting the fee structure serves as the basis for the service agreement between the company and the 3PL. For startup companies, a transaction fee structure is most ideal. A flat fee is typically charged per unit of work or per unit of pallet handled. For our analysis we have contacted various 3PLs and received cursory public warehousing rates for locations in New Jersey and Pennsylvania, which we have used in our model to estimate the costs of warehousing.

1.3.4 Transportation Modes

For transportation modes, we focused on land and ocean-freight literature to understand the movement of components from suppliers to XL Hybrids. The majority of ocean freight literature involved methods to optimize inventory, capacity, routing, and scheduling under different conditions. A review of existing models by Christensen (1999) categorized them by the parameter the user wanted to vary. Because of the complexity of planning and scheduling transportation routes, it would be better for a startup company like XL Hybrids not to engage in these tasks. Instead XL Hybrids should initially use a company such as Fed Ex to manage the transportation of their components so that it can focus time and capital on its core business.

1.3.5 Startup Company Supply Chain Strategy

In this section we looked at other companies' supply chains to gain insights into how their supply chains operate and how they were developed to keep costs down while maintaining a high service level. We looked to see what XL Hybrids could learn from successful startup companies to develop and expand its own supply chain.

Dell's supply chain is focused around an assemble-to-order process with low inventory, which is a key factor to their growth and success. Dell has created a supply chain closely linked to Just-in-Time processing through vendor-managed inventory (VMI). S. Kumar and S. Craig (2007) identified a "store revolver" in the supply chain as a stocking point for inventory. This stocking

point is one of the keys to bridge the gap between suppliers and Dell where the suppliers manage the inventory in the revolver and Dell pulls stock from the revolver to fulfill orders. Dell strives to have modular components that can be combined and interchanged at the final assembly to create different products. This postponement strategy allows for flexibility in meeting customer orders while holding less inventory. For XL Hybrids, modularity of some of the assembly parts such as the screws, bolts, and other off the shelf items will help minimize inventory, as it allows for more sharing of parts across conversions of different vehicle models. Another key success factor for Dell is the partnerships it has developed with suppliers through VMI and sharing of sales forecasts. This again allows for less inventory to be held in the supply chain, and prevents the Bull Whip effect. For XL Hybrids, this approach to VMI may be applicable for its off the shelf parts since these parts will be fast moving and modular.

Aside from Dell, we also looked into the supply chain of CarCo, as it has an assemble-to-order automotive supply chain similar to that of XL Hybrids (Miemczyk and Howard, 2008). CarCo's assemble-to-order approach stemmed from wanting to reduce inventory in the supply chain and allow flexibility to satisfy market demand. The assemble-to-order business has better profit margins than their build-to-stock business. One of the key insights from the paper was that build-to-order systems require more flexibility in the supply chain since market demand is more variable thus suppliers are expected to respond faster. This requires close partnerships with supply chain stakeholders. Similarly, XL Hybrids' long sales cycle of converting a fleet of vehicles is essentially an assemble-to-order system which may allow low inventory levels. For XL Hybrids to have low inventories it will need to have close partnerships with its suppliers.

2. METHODOLOGY

We built models to simulate the following aspects of XL Hybrids' supply chain: production scheduling, capacity expansion, order quantity, and distribution. In our models, we focused on the battery, controller and electric motor, which are the three key parts in the conversion kit's bill of materials. These components make up at least 80% of the cost of goods sold and are, currently, only sourced from overseas suppliers. Hence, these parts account for the bulk of purchasing, transportation, warehousing and holding costs for XL Hybrids.

Section 2.1 describes an optimization model for XL Hybrids' production plan. An overview of the optimization model used to plan XL Hybrids' capacity expansion is found in Section 2.2. Section 2.3 discusses the modified Silver-Meal heuristic model used to determine the economic order quantity for the three key parts. Finally, Section 2.4 describes the simulation model we developed to compare warehousing and cross-docking distribution methods for the key parts.

2.1 Production Scheduling

Our production scheduling model optimizes a production plan to meet the forecasted sales using Microsoft Excel with the Risk Solver add in. The forecasted sales were given as a series of monthly orders from October 2010 through June 2015.

We optimized the production schedule by minimizing costs associated with expanding capacity, maintaining capacity, and postponing vehicle conversions. The decision variables to optimize our production planning model are production capacity addition (A_t) and conversions performed ($x_{o,t}$).

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We assumed the cost of expanding capacity by one unit is a fixed cost and the cost of maintaining one unit of capacity is a constant monthly fee. This model does not take into account the various methods we have at our disposal to increase capacity, such as increasing the number of shifts, mobile teams, or bays. The different methods to increase capacity were considered in the capacity planning model.

2.1.1 Model Setup

<u>Objective:</u>
To minimize total production cost (Γ_p):
$$T_p = min \sum_{t=1}^{T}\left((B_t \times C_A) + (A_t \times C_B) + \sum_{o=1}^{o}\left(L_{o,t} \times CP_{0,t}\right)\right) \qquad \text{(eq. 2.1)}$$

<u>Decision Variables:</u>
Conversions for order o in a month t ($x_{o,t}$)
Production capacity addition in month t (A_t)

<u>Inputs and Constants:</u>
Cost of adding capacity (C_B)
Cost of maintaining capacity (C_A)
Cost of postponing conversions by t periods ($CP_{o,t}$)
Demand for order o (O_o). Customer orders are discrete and will be available the month they are entered. Typically orders are entered in a different month thus XL Hybrids can only start working on the order after the time of entry.

<u>Outputs to the model:</u>
Conversions in month t (x_t)
Production capacity at month t (B_t)
Outstanding conversion for order o at month t ($L_{o,t}$).

The number of outstanding orders is the quantity ordered minus the sum of the vehicles converted for that order:

$$L_{o,t} = O_o - \sum_{t=1}^{T} x_{o,t} \qquad \text{(eq 2.2)}$$

The total production capacity is given by:

$$B_t = B_{t-1} + A_t \qquad \qquad \text{(eq 2.3)}$$

The total number of conversions in a month is the sum of the conversions per order in the month:

$$x_t = \sum_{o=1}^{o} x_{o,t} \qquad \qquad \text{(eq 2.4)}$$

<u>Constraints:</u>
The production conversions are less than or equal to the capacity:
$$x_t \leq B_t$$

Integer requirements are:

$$A_t \in \{\mathbb{Z}\} \; \forall \; t$$

The number of late conversions, capacity additions, and current conversions have to be greater than or equal to 0:

$$L_{o,t} \geq 0$$

$$A_t \geq 0$$

$$x_{o,t} \geq 0$$

The list of constants used in the production planning and capacity expansion model is listed in

Appendix I.

2.2 Capacity Expansion

In Section 2.1, we explained how we optimized a production plan given a demand scenario.

Using this production plan, we now determine the method and size of XL Hybrids' capacity

expansion under certain constraints. Our approach is to use Microsoft Excel with Risk Solver Add

In to optimize capacity expansion by minimizing operating costs and capital costs while meeting the

production plan as well as other constraints that XL Hybrids has. XL Hybrids has the following

methods to expand capacity:

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- Increase the number of shifts
- Increase the number of bays
- Increase the number of facilities
- Increase the number of mobile teams

We use the production plan which was optimized in our production plan model as a constant, and then minimize the cost to expand capacity to meet or exceed the production plan. We assume the number of employees will be a function of capacity expansions and will expand linearly with capacity expansion (i.e. these are simply scalar multipliers of shift, bays, facilities, and mobile teams). In our demand scenario, a percentage of conversions must be performed by mobile teams. This is determined based on service requirements which was stipulated by XL Hybrids because they believe a portion of their customers will require the conversions to be performed at their own facility. We set this as an input in the model which can be modified for different service requirements.

2.2.1 Model Setup

<u>Decision Variables:</u>
Number of mobile teams added in month t (z_t)
Number of bays added in month t (n_t)
Number of facilities opened in month t (f_t)
Number of shifts added in month t (s_t)

All other variables are derived from these decision variables. The salary and costs of expanding a unit of capacity are constants in our model.

<u>Objective:</u>
To minimize the cost of expanding capacity (T_c) :
$$T_c = min \sum_{t=1}^{T}(FC_t + EC_t + MTC_t) \qquad \text{(eq 2.5)}$$

Where

FC_t is the facility costs in month t
EC_t is the employee costs in month t
MTC_t is the mobile team costs in month t

<u>Facility costs:</u>
Facility costs for month t are calculated using the equation:

$$FC_t = (n_t \times C_{BO} + N_t \times C_{BM}) + (f_t \times C_{FO} + F_t \times C_{FM}) + x_{t,Fac} \times C_{Del} \quad \text{(eq 2.6)}$$

Where

<u>Variables:</u>
n_t is the number of bays added in month t,
N_t is the total number of bays in month t,
f_t is the number of facilities opened in month t,
F_t is the total number of facilities in month t,
$x_{t,Fac}$ is the total number of conversions performed in facilities in month t.

<u>Constants:</u>
C_{BO} is the cost of opening a new bay
C_{BM} is the monthly cost of maintaining a bay
C_{FO} is the cost of opening a new facility
C_{FM} is the monthly cost of maintaining a facility
C_{Del} is the cost of delivering a vehicle to a facility which we designated as a constant and independent of customer location.

<u>Employee costs:</u>
Employee costs for month t are calculated using the equation

$$EC_t = M_{FAC,t} \times P_M + CS_{FAC,t} \times P_{CS} + M_{MT,t} \times P_M + CS_{MT,t} \times P_{CS} \quad \text{(eq. 2.7)}$$

Where

<u>Variables:</u>
$M_{FAC,t}$ is the number of facility technicians at time t
$CS_{FAC,t}$ is the number of facility customer support employees at time t
$M_{MT,t}$ is the number of mobile team technicians at time t
$CS_{MT,t}$ is the number of mobile team customer support employees at time t

<u>Constants:</u>
P_M is the technician salary which is the same for both mobile team and facility
P_{CS} is the customer support salary which is the same for both mobile team and facility

<u>Mobile team costs:</u>
The mobile team costs for month t are calculated using the equation

$$MTC_t = z_t \times C_{MO} + Z_t \times C_{MM} \quad \text{(eq. 2.8)}$$

Where

Variables:
z_t is the number of mobile teams added in month t
Z_t is the total number of mobile teams in month t

Constants:
C_{MO} is the mobile team capital expenditure cost
C_{MM} is the mobile team maintenance cost

Capacity:
The total capacity at time t is determined by:
$$\beta_t = (N_t \times S_t \times \delta_{FAC} + Z_t \times \delta_{MT}) \times d \times w \qquad \text{(eq. 2.9)}$$

Where

Variables:
N_t is the total number of bays
S_t is the total number of shifts
Z_t is the total number of mobile teams

Constants:
δ_{FAC} is the facility productivity, measured by conversions per bay per shift,
δ_{mt}, is the mobile team productivity, measured by conversions per mobile team per shift.
d is the number of days per week
w is the number of weeks per month

Employees:

Our model also includes equations to calculate the number of employees.

The number of facility technicians at time t ($M_{FAC,t}$) is given by the equation:

$$M_{FAC,t} = N_t \times S_t \times \alpha_{FAC} \qquad \text{(eq. 2.10)}$$

The number of facility customer support employees at time t ($CS_{FAC,t}$) is given by

$$CS_{FAC,t} = N_t \times S_t \times \sigma_{FAC} \qquad \text{(eq. 2.11)}$$

The number of mobile team technicians at time t ($M_{MT,t}$) is given by

$$M_{MT,t} = Z_t \times \alpha_{MT}$$ (eq. 2.12)

The number of mobile team customer support employees at time t ($CS_{MT,t}$) is given by

$$CS_{MT,t} = Z_t \times \sigma_{MT}$$ (eq. 2.13)

Where

Constants:
α_{FAC} is the number of technicians per bay per shift
σ_{FAC} is the number of customer support employees per bay per shift
α_{MT} is the number of technicians per mobile team
σ_{MT} is the number of customer support employees per mobile team.

Other Equations:
Variables calculated from decision variables:
$$S_t = S_{t-1} + s_t$$ (eq. 2.14)

$$Z_t = Z_{t-1} + z_t$$ (eq. 2.15)

$$F_t = F_{t-1} + f_t$$ (eq. 2.16)

$$N_t = N_{t-1} + n_t$$ (eq. 2.17)

Constraints:
The optimization model is also constrained by the following:
$$\beta_t \geq x_t, \forall \ t$$

$$\frac{N_t}{F_t} \leq G, \forall \ t$$

$$\frac{Z_t}{F_t} \leq Y, \forall \ t$$

$$S_t \leq 3, \forall \ t$$

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$$z_t, n_t, f_t, s_t \geq 0, \forall\ t$$

$$z_t, n_t, f_t, s_t \in \{\mathbb{Z}\} \forall\ t$$

Constants:
G is the maximum number of bays per facility
Y is the maximum number of mobile teams per facility

2.3 Inventory Analysis: Silver-Meal Heuristic Model

The Silver-Meal heuristic is an approach to determine the order quantity when there is variable demand. It approximates for the optimal duration of the replenishment quantity based on minimizing total relevant costs per unit time (TRCUT). This heuristic is particularly relevant for startup companies when they are in the developmental phase of their business plan.

2.3.1 Model Setup

The modified Silver-Meal heuristic accounts for inventory carrying cost, order cost, and lost opportunity cost of not taking advantage of the largest possible quantity discount. We have expanded the model to take into account of economies of scale gained from transportation.

Objective:
Minimize total relevant costs per unit time, TRCUT(T)

Decision Variables:
Order quantity (q)

Inputs and Constants:
Demand for week t (D_t)
Number of weeks (T)
Order Cost (A)
Purchase cost per unit at order quantity q (v_q)
Lowest possible purchase cost per unit achieved through volume discounts (v_m)
Transportation cost per unit at order quantity q (m_q)
Inventory carrying cost (r)

The heuristic evaluates TRCUT(T) for increasing values of T until for the first time,

$$TRCUT(T + 1) > TRCUT(T) \qquad \text{(eq. 2.18)}$$

The optimal first replenishment quantity would then be the sum of the demand over t periods,

$$q = \sum_{t=0}^{T} D_t \qquad \text{(eq. 2.19)}$$

TRCUT(T) is determined by summing all the relevant costs associated over T periods and dividing by T.

$$TRCUT(T) = \frac{A + Carrying\ cost + Lost\ opportunity\ cost + m_q}{T}$$ (eq. 2.20)

Purchase and transportation costs vary as order quantity changes, and are determined through supplier quotes. Transportations costs were modeled with an exponential function that is dependent on the order quantity. Figure 2-1 shows an example of how we estimated transportation cost of the electric motor

Figure 2-1: Estimating Transportation Cost of Electric Motor
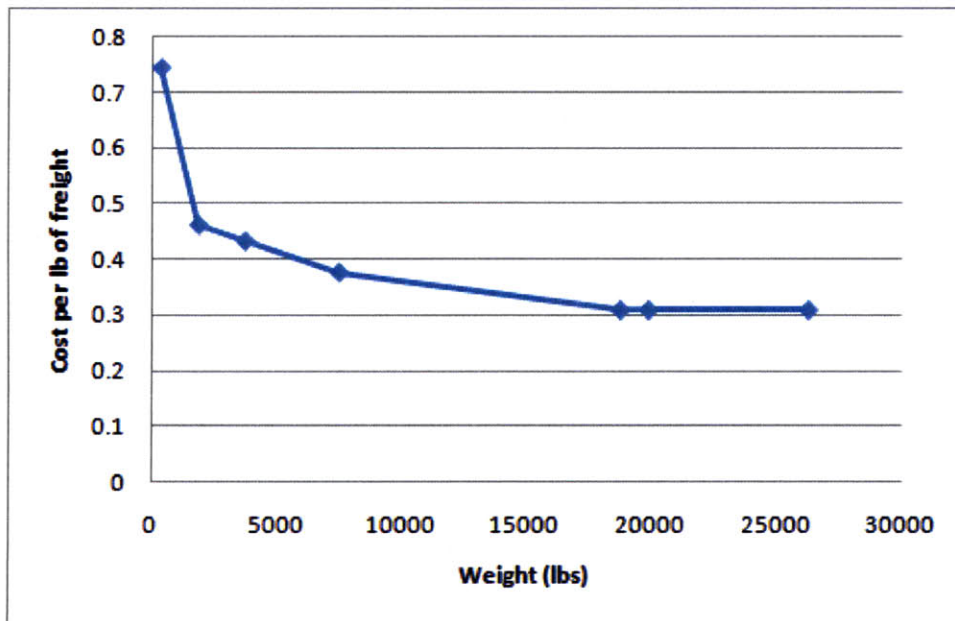
In the calculations for total relevant cost per unit time we define carrying cost and lost opportunity cost:

$$Carrying\ cost = \sum_{t=0}^{T}(t-1)D_t * v_q r$$ (eq. 2.21)

$$Lost\ opportunity\ cost = (v_q - v_m) * \sum_{t=0}^{T} D_t$$ (eq. 2.22)

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2.4 Sourcing and Distribution Network

The main purpose of this section is to describe our simulation model that compares two methods by which component parts can be distributed to XL Hybrids' conversion centers. Our model considers warehousing and transshipment options to get parts from the Newark port to the conversion centers. In the warehousing scenario, different parts are shipped to a central location where they are repacked into individual conversion kits that contain the necessary parts to convert a vehicle. In the transshipment scenario, the components are divided at the port and directly transported to the individual conversion centers without repacking as a kit.

Due to the complexities and uncertainties of planning the supply chain for a startup, we made several assumptions while designing the model. For a fixed service level, we assumed that transshipment requires higher system inventory levels than warehousing, leading to higher inventory holding costs. There are two reasons for this. First, warehousing allows for risk-pooling between facilities, which reduces overall safety stock levels. Second, repacking components into a conversion kit reduces inventory levels at each conversion center. Since orders come from different suppliers, transshipment means that a separate shipment has to be done for each component. Because there is misalignment of delivery times, there would be mismatched inventory levels between components.

XL Hybrids' key components are currently sourced from foreign suppliers. We chose to focus on planning the distribution network of components from the Newark port to the conversion centers. Because of the cost of air freight and the long sales cycle, component parts will be transported by ocean freight to the local ports. Planning and scheduling of shipping lanes would be left to the freight forwarders. For both warehousing and transshipment options, we assume shipment to the Newark port will be the same, hence the costs involved are irrelevant to our model.

2.4.1 Model Setup

Our model determines the most cost effective distribution option by changing the following variables:

1) Order quantity

2) Demand per month

3) Number of conversion regions

The costs are also affected by several key parameters. Appendix II provides a table summarizing the numbers of all the parameters. These are divided into non-cost components and cost components. The non-cost components are:

1) Safety stock - Since demand forecasts are discrete with unknown variability, we assumed that each conversion center/warehouse would have 20% of its capacity as safety stock. Given the long sales cycle, this number is based on a market estimate of the percentage of customers that would want expedited conversions.

2) Conversion center storage capacity - Estimated by considering the possible floor sizes of conversion centers. A cost factor is also added to consider the possibility of renting larger floor space.

3) Financial constraint of money tied down in inventory - Determined by capping the number of months of supply of inventory. It reflects the fact that it is risky for a startup company to have too much money tied in inventory when demand is uncertain.

4) Cost of capital - Set at 20%, which is higher than average, to reflect the expectations of investors and the tighter financial situation that startups have compared to established companies.

The cost parameters are:

1) Transportation cost - Transportation cost for different cargo weight of shipment for one departure/destination route was requested from Fed Ex freight services. By assuming a fixed and variable component of the cost based on distance, we estimated the transportation costs of different routes.

2) Warehousing costs - Warehousing costs were determined by initial estimates provided by multiple 3rd Party Logistics (3PL) providers located in Newark and Harrisburg which are proposed locations of the public warehouse that XL Hybrids will use.

3) Transshipment costs - Transshipment costs were estimated by the labor cost required to split an incoming shipment into smaller shipments for the individual conversion centers.

4) Purchase cost of key components - Determined by quotes from overseas suppliers. A look-up table followed by linear interpolation was used to determine the price. Beyond 400 units ordered, we assumed the price to stay constant.

2.4.2 Calculations

To analyze the cost differences between warehousing and cross-docking, we first determined the total landed cost of obtaining the necessary key components needed for a conversion. As mentioned in the assumption, we ignore the cost of shipping the components from overseas suppliers to Newark. The model is set up such that order quantity, average demand per month and number of conversion regions opened can be varied to give us the total relevant landed cost for both warehousing and cross-docking scenarios. Simulations were run to determine the optimal order quantity and the distribution option based on forecasted demand. For each demand scenario, we ran simulations for order quantities of 10, 20, 40, 60, 100, 150, 200, 250, 300, 400, 450, 500, 600,

700 and 800. The order quantity with the lowest total relevant landed cost was then compared to the demand forecast for that month to estimate inventory and determine the order frequency.

Total relevant landed cost was broken down into sub components: Purchasing, Transportation, Warehousing, Cross-docking and Inventory. Aside from total relevant landed cost, we also used average money tied up in inventory as a metric. This metric is important for startups to consider because of greater financial constraints compared to an established company.

Based on the number of units ordered by XL Hybrids, the supplier's price quote for each component would vary. As the order quantity increases, unit cost decreases exponentially up to a certain amount before leveling off. Total purchase cost was obtained by multiplying the number of units ordered with the unit price.

To determine transportation cost, the number of shipments and size of each shipment was calculated. This was based on the structure of the network and the capacity of each conversion center. The weight of the shipment was then used to determine the cost of each shipment based on the following equation:

$$Shipping\ Cost = A * Shipment\ Weight^B * Shipment\ Weight \qquad \text{(eq. 2.23)}$$

The coefficients and exponents for the shipment cost are determined by extrapolating from data points obtained from the Fed Ex website. In Figure 2-3 below, A would be 1.89 and B would be -0.247.

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Figure 2-2: Estimating Transportation Cost from Newark to Somerville with an Exponential Function
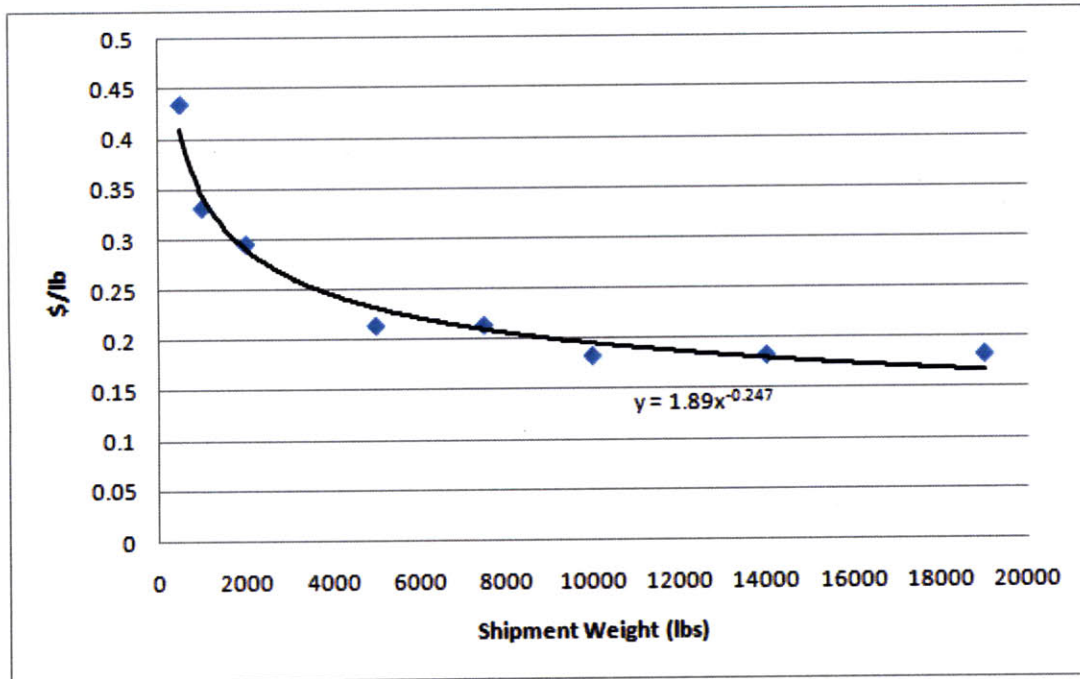
A simplified method to determine warehousing cost was provided by vendors. Warehousing costs consists of four components: storage space ($/pallet/month), order cost ($/order), handling cost ($/pallet), assembling cost ($/kit). Assembling cost is the cost associated with breaking down pallets and reassembling them into conversion kits. We calculated the number of pallets and the frequency that orders will be processed at the warehouse to determine the overall warehousing cost incurred for the warehousing option. For the cross-docking scenario, costs were determined by multiplying the cost of breaking down a pallet with the number of pallets that passes through the port.

Finally, inventory holding cost of each component was determined by the following equation:

$$Inventory\ holding\ cost = Holding\ cost\ per\ month * \frac{Order\ quantity * Unit\ cost}{Average\ demand\ per\ month} \qquad \text{(eq. 2.24)}$$

The sum of inventory holding cost of each component gives the overall inventory cost.

2.5 Others (Interview/Qualitative)

In addition to researching literature and creating models for various parts of XL Hybrids'
supply chain, we interviewed supply chain experts and managers at startup companies. We aimed to
distill lessons from successful startup companies to assist us in strengthening our Supply Chain
framework. In addition we hoped to gain verification of our models and our supply chain approach.
In interviewing the various industry experts we asked the following questions and let the discussion
stem from there:

- What are the main constraints that startup companies face?

- Do startup companies typically consider supply chain planning? Is supply chain planning
  important for startup companies?

- How did your company design the supply chain?

- What factors and key turning points do you consider before making decisions for the
  following:
  - Warehousing
  - Transportation options
  - Sourcing
  - Volume discounts
  - Capacity Expansion
  - Risk pooling

- What supply chain design factors do you consider most important for startup success?

- If you were to change your supply chain, what would you do differently?

- How do supply chains for startup companies differ from an established company, given the
  constraints they face?

- Can you direct us to good examples of first-rate start up supply chain management?
  (Literature/case studies?)

3. MODEL RESULTS AND OUTPUTS

Our recommendations for XL Hybrids were based on our models. Some of the key takeaways from our models were:

- Capacity expansion and production scheduling are heavily impacted by customer demand.
  - If there are few customers then it is recommended to prolong production and delay capacity expansion in order to decrease capital investments.
  - If demand continues to grow, the production and capacity expansion should grow at a similar rate to demand.
- Increasing work shifts is the most cost efficient method to increase capacity, compared to adding bays, facilities, or mobile teams.
- From the total cost of goods sold which comprises of inventory holding, purchasing, transportation, warehousing, and order costs, we found that purchasing costs were the primary contributor. Hence, ordering in bulk allows for significant volume discounts.
- Negotiating contracts that provide discounts based on annual purchase volumes enables XL Hybrids to approach Just-In-Time inventory and save on inventory cost. However, these benefits see minimal impact by the 3rd year of operations. This could signal the start of an RFP process since benefits from annual volume discounts have maxed out.
- XL Hybrids should begin sourcing components via transshipment but quickly transition to warehousing because as volumes increase, it becomes more cost effective to warehouse. Additionally, warehousing allows XL Hybrids to focus on their core business of vehicle conversions.

Scenario analysis was crucial in this context because the business dynamics of a startup company are unpredictable. Understanding the different optimal decisions for each scenario allows XL Hybrids to be prepared to handle uncertainty in their business.

3.1 Production Plan and Capacity Expansion

In this section we focused on four demand scenarios that we believed XL Hybrids (as any startup company) could likely face. For each of the scenarios, we optimized the production plan and the capacity expansion. The scenarios are:

1. Low Demand
2. Variable Demand
3. Exponential Growth
4. Fall in Demand after High Initial Spike

3.1.1 Low Demand Scenario

This scenario is where XL Hybrids has low level demand with some customers and little growth. We ran this scenario as a boundary condition for the model to confirm that the optimization model does not add capacity when there is no need.

Figure 3-1: Production Plan for Low Demand Scenario
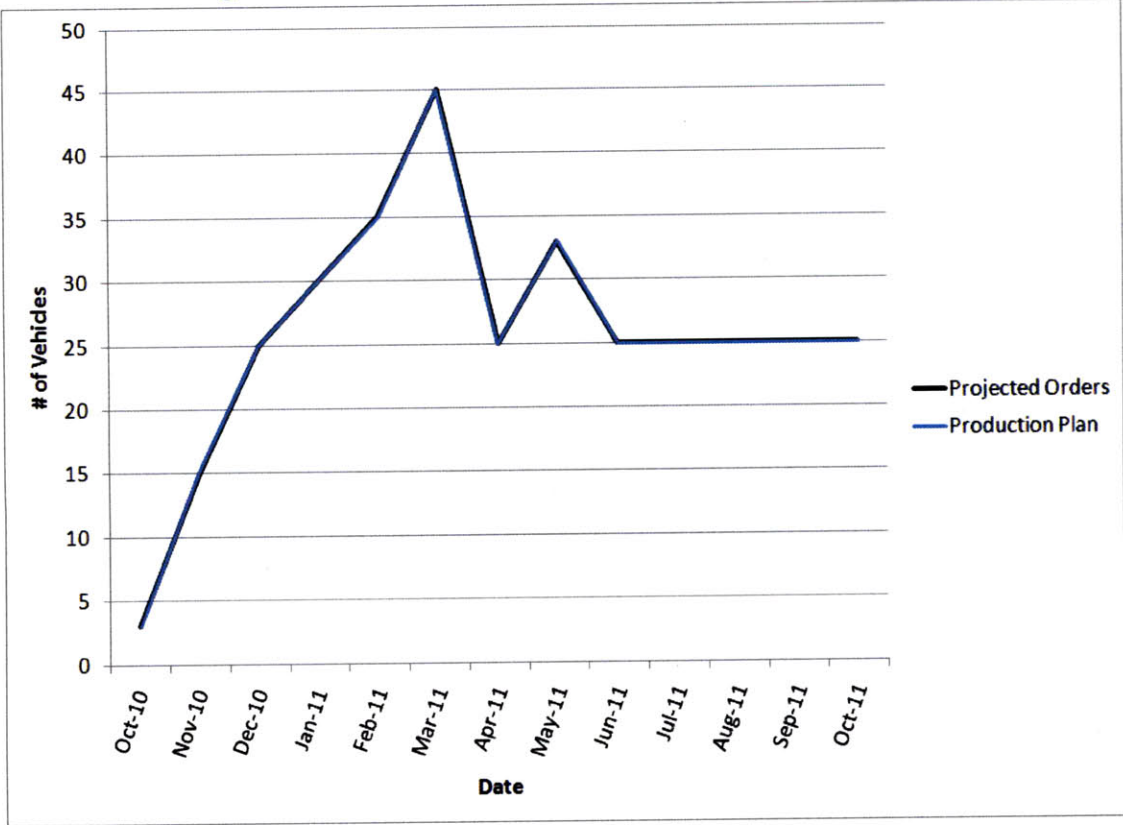
When demand is low and remains below capacity, XL Hybrids would perform the conversions as the orders come in since capacity is available. Figure 3-1 illustrates this.

Figure 3-2: Capacity Plan for Low Demand Scenario
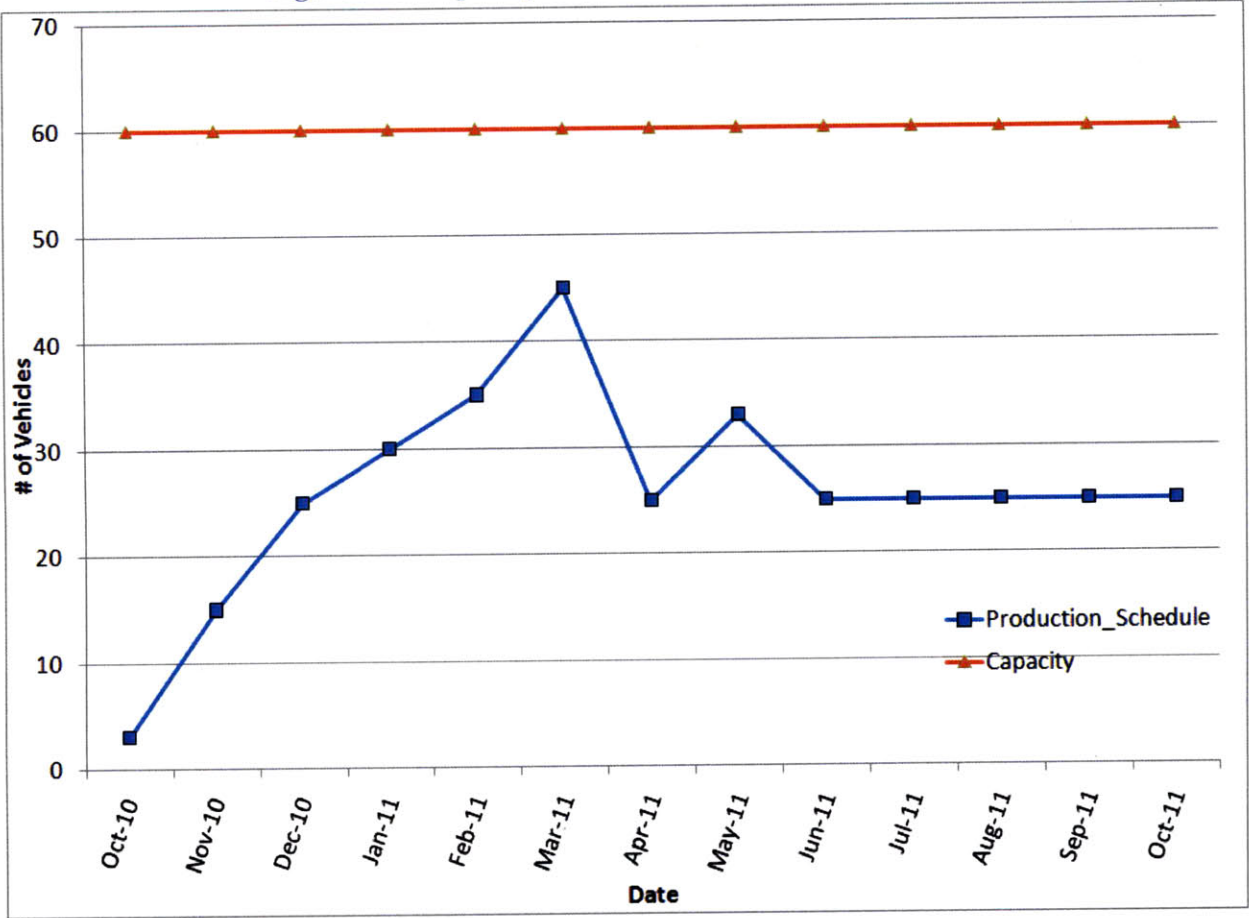
Figure 3-2 shows that capacity remains constant at the initial current capacity of 60 conversions per month. As expected XL Hybrids should not invest any capital into expansion since XL Hybrids already has the capacity to perform the scheduled production.
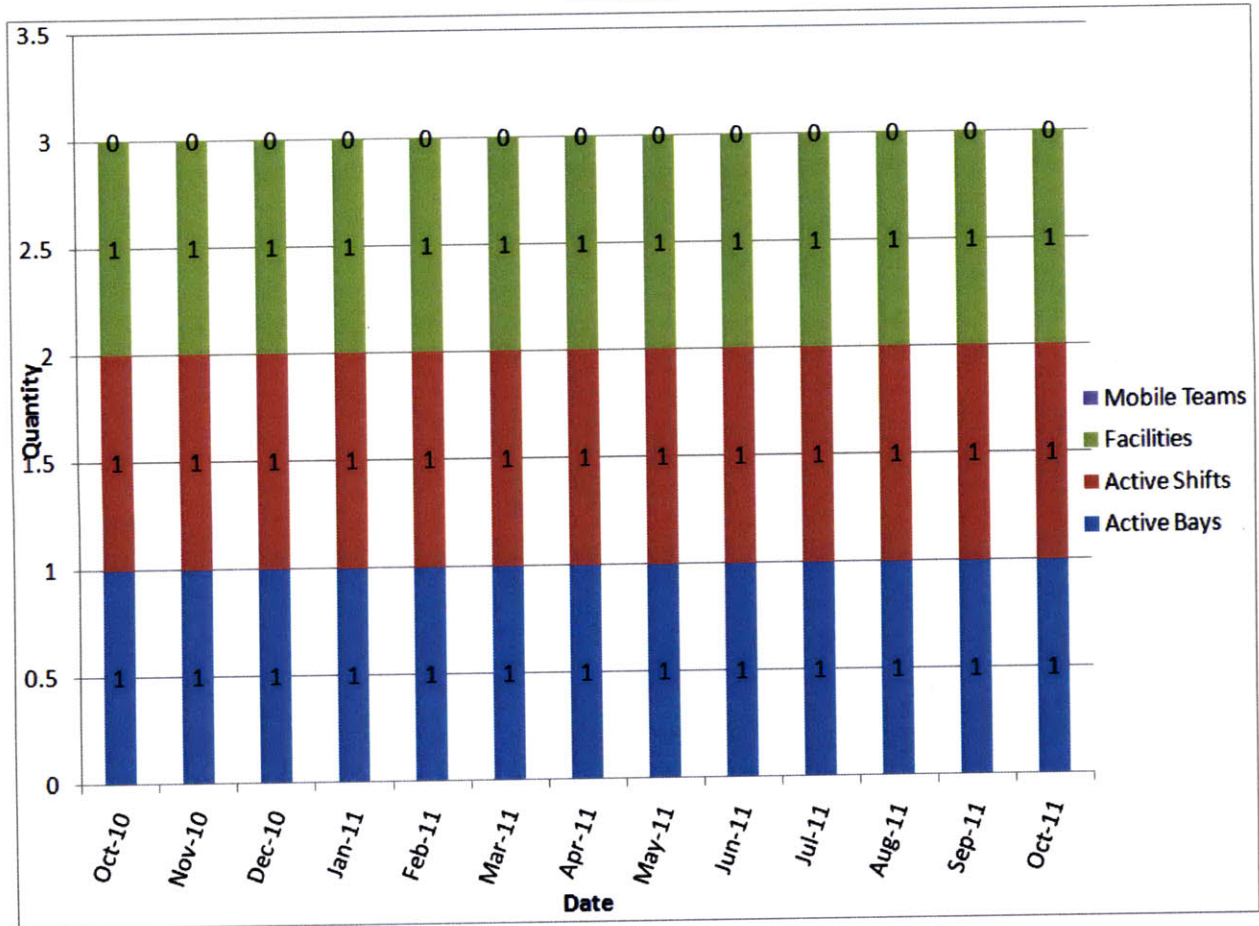
Figure 3-3 shows capacity to be constant and no additional investment in any of the forms of capacity expansion.

3.1.2 Variable Demand Scenario

In this scenario we envisioned a circumstance where a couple of big customers such as UPS and Staples approach XL Hybrids to hybridize their delivery fleet. In addition to the big customers, XL Hybrids would also receive orders from smaller companies. In this scenario, the big customers would account for a couple of large orders that are sparsely distributed whereas there would be continuous demand from the small customers.

Figure 3-4: Production Plan for Variable Demand Scenario
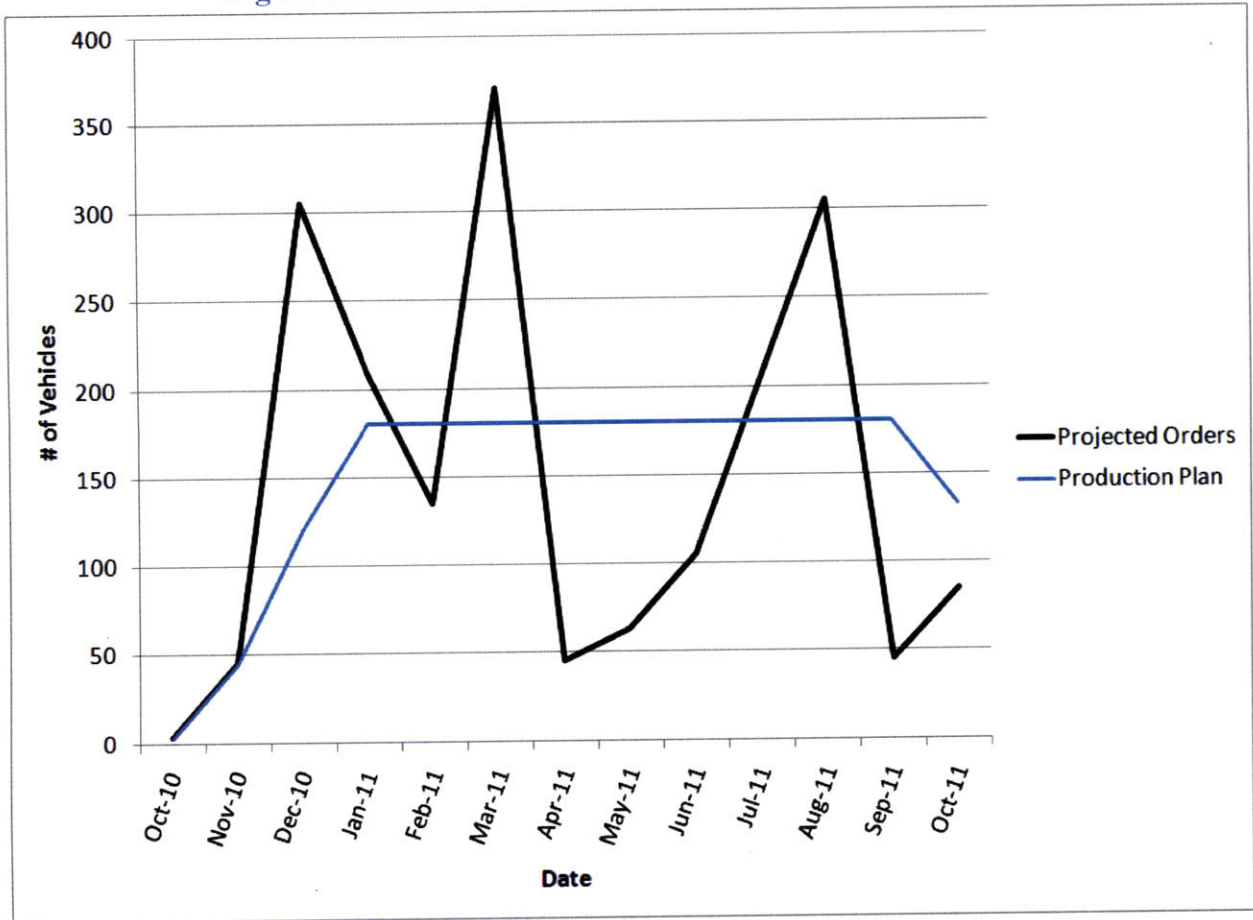
In Figure 3-4, the production plan ramps up, but then levels off. In this scenario, the production

plan acts as a demand smoothing technique, so production becomes constant in comparison to the

noisy demand.

Figure 3-5: Capacity Plan for Variable Demand Scenario
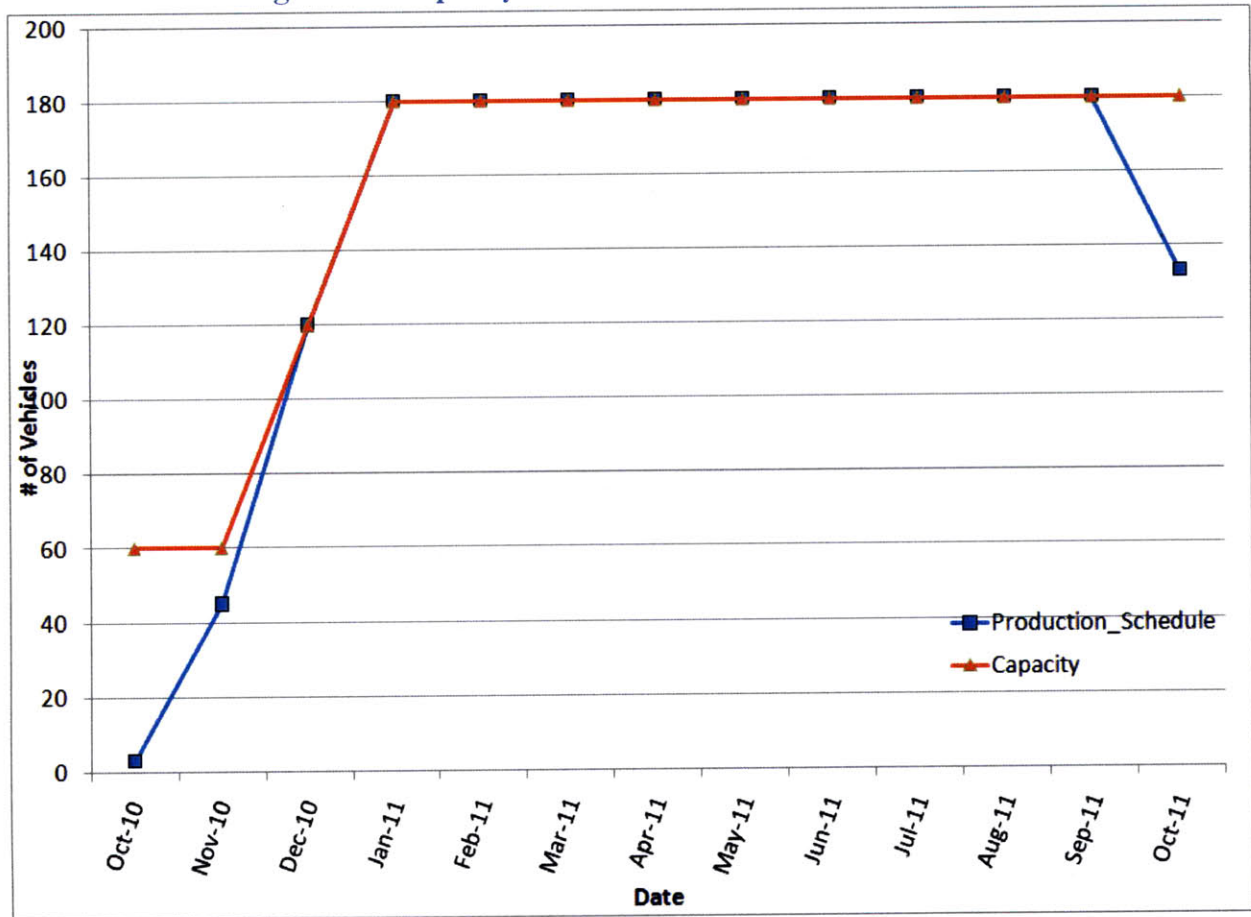
Figure 3-5 shows that the capacity starts higher than production thus there is no expansion at this point. However, as production grows, the capacity expands and tracks closely with production.

Figure 3-6: Quantity of Mobile Teams, Shifts, Bays, and Facilities for Variable Demand Scenario
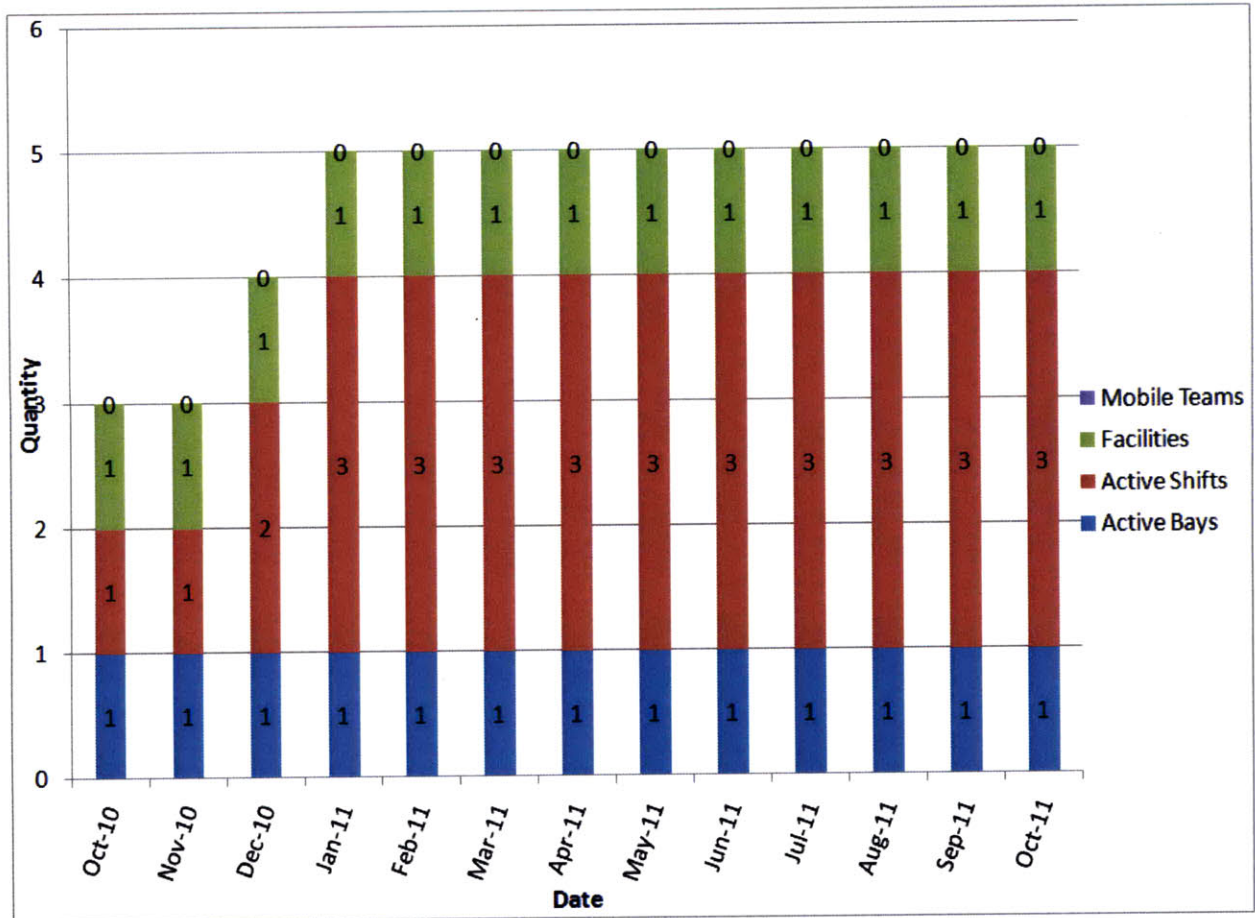
As capacity increases, the method to increase capacity starts with increasing shifts since this is the least expensive way to expand capacity. This is because increasing shifts do not require capital investment. The increased labor needed with increasing shifts would be the same for adding a bay or adding a facility. We discuss the option to increase the mobile teams in Section 3.1.5.

The incremental increase in capacity associated with adding a shift for one bay is 60 conversions per month. This is low relative to the variability in demand, thus we are able to closely track capacity with production to have high utilization.

3.1.3 Exponential Growth Scenario

In this scenario, XL Hybrids' sales takes off and customers love the service. As more vehicles are converted, more customers seek XL Hybrids to hybridize their vehicles. We modeled this with close to exponential growth.

Figure 3-7: Production Plan for Exponential Growth Scenario
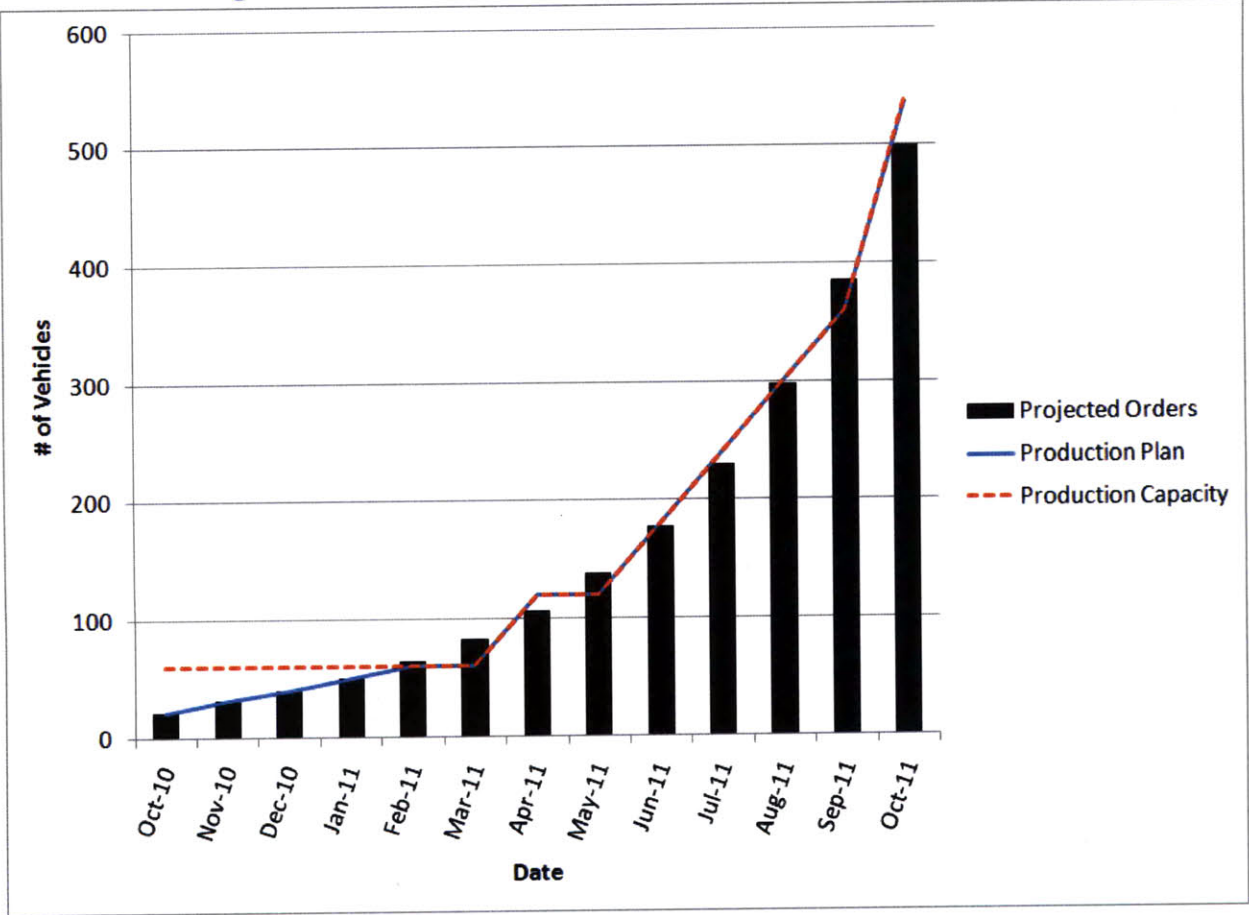
Results from Figure 3-7 indicate that production will follow the order cycle very closely as demand continues to increase.

Figure 3-8: Capacity Expansion for Exponential Growth Scenario
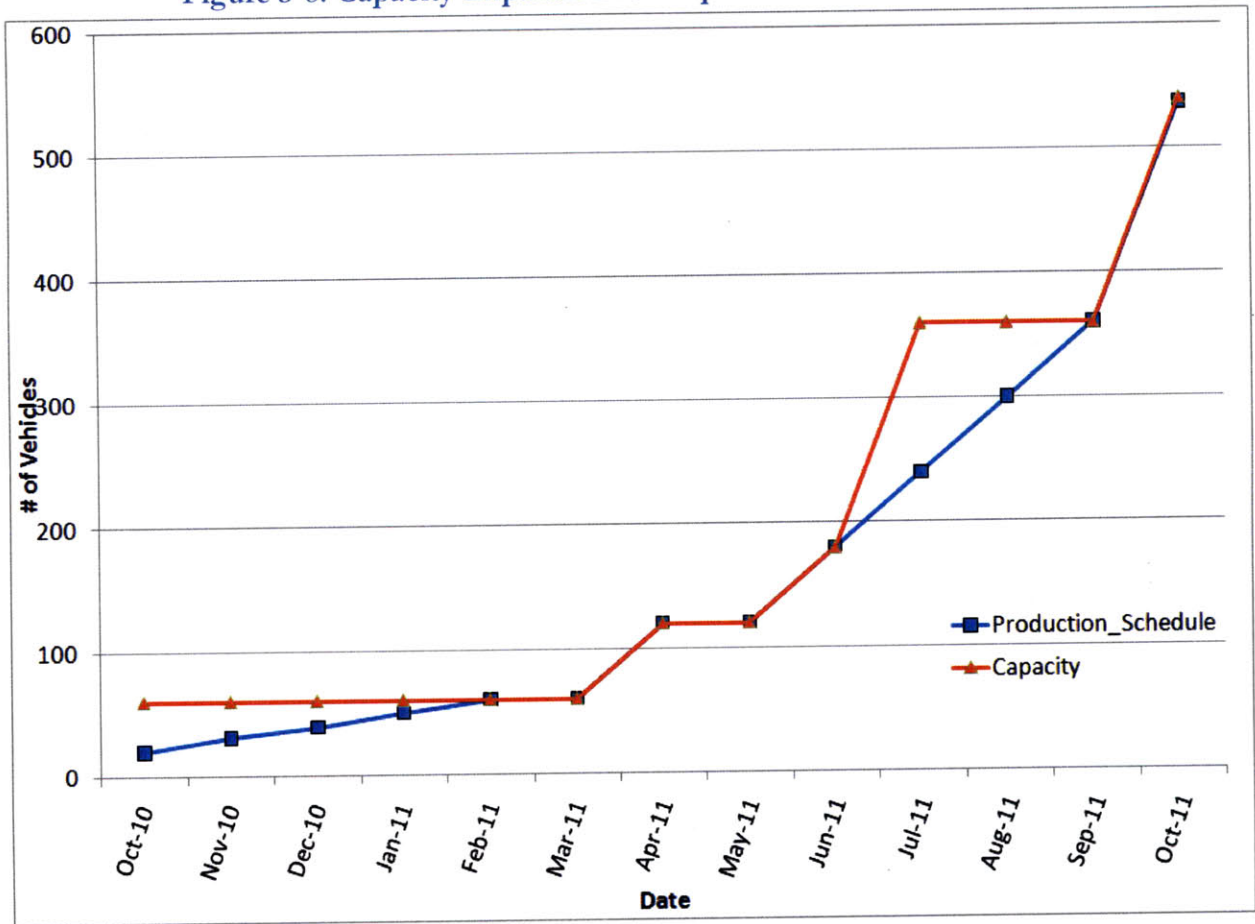
When expected production continues to increase, capacity will grow very quickly, and trends well with the production schedule. As constrained in the model, capacity follows or exceeds the production schedule.

Figure 3-9: Quantity of Mobile Teams, Shifts, Bays, and Facilities for Exponential Growth Scenario
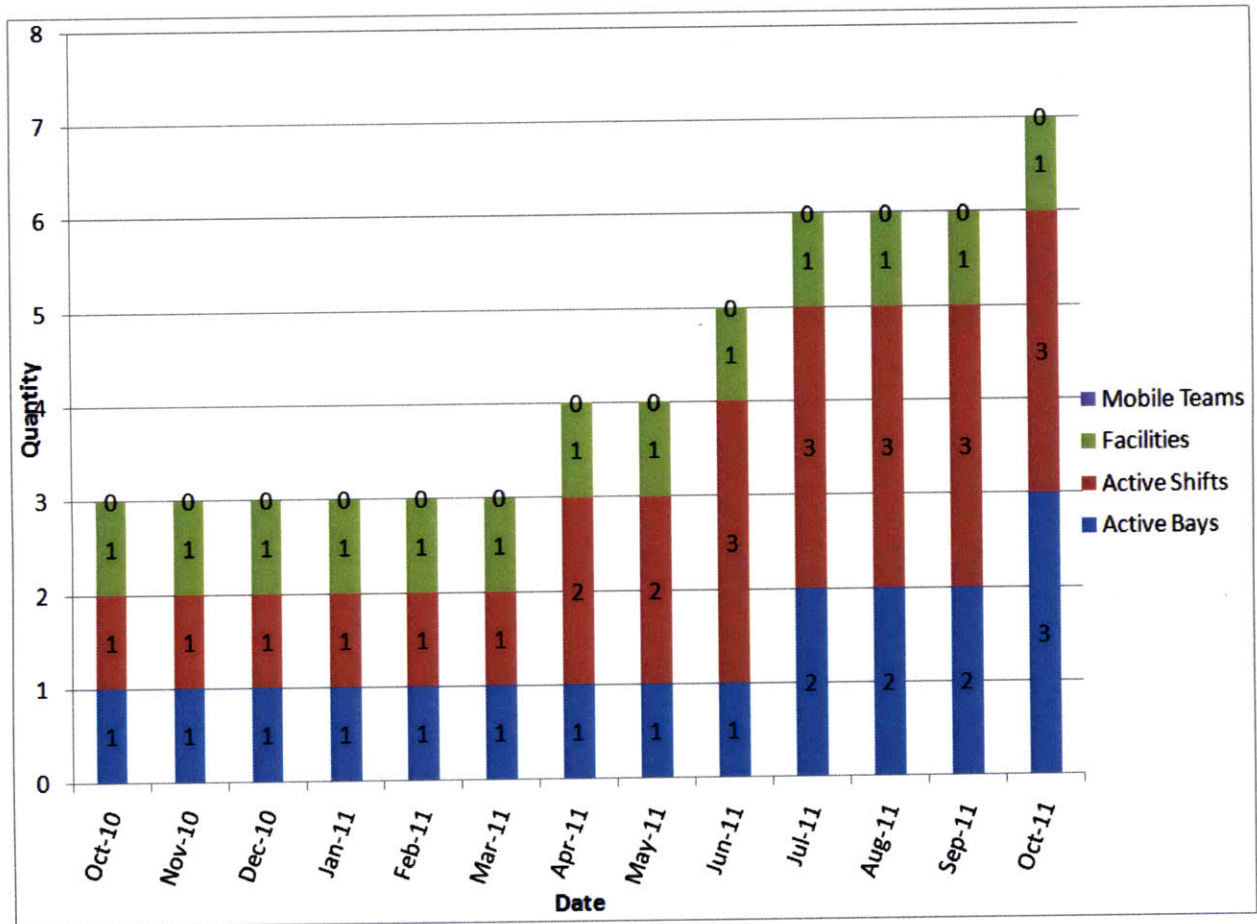
Figure 3-9 shows that capacity expansion starts by increasing the number of shifts. Once this is maximized at three, then the optimal way to expand capacity would be to increase the number of bays.

3.1.4 Fall in Demand after Initial Spike Scenario

In this scenario we propose a situation where two big customers like UPS and Fed Ex contract XL Hybrids to hybridize their fleet of delivery vehicles in the New England area. After the initial success, XL Hybrids is unable to attract more demand in the subsequent months.

Figure 3-10: Production Plan for Fall in Demand after Initial Spike Scenario (Regular Order Deadline)
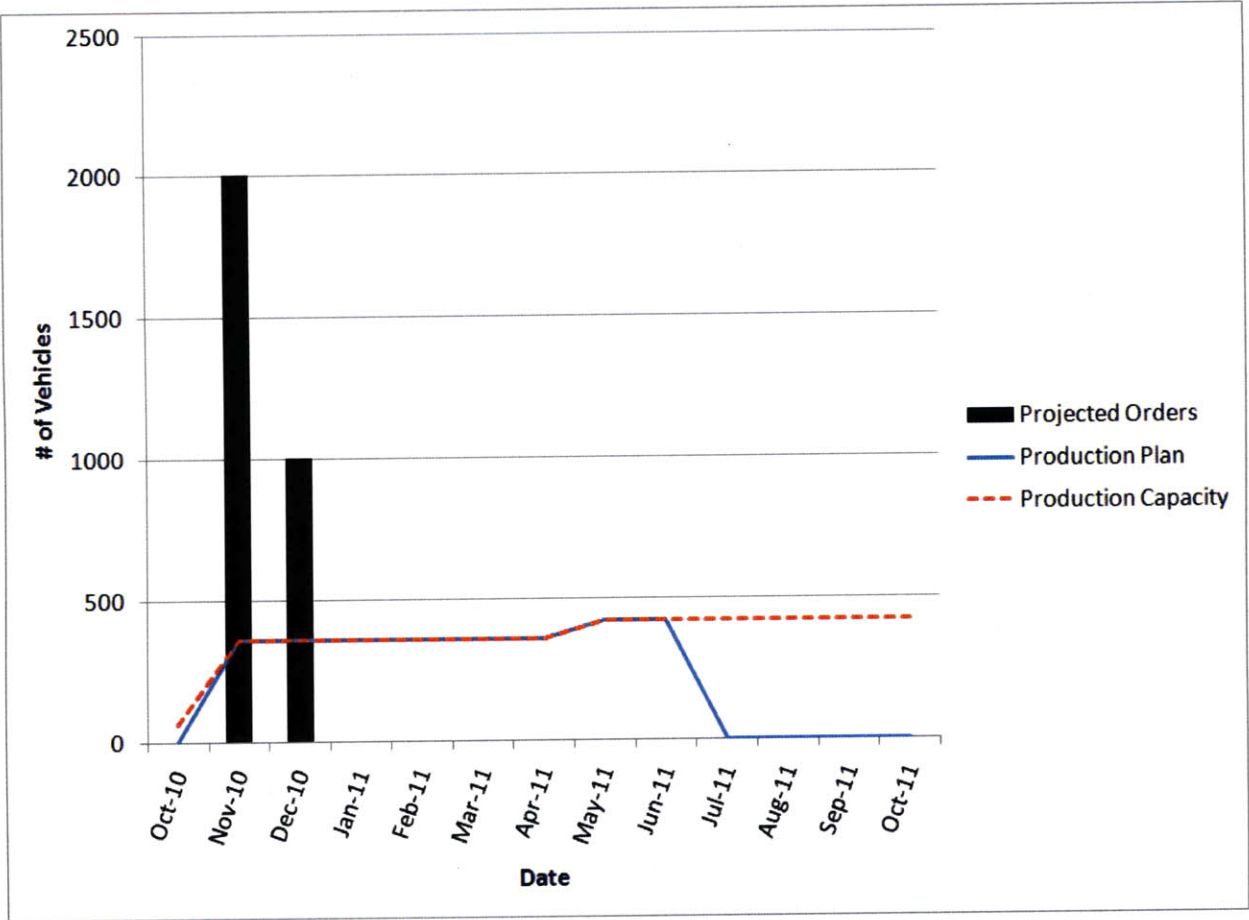
When there are two big orders, the production model averages out the demand over 6 months. Thus there is fairly constant production until June 2011, after which the production drops to zero since there are no new orders.

Figure 3-11: Capacity Expansion for Fall in Demand after Initial Spike Scenario (Regular Order Deadline)
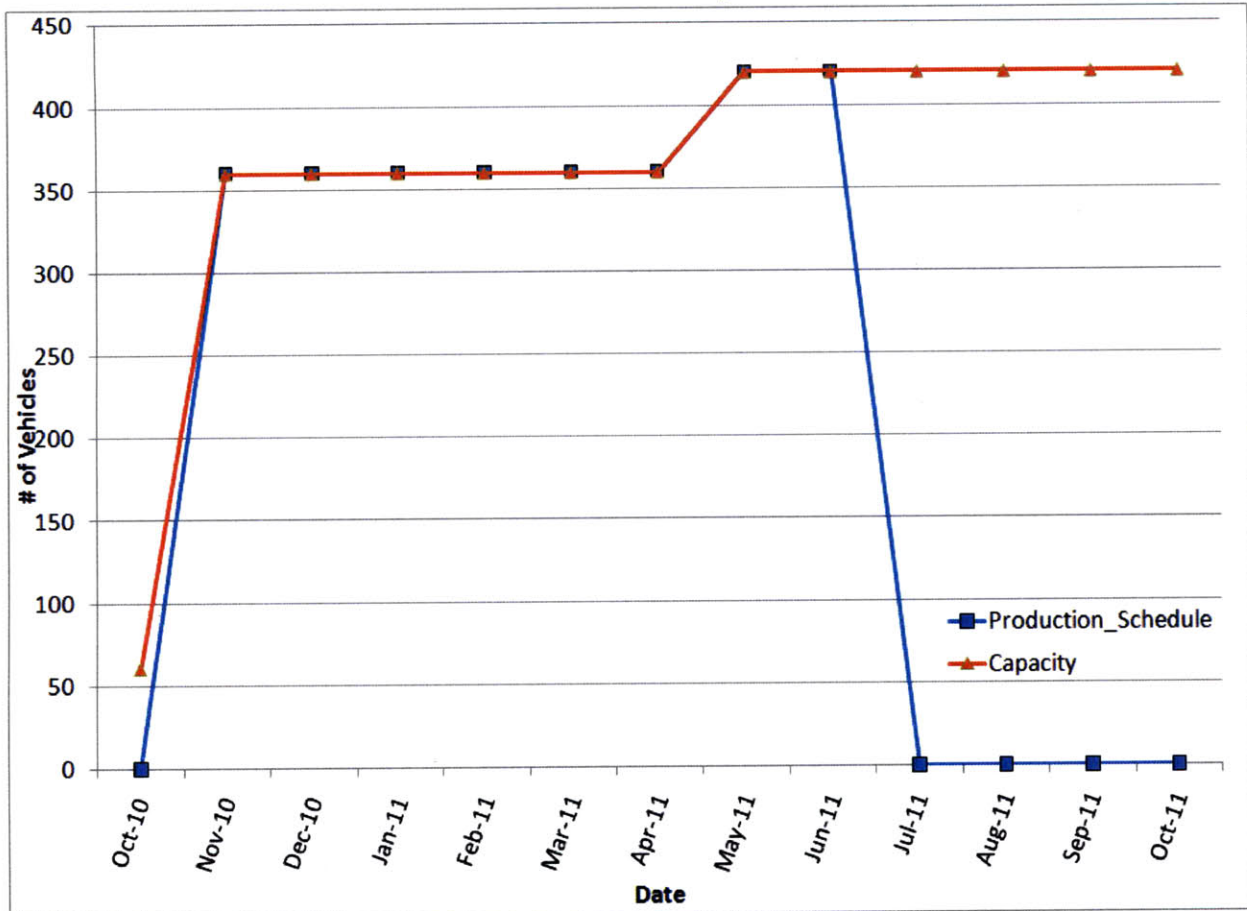
In order for capacity to meet the production requirements calculated in the production scheduling model, the capacity has to increase in November 2010. The capacity expansion model does not allow for capacity to drop, thus once investment has been put into adding capacity, there is no salvage or selling opportunity for reducing capacity. This means that having excess capacity results in having high operating costs while not earning revenue.

We found that once again shifts are the least expensive way to increase capacity. For this scenario, it is also recommended to increase the number of mobile teams.

The cost for maintaining and adding the capacity from October 2010 to October 2011 is $2,786,100. This cost is driven by an aggressive production plan. With this production plan, there is excess capacity after the completion of the initial orders, resulting in high operating costs to maintain capacity that is not used. If we could postpone the production deadline, less capital investment would be needed upfront to complete the orders. Postponing the production deadline by six months yields a total cost of $2,010,900 which is $775,200 less expensive. See plots below for scenario with extended due dates:

Figure 3-13: Production Plan for Fall in Demand after Initial Spike Scenario (Extended Order Deadline)
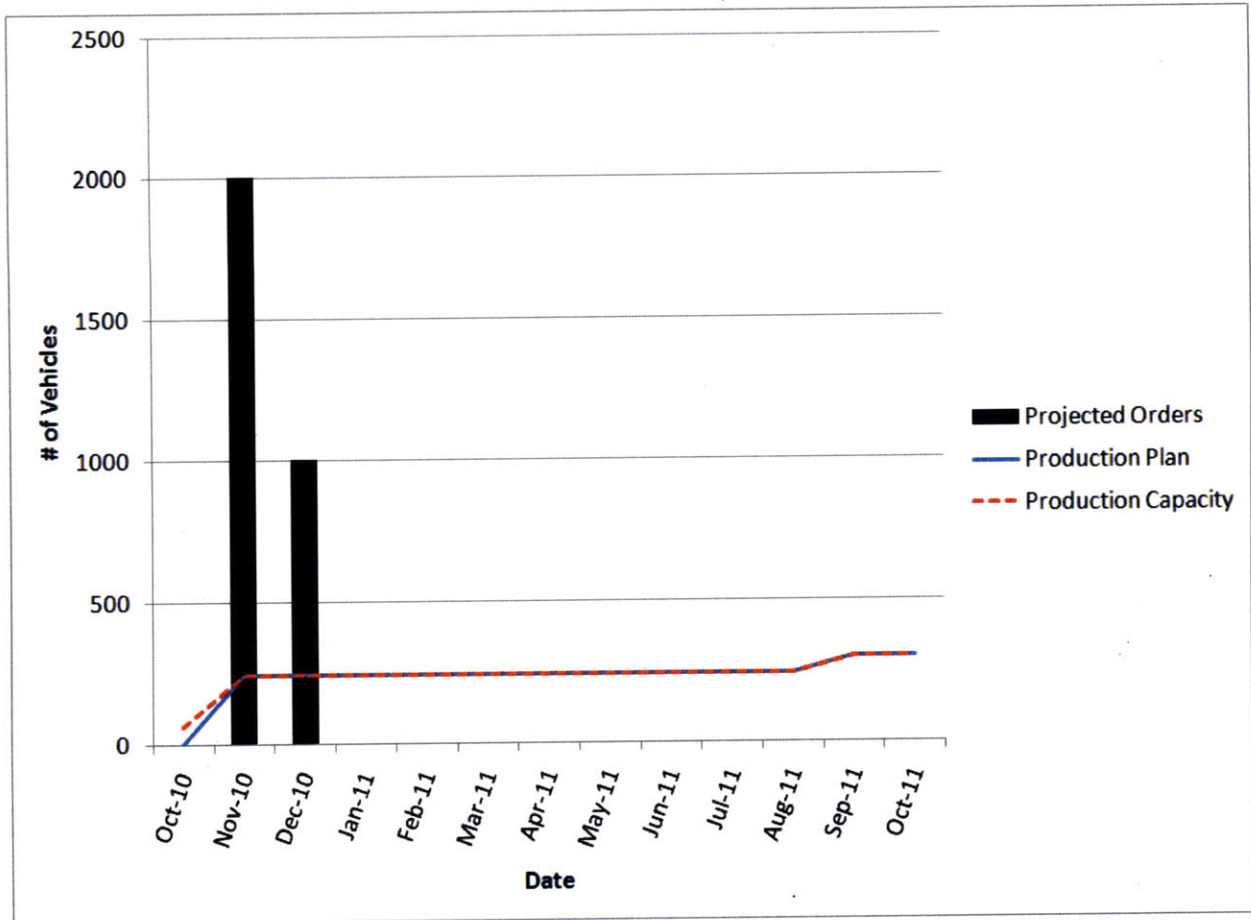
When the production deadline is extended by 6 months, the monthly conversions peaks at 300 conversions per month, which is ~120 lower than the production plan using the regular deadlines.

Figure 3-14: Capacity Expansion for Fall in Demand after Initial Spike Scenario (Extended Order Deadline)
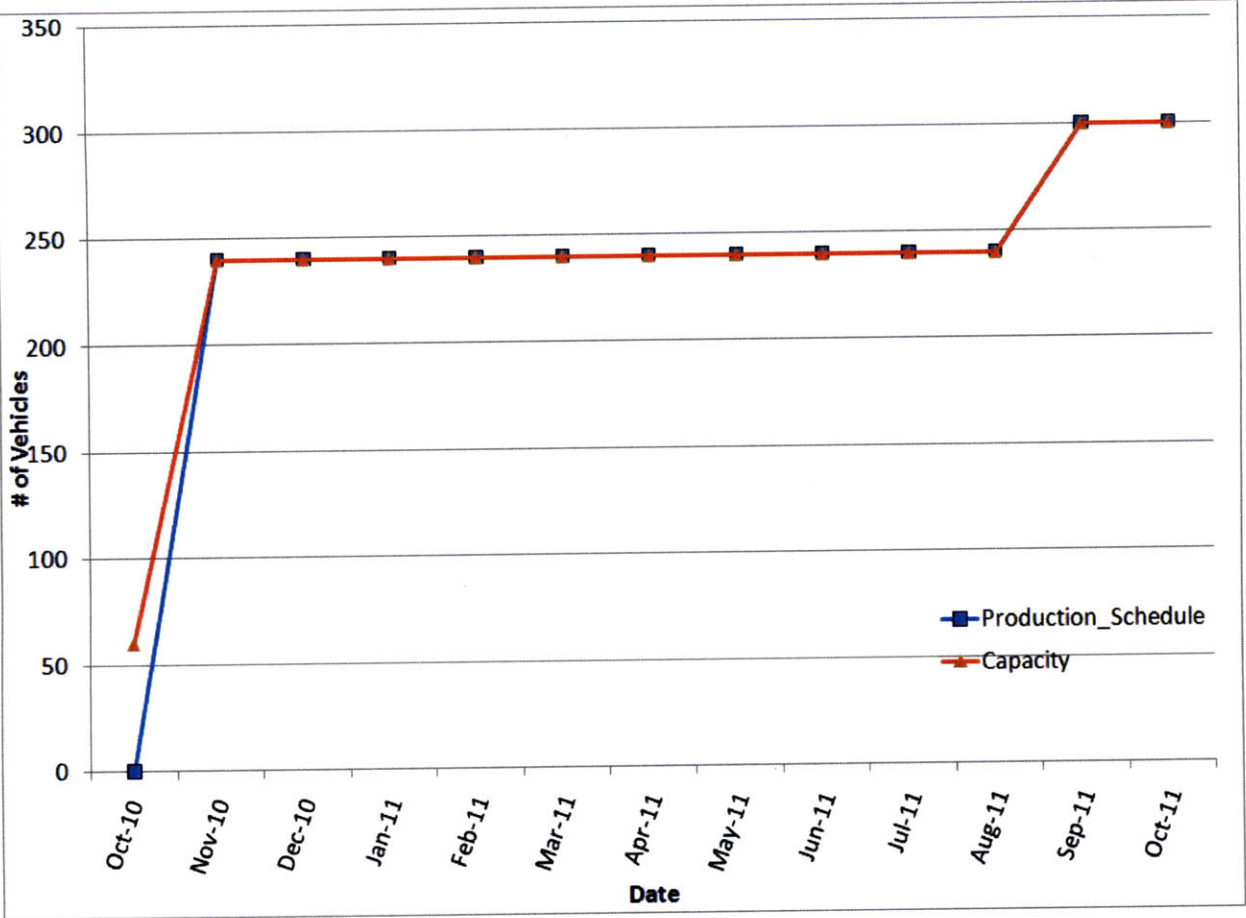
For the extended due date, the capacity reaches 300 vehicles per month converted compared to 420 vehicles per month converted for the regular production schedule. Having lower capacity allows for both lower capital investments and lower operating costs.

Figure 3-15: Quantity of Mobile Teams, Shifts, Bays, and Facilities for Fall in Demand after Initial Spike Scenario (Extended Order Deadline)
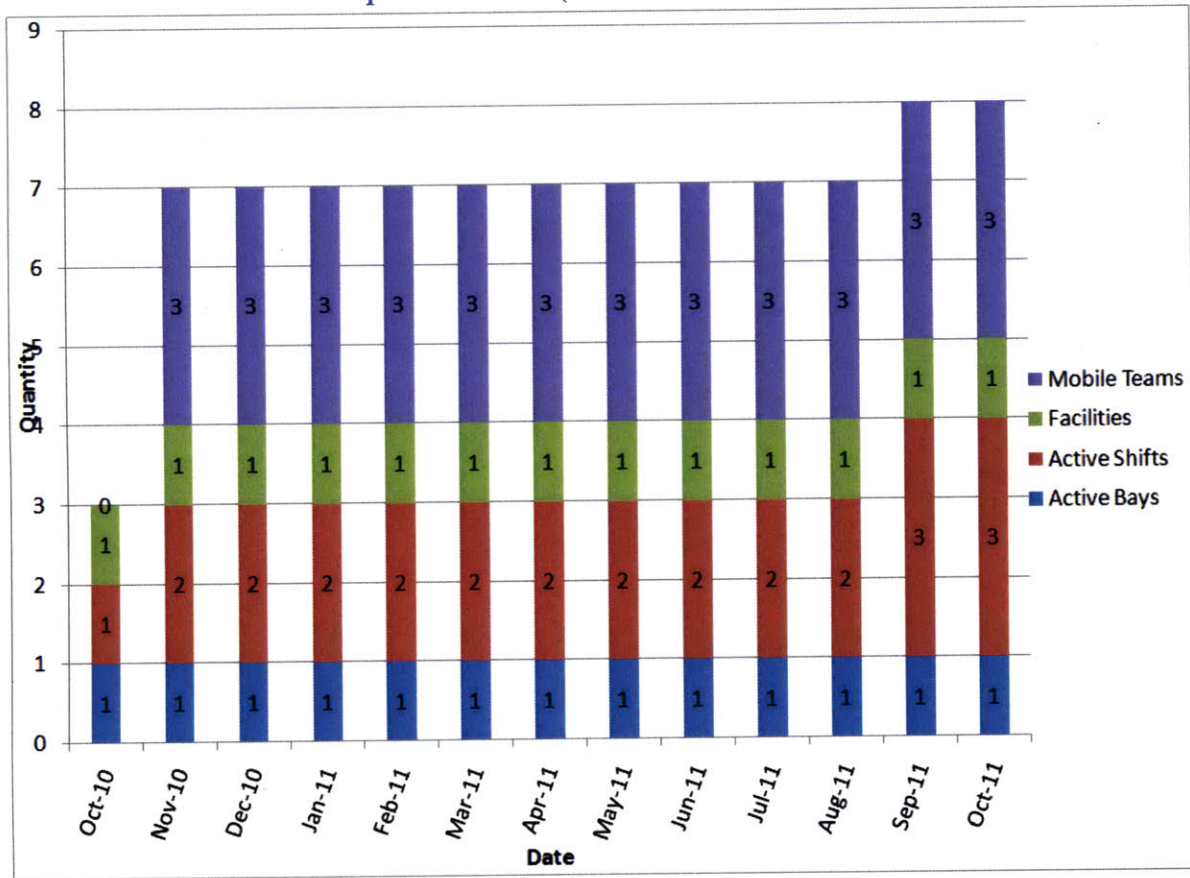
For the slower production schedule, there are 3 mobiles teams in comparison to 6 mobile teams for the regular production schedule expansion plan.

Under this scenario of a few very large orders followed by low demand our recommendation is for XL Hybrids to drag out production so that there is less investment in capital. This also allows for lower operating costs to maintain capacity. Conclusion: "Don't put all your eggs in one basket" since the extra capital investment may result in excess capacity.

3.1.5 Capacity Expansion Cost Summary

In looking at the four methods to increase capacity, we found that increasing mobile teams has the lowest operating cost since hybridizing vehicles using a mobile team does not incorporate a

$200 vehicle delivery cost which the conversion centers do. This charge accounts for a significant portion of the total operating cost of performing the hybrid conversion at the conversion center. The lower operating cost of using mobile teams means XL Hybrids should maximize the utilization of their mobile team capacity. Mobile teams also provide flexibility since they can be easily transferred to new regions where XL Hybrids wants to expand. Mobile teams however, have a high capital cost of $30000. Nevertheless the combination of low operating costs and flexibility make mobile teams a good option for expanding capacity.

Increasing the number of shifts has low operating cost and no capital investment, which makes it the ideal method to increase capacity. However, having a night shift would involve delivering vehicles in the day and parking them overnight. This leads to parking space problems at the conversion centers since parking area will likely be limited. Furthermore, it is hard to entice people to work night shifts. Nevertheless, there is probably a compromise by working partial shifts, which will enable XL Hybrids to have lower operating cost increase with no additional capital cost. Increasing the number of bays has the second highest operating cost because bays incur a maintenance cost as well as a cost of delivering a vehicle. The increase of three bays to four bays requires an additional facility, which entails additional capital investment as shown in Table 3-1.

Table 3-1: Operating and Capital Cost of Different Methods of Increasing Capacity

Method	Operating Cost $/Vehicle	Capital Cost $/Vehicle	Increase in Conversions (Conversions/Month)
Bay	$ 663.33	$ 200.00	60
Bay Plus Facility Constraint	$ 665.00	$ 1,650.38	60
Shift	$ 655.00	$ -	120
Mobile Teams	$ 600.00	$ 750.00	40

* Calculation assumes 100% utilization

3.2 Silver-Meal Heuristic

Results from the modified Silver-Meal heuristic model showed us the importance of volume discounts when purchasing the three key components in XL Hybrids' conversion process. Figure 3-16 below demonstrates the optimal order quantity for varying demand for the electric motor component.

Figure 3-16: Optimal Order Period for the Electric Motor as a Function of Average Demand/Week
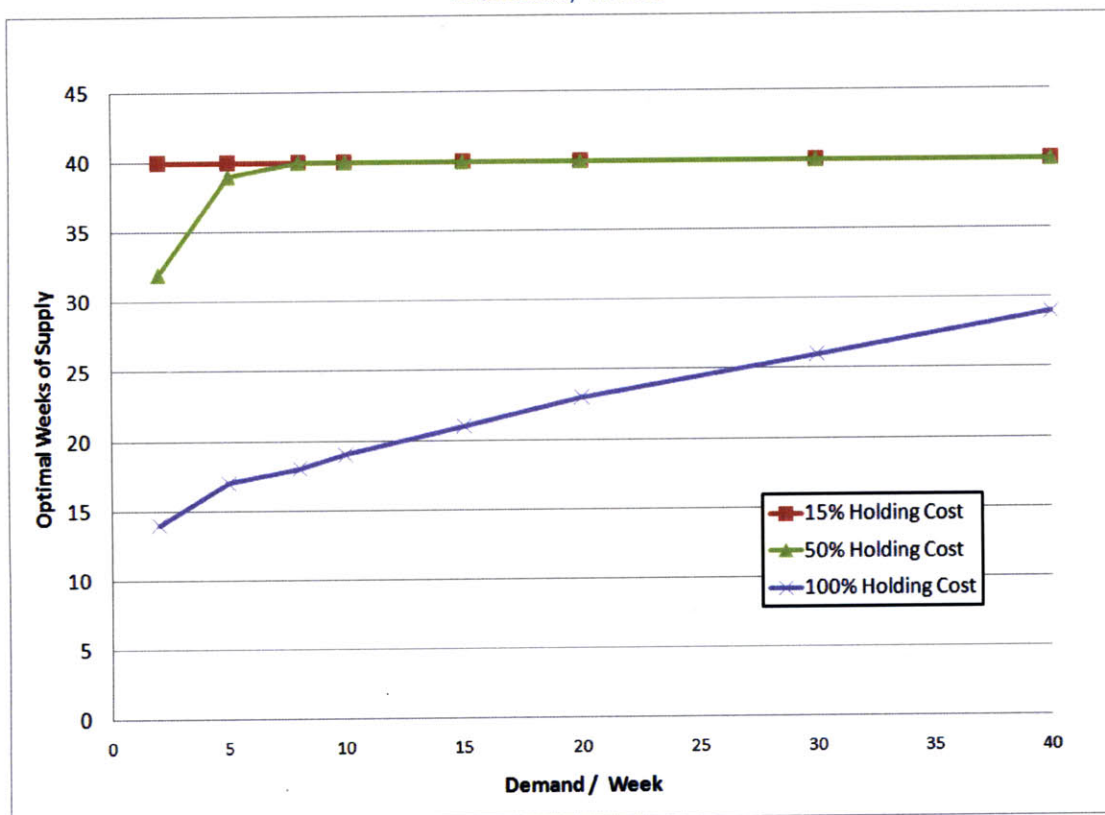
At a 15% holding cost, our model showed that purchasing the order quantity that gives the maximum volume discount was the most cost effective approach. Even at a 50% holding cost and at low demand for conversions, the optimal number of weeks of supply to stock is still greater than 30. It was only when the holding cost was set at 100% did we see significant decrease in optimal weeks of supply. However, a 100% holding cost is unrealistic even for a startup company. Similar graphs were obtained for the battery and the controller.

Figure 3-17 below shows the contribution of purchasing, shipping, warehousing and inventory-holding cost to the total relevant cost of procuring a conversion kit. (The conversion kit is the combined cost of the electric motor, the battery, and the electric motor). Since purchasing cost formed the bulk of the total relevant cost, being able to decrease this cost through volume discounts decreases the total relevant cost significantly. Volume discounts from bulk ordering could reach up to 50%. Hence, the lost opportunity cost dominates the total relevant unit cost equation.

Figure 3-17: Cost Breakdown of Total Relevant Costs of Procuring a Conversion Kit
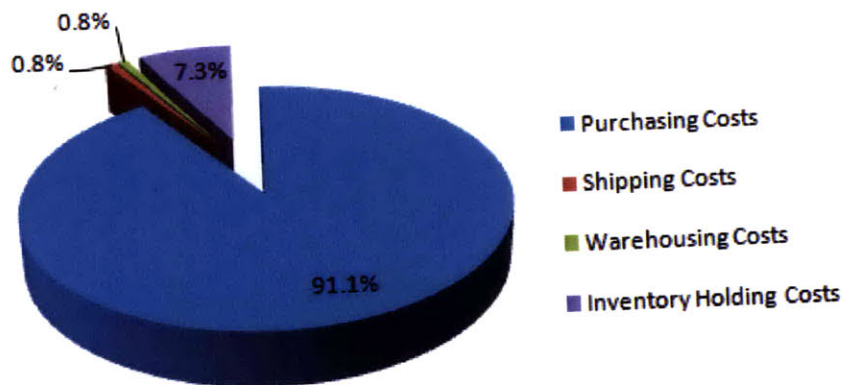
The large order quantity that we found from using the Silver-Meal Heuristic model is unrealistic for startup companies. Startup companies have limited financial ability to pay the cost of procuring large quantities. They are constrained by the funding raised and the amount of risk that management wants to take. In our warehousing and transshipment model, we take into account this issue when deciding what the optimal order quantity should be for each distribution option.

Our next step with this model was to perform a scenario analysis for the case where XL Hybrids manages to obtain an annual volume pricing contract as opposed to the current per-order volume pricing contract. Such a pricing contract eliminates volume discounts for individual orders. As XL Hybrids obtain more conversions and have more influence over contracts with their

suppliers, they will move towards such a contract system. Running this scenario enables us to see how their order quantity would change under this circumstance. Figure 3-18 shows the reduction in weeks of supply of the electric motor component when such a contract is obtained. From 40 weeks as shown previously, we get somewhere between 2 to 12 weeks. The U-shaped graph is describes the tradeoffs between warehousing, transportation and holding costs.

Figure 3-18: Unit Cost as a Function of Order Period at Different Levels of Demand (At 20% Holding Cost)
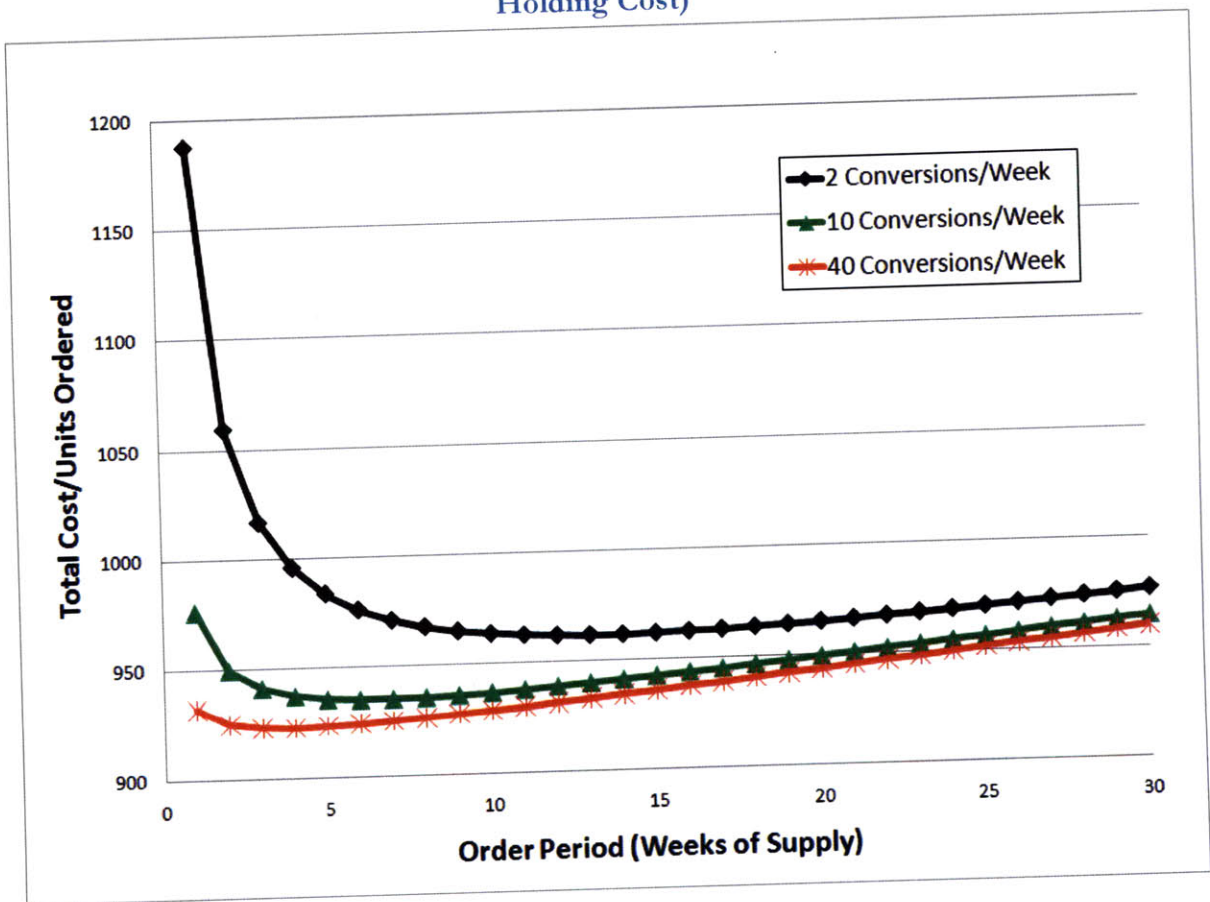
3.3 Warehousing/Transshipment

The warehousing/transshipment model compares the cost of the two distribution options when average demand per month, number of conversion centers, and order quantity are changed. The model output for one set of decision variables is shown in Table 3-2. Order quantity is represented in conversion kits. Ordering one conversion kits means ordering one of each of the three key components. For this set of decision variables (monthly demand of 2800, and 9 conversion centers), we see an annual savings of $205,000 by choosing warehousing over transshipment.

Table 3-2: Cost Summary of Warehousing and Transshipment Option

	Warehouse	Transship
Order Quantity (# of kits)	400	400
Shipping Cost	$ 19,566	$ 22,228
Warehousing Cost	$ 4,670	$ -
Cross Docking Cost	$ -	$ 4,000
Inventory Cost	$ 2,584	$ 3,014
Total Cost net of Purchasing Cost	$ 26,820	$ 29,242
Savings per Order	$ 2,422	
Annual Savings	$ 205,270	
Purchasing Cost	$ 1,824,800	$ 1,824,800
Average Money Tied in Inventory	$ 1,094,880	$ 1,277,382

XL Hybrids' different demand scenarios were simulated in our model at different order quantities to find the recommended order quantity for each set of decision inputs. For all the scenarios, the model states that transshipment is the less expensive distribution option initially. However, as demand and the number of conversion regions increase, XL Hybrids should shift towards warehousing. Aside from the optimal order quantity, the model also suggests when to transition from transshipment to warehousing using cost as the criteria. Our next section presents two of the more probable scenarios that we have mapped out.

3.3.1 Fast/Medium Growth Scenario

Figure 3-19: Fast and Medium Growth Scenario Analysis of Total Relevant Unit Cost
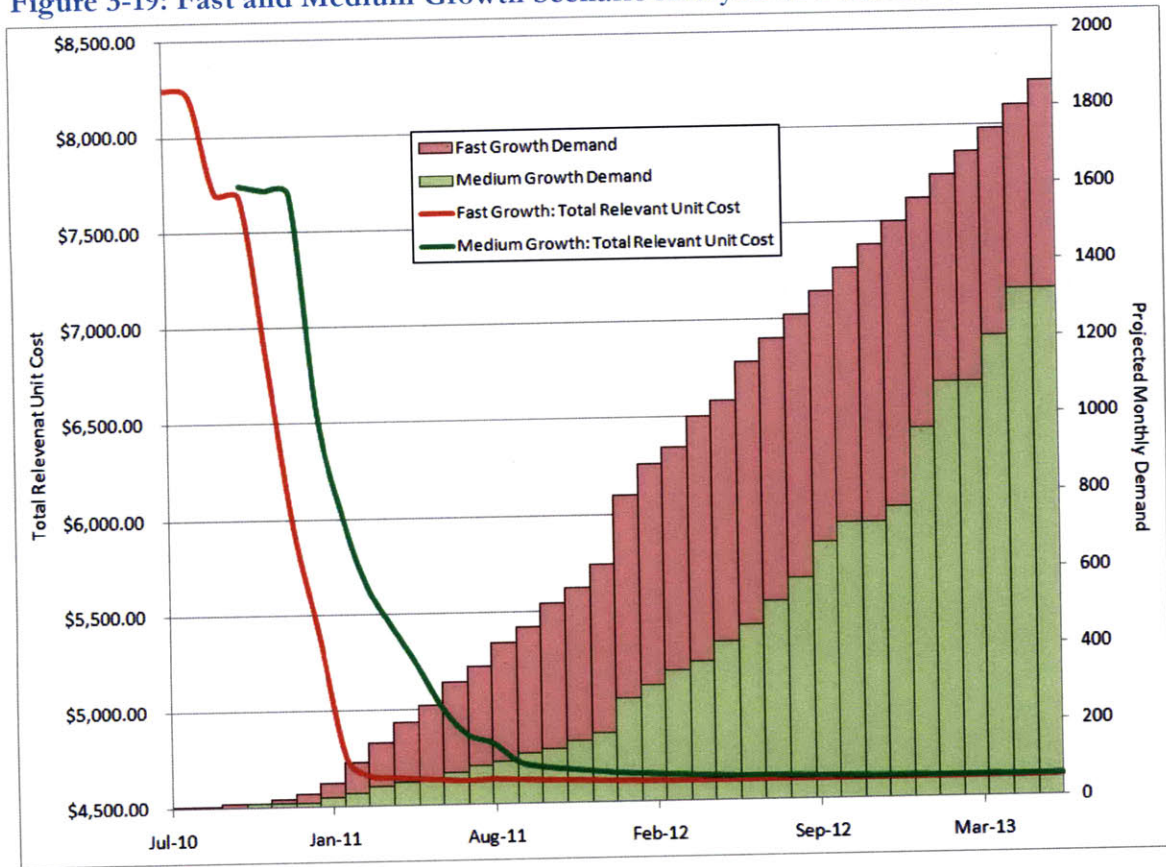
Figure 3-19 shows the total relevant unit cost for XL Hybrids' fast and medium growth scenarios. The total relevant unit cost numbers obtained from this model were used by XL Hybrids in their overall financial models. This analysis is important because it gives a better representation of the costs that will be incurred by XL Hybrids over time. XL Hybrids can then use the cost to determine the pricing of their hybridization service and the amount of funds needed.

The costs were high initially because of lower order quantity. Figure 3-20 shows the order quantity and frequency of the conversion kit for both fast and medium growth scenarios. This recommended order quantity was the lower number between the optimal order quantity obtained from our model and the quantity constraint by XL Hybrids' financial position. Until the average demand per month reaches 120, the order quantity would not be optimal. This constraint was

added to reflect the increased difficulty for startups to raise money, and to prevent over-stocking of components when future demand has not yet realized. Even though XL Hybrids would incur higher procurement costs, it minimizes the amount of money tied in inventory and hence the amount of risk that XL Hybrids undertakes.

Figure 3-20: Fast and Medium Growth Scenario Analysis of Order Quantity and Frequency of kits
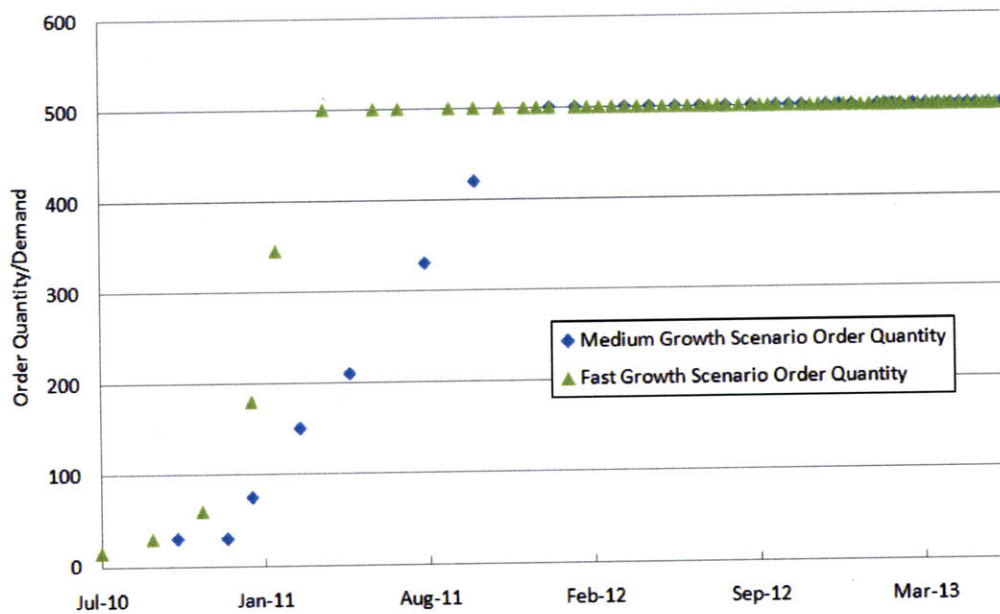
The model recommends warehousing as the ideal option once there is adequate demand. For the fast growth scenario, the model recommended that XL Hybrids start with transshipment and switch to warehousing in **November 2010**. For the medium growth scenario, the recommended date was **January 2011**. This knowledge helps XL Hybrids to plan in advance when they should start looking for 3PLs to handle their warehousing operations.

Aside from cost, switching to warehousing also provides other benefits. Warehousing allows XL Hybrids to better focus on vehicle conversions, which is their core competency. As demand and number of conversion regions increase, so does the complexity of coordinating transshipment.

Given the limited manpower that startup companies typically have, they should not be distracted with the distribution of their key components.

3.3.2 Adjusted Purchase Cost Contract Scenarios

Our next step was to run the same scenario under the assumption that the volume discount can be negotiated based on an annual volume rather than based on individual orders. By guaranteeing the supplier a certain order quantity over the year, XL Hybrids might be able to obtain cheaper prices for individual orders of smaller quantity. The goal was twofold. First, we wanted to determine the cost savings achieved if the volume discount was based on an annual volume and hence the importance of negotiating such contracts. Second, we wanted to determine if this type of contract would enable XL Hybrids to move towards a Just-In-Time system.

Figure 3-21 shows us the order quantity and frequency of both the contract that considers volume discounts by individual orders and by annual volumes. The savings for each year if an annual volume discount contract is negotiated is also listed.

Figure 3-21: Order Quantity/Frequency and Yearly Savings of Annual Volume Discount Contract under Medium Growth Scenario
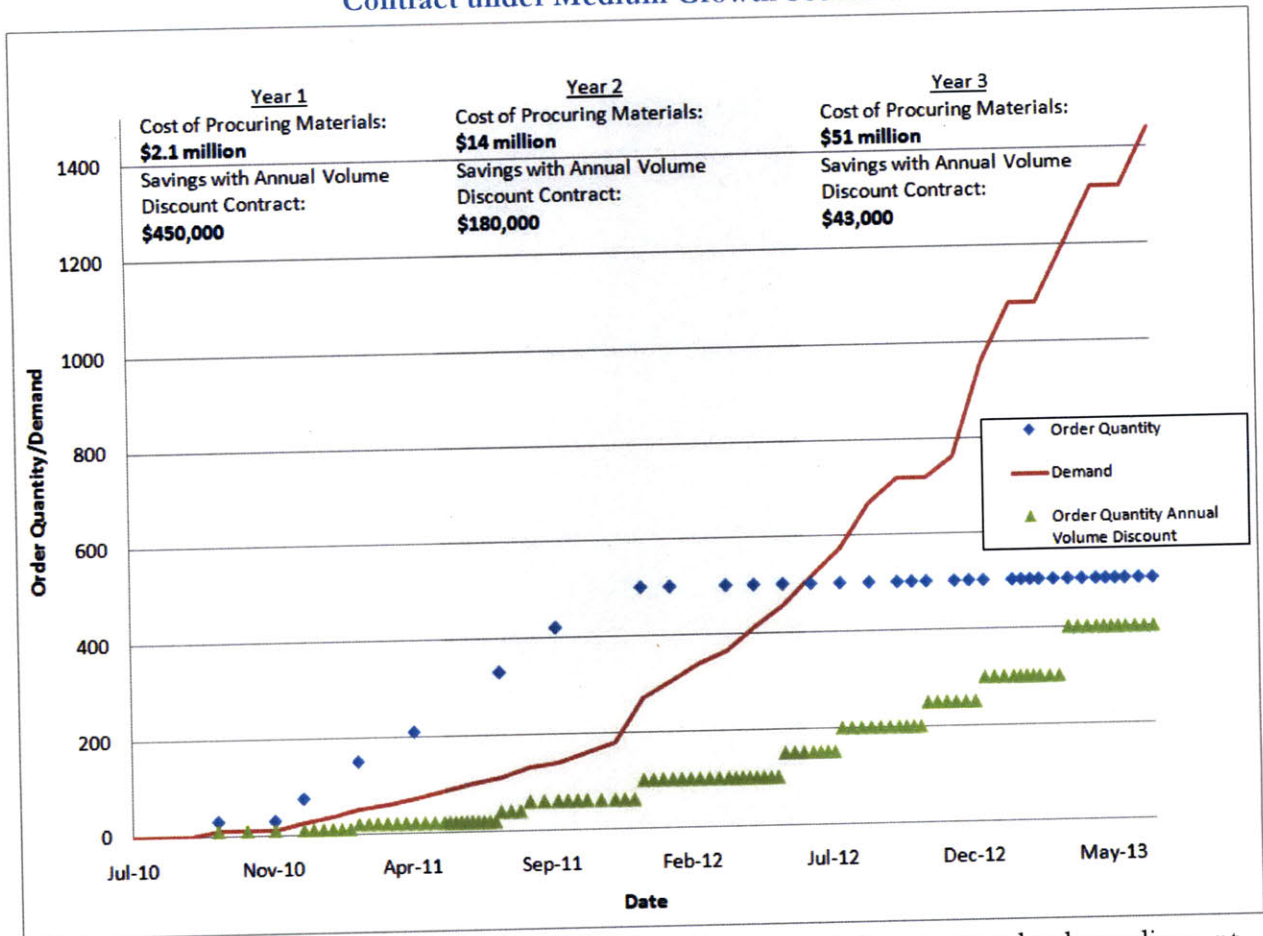
For the medium growth scenario, cost savings from negotiating an annual volume discount contract would only be significant in the first year of operations (20%), whereas in the second year (1.2%) and third year (.08%), it becomes negligible. This implies that from the second year onwards, XL Hybrids does not need to focus on negotiating the annual volume discount contracts. Knowing when the cost savings become negligible allows XL Hybrids to determine how long they should commit to their initial supplier. XL Hybrids can then open the sourcing to an RFP process where they leverage a wider supply base to find a supplier that fits their need better. While annual volume discount contracts have minimal cost savings after the first year of operation, they enable XL Hybrids to move towards a Just-In-Time system. Under such contracts, order frequency is a lot higher and often result in weekly orders. If XL Hybrids wants to adopt a Just-In-Time system, then

negotiating for such contracts would be valuable at least for the first three years of operations. For the fourth year, we believe that there is no significant difference in order frequency between both types of contracts.

In deciding between transshipment and warehousing, the model recommends that under an annual volume discount contract, XL Hybrids should start with transshipment and switch to warehousing only in **July 2012**. However, given the additional benefits (mentioned above) that warehousing has over transshipment, XL Hybrids might want to consider performing the switch earlier.

4 Supply Chain Framework for Other Startup Companies

Our thesis also aims to deliver a framework for startup companies with business concepts that require supply chain planning. This framework is for startup companies that have a sellable product or a product with at a later stage of development. Figure 4-1 is a flow chart illustrating the steps that a company should consider when planning their supply chain.

As with all companies, the most important part of the business is to understand the customer and the market. Startup companies have the opportunity to find out what the customer wants before designing their process and supply chain. Companies must estimate the size of the customer base in order to develop demand and revenue projections. Section 4.1 talks about understanding the market and the customer, while Section 4.2 gives a guideline on how product and process are related.

Once the process is laid out, the company should identify where its competitive advantage lies. This requires having an understanding of their competitors. If the competitive advantage or if the biggest profit margins are in the supply chain, then the company should manage and own everything in-house. Otherwise, it is recommended that companies outsource the supply chain so that they can focus on their core competencies. Section 4.3 discusses this in greater detail. After a company understands its customers, product, process, and competitive advantage, it can begin to develop a supply chain plan for the business.

Even if a company decides to outsource supply chain operations, it should still develop a supply chain plan for two reasons. First, the company may want to shift from outsourcing to in-sourcing the supply chain as its business develops. Managing outsourced supply chain competencies would allow the company to gain expertise in-house, and thus enable the company to perform

Figure 4-1: Framework for Startup Companies


```
┌─────────────────────────────────────┐
│  Understanding the Market and        │
│  Customer                            │
└─────────────────────────────────────┘
                  ↓
┌─────────────────────────────────────┐
│  Identify Product and Process        │
└─────────────────────────────────────┘
                  ↓
┌─────────────────────────────────────┐
│  Identify Competitive Advantage      │
└─────────────────────────────────────┘
                  ↓
              Outsource?
      No                        Yes
┌──────────────────────┐   ┌──────────────────────┐
│ Outsource but Manage │   │ Manage and Design    │
│ Strategic Supply     │   │ Supply Chain         │
│ Chain Plan           │   │ in-house             │
└──────────────────────┘   └──────────────────────┘
```

Supply Chain Plan

| Capacity Expansion | Production Plan | Sourcing | Network Design /Distribution | Transportation |

Considerations

Lever Points | Long Term Plan | Risk

Flexibility | Financial Constraints

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supply chain functions that were previously out-sourced. Second, internally managing supply chains drives continuous improvement.

Third-party logistics (3PLs) companies typically have less incentive to improve a company's business (Judith Taylor, 2010).

In planning the supply chain, it is important to note that there is no one-size-fits-all approach. Specifics of the supply chain depend on the product/process type, the industry, and the customer. What we attempt to do in this framework is provide discussion and analysis of the key areas of the supply chain that companies should consider when planning its supply chain. For each of the key areas listed, we discuss how we addressed the issues for XL Hybrids. The remaining sub-sections are devoted to discussing these key areas in greater detail:

- ➢ Production Plan – Section 4.4

- ➢ Capacity Expansion – Section 4.5

- ➢ Network Design – Section 4.6

- ➢ Sourcing – Section 4.7

- ➢ Additional Considerations – Section 4.8

It is useful for companies to go through several iterations of this framework. The ideal state is when a company designs every aspect of its business simultaneously to ensure proper coordination between its different arms. Since this is often impossible, the next best thing to do is to go through several iterations to see if there are ways in which products and processes might also be modified to better fit the supply chain.

4.1 Customer and Market

Understanding the customer and the market are critical to the success of a startup company, and need to be considered when designing a startup's supply chain. Questions for startups to consider when thinking about the customer and the market from a supply chain perspective are:

- How long is the sales cycle?
- Are order fulfillment/service fulfillment dates flexible?
- How long are customers' typical payment terms and how does that impact supply chain planning?
- Are customers focused on service or price and how does that impact supply chain planning?
- What are competitors doing successfully or unsuccessfully with their supply chain?
- Are suppliers located globally or regionally and how does this impact the startups financial/supply chain assumptions?
  Is this a new product or technology?

Answers to these questions will vary depending on the type of startup, however these questions will give entrepreneurs ideas of things they should be considering when designing their supply chain. For example, XL Hybrids has a six month sales cycle, which tracks the time customers approach XL Hybrids to convert their vehicles to the time the whole fleet of vehicles is expected to be hybridized. This means that XL Hybrids can plan their capacity and inventory levels of supplied parts around these orders. If the sales cycle was much shorter, XL Hybrids would need more inventory on hand and have capacity readily available.

The level of competition in the market also has a direct impact on the supply chain in that the company needs to identify the portion of the supply chain where the company can differentiate itself. For example, a company could source locally so that it can be more responsive to customer needs and thus provide a higher level of service. Lastly, the maturity of the product or technology will dictate how much investment and flexibility should be considered. New products or technology have additional uncertainty in demand thus cautious capacity planning and inventory management need to be considered.

4.2 Product and Process

Understanding the product and the process is required in order for companies to plan the supply chain. The product shapes the complexity of the supply chain and the operations needed to make the product because it dictates component sourcing, logistics, level of inventory, and order processing to meet customer service requirements. Classifying the product and the process into categories based on volume, speed, and production processes (See Table 4-1) allows companies to determine how they should expand capacity, store inventory, and plan production. Additionally, classifying the product and process will enable companies to determine the part of the supply chain that is critical to their business. This is especially important for a startup company since it has significant cash constraints, and thus needs to identify the portion of the product or process to be produced in-house so that it does not overextend itself under scarce resources. The firm also needs to understand the product characteristics that are critical to the success of the business and know the value added steps that drive profit and contribute to the product's success. Lastly, in the early stage of the business, there is the flexibility in designing the supply chain, thus taking this into consideration early will minimize future problems. Here are some of the questions to think about when focusing on the product and process:

- How long does it take to make the product?
- How mature is the technology/product?
- Is the product a low volume/specialty?
- Is the product a high volume standard commodity?
- Is the process a batch product?
- Is the process a continuous flow?
- What are the complexities of the components and the production process?

The answer to these questions may lie between the extremes, however, having a sense of the product and the process will determine the order processing, sourcing requirements, inventory level, capacity expansion, and production planning. Table 4-1 shows the various product and process combinations that lead to various sourcing, capacity expansion, and production planning strategies.

To use the table, one must first classify the product before one can determine the type of process, capacity strategy, and planning strategy that should accompany the product type.

For example, for a high volume commodity product, the process should be a continuous line. Thus, it will have a build-to-stock process order system with finished product stock. For a build-to-stock item, companies will gear their supply chains towards forecasted sales, which means they have a stable supply chain. This results in the company planning its production towards the forecast with inventory covering the fluctuations in realized demand. Additionally, capacity should be available in advance of demand. Conversely, for an assemble-to-order process, the production is more reactive to incoming orders which allows for less inventory in the pipeline since demand is known before production starts. Both of these product types require very different processes which in turn necessitate different supply chains.

Table 4-1: Product, Process, Strategy

Product Mix				
	I. Low Volume, Non-Standard, one of a kind	II. Low volume, many products	III. High volume, few major products	IV. High Volume, standard commodity
I Job Shop	1			
II. Flow Shop/batch		2		
III. Line Flow			3	
IV. Continuous Line				4

Characteristics				
Typical Order winner	Flexibility	←	→	Price
Typical Order Peneration Point	Engineer to Order	Make to Order	Assemble to Order	Make to Stock
Capacity Strategy	Lead	←	→	Lag
Planning Strategy	Chase	←	→	Level

(Jan, O., Martin, R., & Joakim, W. 2001)

For XL Hybrids, the product is aftermarket vehicle hybridization. The components that go into the conversion process are critical to its business. Hence, careful sourcing of these components is necessary. XL Hybrids' process can be broken down into sales, operations (performing the conversion), sourcing, and financing. As a startup company introducing a new product in a new

market, XL Hybrids' sales could have extreme variability. The conversion process is relatively simple but requires capital and labor. XL Hybrids can expand the network quickly since their conversion centers are small and easily upgraded from existing garages. The components will be sourced overseas, thus they require more planning for order quantity, storage requirements, transportation, distribution, and conversion center locations. The conversion process is similar to a conventional car maintenance operation performed in a garage. The complexity of this process, the time it takes to perform the process (i.e. the conversion), and the understanding of the sales cycle dictate the supply chain. Typically, orders to convert a fleet of vehicles will come directly from customers, with an expected time from order to delivery of six months. XL Hybrids' assemble-to-order process means it can hold less inventory and thus reduce costs. Additionally, XL Hybrids will have the ability to expand capacity once demand has materialized, and to plan conversions around its current and expected capacity six months ahead.

4.3 Identifying Competitive Advantage

There is a good amount of literature that discusses the importance of establishing a competitive advantage in any business. Michael E. Porter's book, "Competitive Advantage: Creating and Sustaining Superior Performance" (Porter, 1985) is a great reference for companies who seek to gain insights into identifying their competitive advantage. For a startup company, this concept is more important because it has to compete with established players in the market under limited financial and human resources. Identifying one's competitive advantage early allows a startup to focus its resources on aspects that strengthen this advantage.

There are several questions for a startup to consider when identifying their competitive advantage:

- What are my competitors currently competing on?

- What differentiates my company from my competitors?
- Is this differentiation sustainable and how should my company defend this position?
- Is the supply chain plan crucial in establishing a competitive advantage for the firm?

Having a competitive advantage requires identifying a profitable and sustainable way in which a company has an edge over its competitors. Once this is identified, the company should focus on activities that help to solidify this position.

If the supply chain plan is crucial in establishing a competitive advantage for the firm, it is recommended that the firm bring this competency in-house and fully own the supply chain. While this involves increasing capital expenditure (warehouses, trucks, etc.) and hiring and training more people to develop the supply chain, it allows the firm to have greater control and ownership. If such a capability is outsourced, competitors can replicate their supply chain by seeking the same services, thus nullifying the competitive advantage.

If the supply chain is not part of maintaining the company's competitive advantage, we recommend that most of the supply chain be outsourced. Outsourcing reduces capital expenditure, hence reducing the risk of the venture. The company can then use the cash and resources saved to invest in developing its core competencies. However, as mentioned in the introduction, the company still needs to understand and manage the outsourced supply chain responsibilities.

For XL Hybrids, we looked at Porter's five forces of competition to establish their competitive advantage. According to Porter's framework, the two key threats to XL Hybrids are suppliers and new entrants to the industry. First, XL Hybrids has relatively low bargaining power over their suppliers because XL Hybrids is a new company and has yet to prove its viability. Second, the threat of new entrants is high because the industry is untapped and the first-mover will have a big advantage in capturing that demand. As such, we believe that the company's strategy should focus on speed to entry and supplier coordination. Since the industry is new, speed to entry

would allow XL Hybrids to capture market share. The advantages of supplier coordination are discussed in Section 4.7. Since transportation and distribution are not part of maintaining its competitive advantage, outsourcing these responsibilities is a more viable option as it will allow XL Hybrids to focus on its core competencies of marketing and performing the conversions.

4.4 Production Plan

Production planning involves converting customer orders or forecasted demand into production given that orders and demand will fluctuate. Having a production plan enables companies to smooth out demand and maximize capacity utilization, reducing cost. Additionally, having smooth continuous production improves worker efficiency and performance, which results in higher product quality. Having a production schedule also enables procurement to ensure that products are sourced at the appropriate times. Lastly, a production plan is required to determine the capacity requirements.

Key questions to consider when doing production planning are:

- How will customer orders be received?
- What is the order cycle?
- What is the production processing lead time?
- What level of service do customers need?
- How will demand change?

All these questions are factors/variables that dictate the production plan. We recommend creating a production planning model that takes into account these variables, as well as costs associated with increasing capacity, performing production early, and not meeting service level requirements. Assigning costs of increasing and maintaining capacity, early production, and service requirements should be used to determine the appropriate production plan.

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If a startup company understands how its orders are received based on the framework described in Section 4.2, then the startup company can create a production schedule around these orders. Different types of ordering systems, i.e. build-to-stock versus assemble-to-order will have different production schedules. Build-to-stock production schedules will be based on forecasted demand whereas assemble-to-order production schedules will be based on realized demand. For both ordering systems, the cost of capacity needs to be considered.

XL Hybrids' conversion process follows an assemble-to-order process with a long sales cycle. Thus our recommendations follow closely with this order type which is a hybrid "lag and level" process. We created an optimization model for the "lag and level" process; a similar model can be established for other types of expansion by adjusting the cost of production and the cost of postponing production. Using our approach smoothed out demand because capacity expansions costs were high whereas the costs associated with postponing production were low until the production went beyond the sales cycle. In our model, it is better to maximize capacity utilization versus capacity expansion if service requirements can still be met. Our optimization approach to production planning is applicable to other startup companies because it focuses on maximizing utilization while minimizing costs and smoothes out fluctuating demand. Furthermore, the costs associated with expanding capacity, postponing production, and holding inventory is standard.

For startup companies, since the demand is typically projected to increase, production has to keep up with demand since postponing will cause undesired backlog. If the demand was to ramp high and then level off, it would be preferential to postpone the conversion/production as this would allow for less downtime. We ran the optimization for multiple demand scenarios to give us an idea of how the production plan would vary. Having a range of forecasted production plans is recommended to avoid point forecast errors and give management a list of possible outcomes.

4. 5 Capacity Expansion

Growing capacity and hiring people at the right rate is critical to the success of a startup company since startup companies do not have the financial reserves to buffer for business failures. There are extensive examples of companies growing too fast and having excessive capacity, such as Webvan and People Express, whose capital expenditures far exceeded their sales growth resulting in the companies going bankrupt. Conversely, if companies grow too slowly they are liable to increased competition and losing market share. Typically when a company invests capital into expansion, there is an incremental addition to capacity and this increment can vary greatly depending on the industry. Understanding when to pull the trigger to expand capacity allows the company to know when additional funding is needed.

Some of the critical questions to consider when looking at capacity expansion are:

- How to grow the business?
- When to open new facilities?
- When to expand the current facility?
- What are the different means to expand production capacity?
- When to hire employees?

These decisions are typically based on forecasted sales but in some circumstances can be done after sales have been realized. When deciding the rate at which to grow capacity, companies should look at a time horizon. With startup companies, demand is very uncertain thus we recommend using a shorter time horizon so that companies do not over extend themselves based on long term projections which tend to be more tenuous. We recommend that startup companies develop a model to calculate how and when to expand their capacity to meet demand. Using an optimization model works well since it focuses on using the most cost efficient method to increase capacity while meeting service requirements. Taking into consideration the associated costs of investing capital versus postponing expansion, and building inventory are factors that should be incorporated in the

model. There is risk associated with expanding capacity thus postponing capacity expansion is usually preferable since this decreases risk exposure. We have used an optimization model to do capacity planning, however a simulation model would work well too.

For XL Hybrids, we looked at both a short and long time horizon of 1 year and 3 years respectively. We developed an optimization model given a fixed production plan which was optimized using our production planning model. We believe that using an optimization model is applicable to other startup companies because it weighs the various methods to increase capacity and optimizes for the most cost effective way to increase capacity in order to meet service requirements. The service requirements were an input in the model and fixed. We followed a lag and level approach to postpone expansion. Other startup companies will need to determine the methods it has to expand their business, and the human and capital investments that it entails.

In our optimization model we have taken high, medium, and low demand projections and optimized capacity for each of these scenarios. This gave us a range of possibilities of the rate of capacity expansion to give XL Hybrids a sense of the budget required to meet various sales forecasts.

Note: The time it takes to open a new facility was not taken into account in our model. Nevertheless the decision to open a new facility would be based largely on current capacity and the forecasted demand.

4.6 Network Design

Network design aims to optimize how components move from a supplier to a firm and how final products move from the firm to the customers. A company has to consider network design to minimize transportation and distribution costs of components and products. Furthermore, network

design allows a company to identify the infrastructure and financial requirements necessary to support its projected demand.

Network design is a broad topic, and there are several key issues to consider:

- Where are the locations of my suppliers and customers?
- Does the network support the overall strategy of the company?
- How many tiers in the distribution network are optimal?
- How will reverse logistics affect network design?

There are three basic structures for a distribution network of a company with multiple branches located in different geographies:

1. Each branch of the firm places individual orders with the suppliers.

   This reduces the complexity of the system (especially if the supplier takes care of delivery), but negates costs savings from volume discounts.

2. Orders between branches are coordinated. Items shipped in bulk to a certain location and divided to be transshipped to individual sites.

   This allows the firm to make use of volume discounts, but usually results in higher system inventory levels due to mismatched quantities.

3. Orders between branches are coordinated and suppliers deliver components to a warehouse or holding area. Individual branches then place orders through the warehouse as required.

   This allows for lower system inventory due to risk pooling, and gives each branch the flexibility of having its own ordering system. However, it incurs warehousing costs and increases transportation costs for the firm.

The choice between the different structures should be made based on balancing transportation, holding, purchasing, and warehousing costs. Firms should develop a model that estimates the costs for the three options and use it as a starting point for their decision. Often, the most cost efficient distribution structure will change as business grows. Understanding when the transition between

structures has to take place and laying out the transition plan ensures smoother business operations in the future.

A startup company also has to consider how reverse logistics might impact the design of the supply chain network. Reverse logistics might differ for individual components, and is tied with the overall service that the company wants to provide. It is usually cost advantageous to exploit economies of scale when shipping defective or recycled parts back to the company or the suppliers. Furthermore, aggregating these components makes the process less complicated. However, the company would have to balance this with the urgency of getting the parts back. This could stem from the need to trouble-shoot parts to improve the manufacturing process, or from a service level requirement promised by the company.

As mentioned in the earlier sections of the thesis, we built a model for XL Hybrids to analyze how changing the demand and the number of regions that XL Hybrids has would affect the choice between warehousing and transshipment. For XL Hybrids, results from our model suggest using the transshipment option during the first few months before quickly switching to the warehousing option. Warehousing would also facilitate the reverse logistics process. The warehouse can be a stocking point for defective parts from the regional conversion centers before it is shipped back to the overseas suppliers. Since XL Hybrids plans to outsource its transportation and warehousing, the transition from transshipment to warehousing is simple.

4.7 Sourcing

Instead of developing the technology and infrastructure to build its product from raw materials, sourcing for components allows a company to focus on its core product or service. Sourcing is particularly important if component costs play a major role in the total expenditure of

the company. Proper sourcing can lower procurement expenditure and improve the quality of components delivered from suppliers. Below are some questions for startups to consider when considering sourcing:

- What are the components that require sourcing?
- What sourcing method should my company use for each of the component? (Single sourcing vs. Multiple sourcing; Distributor sourcing vs. Direct sourcing)
- What kind of relationship does my company want with its supplier?
- What order quantity/frequency should my company source for each component?
- When should my company open the sourcing process to a Request for Proposal (RFP)?

Based on the product and process, the company will be able to identify the list of components that need to be sourced. Because each component has its unique characteristics and contribute differently to the final product, the company should consider having different sourcing strategies for each of them.

Startup companies need to consider whether to source from a single supplier or from multiple suppliers; from distributors or directly from component manufacturers. Single sourcing reduces purchase cost of components but is usually riskier. Conversely, sourcing from multiple suppliers may cost more than single sourcing due to lack of volume discounts and increased administrative costs from managing multiple suppliers, but mitigates risks associated with single sourcing such as quality issues, factory disasters, etc.

Sourcing from distributors minimizes the complexity of the sourcing process, allowing firms to better focus on their core competencies. Furthermore, a startup can tap into the volume and experience that distributors have when negotiating with suppliers. However, directly sourcing from the component manufacturers allows the startup to develop close relationships with its suppliers.

Besides knowing who to source from, a startup company should decide the nature of its relationship with its suppliers. Developing close relationships enable both companies to work together to improve the quality of the components. Suppliers would also be more willing to share

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ideas and split cost savings attained as a result of the collaboration. On the other hand, a company might choose to let suppliers compete through a Request for Proposal (RFP) process to determine who is awarded the contract for the components. This potentially reduces the costs of procuring parts and gives startups the chance to work with bigger companies. Because startup companies have less negotiating power over their suppliers and have a need to leverage suppliers for component development or customization work, it is usually in their interest to begin by collaborating closely with a few key suppliers rather than casting a wide net to many suppliers. As demand grows and their initial supplier can no longer support the volumes required, an RFP process should be considered.

After the sourcing strategy is mapped out, order quantities from suppliers has to be decided. Order quantities are an important driver in deciding the type of operation process and distribution network for a firm. Volume discounts are typically given based on individual shipment orders. With larger companies, it is possible to establish prices based off annual contracts, but for startup companies, this is harder as they have less negotiating power with their suppliers.

With volume discount based on individual orders, it is more economical for a startup company to purchase in large shipment quantities, resulting in high inventory levels for their components. However, when deciding the order quantity, a startup must also balance between volume discounts and amount of money tied in inventory. Startup companies cannot afford to have a lot of money tied in inventory given their financial constraints and the inherent higher risk of their business.

As a startup company sees growth in its business, it will have increased negotiating power and thus may move towards establishing contracts based on an annual commitment. Such a step could mean switching from buying in bulk to Just-in-Time purchasing. Hence, it is important for

startup companies to understand how this change would affect their business process and how it can increase their profitability to best make use of volume discounts.

XL Hybrids chose to source the three key parts of its hybridization process directly to establish strong supplier relationships while sourcing the rest from distributors to simplify the ordering process. Depending on the type of contract and the projected demand of XL Hybrids, the optimal order quantity would change. This was reflected in Figure 3-21 in the Results section.

The key parts are also single sourced because the technologies of these parts are under the developmental phase and require close relations with a supplier to fine-tune them. Once the technologies become more commonplace, XL Hybrids might want to consider using an RFP process to place pressure on the suppliers to reduce costs.

4.8 Additional Considerations

Once the main decisions of the supply chain have been made, the startup should look into other issues that affect the firm's supply chain. Because the possibilities of business operations are so diverse, it would be difficult to brainstorm a comprehensive list of these issues. However, here are some guidelines as to what a startup should think about:

- What are the other supply chain issues that affect business operations?
- Are there any established companies/industries that have similar operations as my company?
- What lessons can be learnt from studying their supply chain operations?
- How does having a different business strategy from my competitors affect the supply chain operations within my company (as opposed to the competitor's)?

One such issue, as listed in our framework above, is transportation. For a startup company, transportation of materials into and out of a firm is typically outsourced. As mentioned earlier, this allows the company to focus on its core business and minimize financial and human capital spend.

When outsourcing transportation, the level of service provided by the forwarder should be one of the metrics that the startup considers. Startup companies should seek a high level of service even at the expense of higher costs so they can better focus on their core competencies (Jonathan Byrnes, 2010). Other considerations include past records of the forwarder, financial stability of the forwarder, and liability coverage for the shipment. This aims at reducing the risk that the startup company faces in the area of transportation.

For XL Hybrids, we recommend using a third party logistics (3PL) company because it integrates both transportation and warehousing services under a common interface, making it easy for XL Hybrids to manage its transportation and distribution network.

5. Future Work

Our recommendations for future work were based on the two different aspects of our thesis. The first section discusses the work that can be done to our models to more accurately map out XL Hybrids' supply chain, while the second section discusses improvements to the supply chain framework for startup companies.

5.1 Improvements to Models for XL Hybrids

Our models cover production planning, capacity expansion, order quantity and warehousing/ transshipment aspects of XL Hybrids' supply chain. These models can be refined and improved in the following ways:

1) We focused on the three key components of the vehicle hybridization process: the battery, the electric motor, and the controller. To ensure a complete understanding of the procurement process, the models should be extended to include the full range of SKUs purchased by XL Hybrids. Furthermore, as XL Hybrids expands, they seek to extend their services to other classes of vehicles. This requires different types of batteries and electric motor. Ideally, the model should reflect this.

2) Some of our models' costs and demand inputs were estimates and could be inaccurate (e.g. warehousing costs and transportation costs). Our thesis focused on ensuring that the models were user-friendly and operational. While we obtained rough data numbers through calls to different businesses, further work should be done to increase the data's accuracy.

3) Our models for production planning and capacity expansion currently optimize separately from each other. This greatly reduces the amount of computing power needed. However, it

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would be interesting to see if the results would change if these models are combined and global optimization of both production planning and capacity expansion is achieved.

4) For sourcing, we focused on the movement of parts upon arrival at the ports. For a more complete understanding of the supply chain, the model could be extended to track movement from the overseas suppliers.

5) While our models account for supply chain flow from suppliers to warehouses to conversion centers, reverse logistics was not planned for. More work can be done to incorporate the return of components into the current network.

6) Our models are currently done in Excel with limited web-interface capability. As XL Hybrids expands and increases the number of conversion centers, the models should be made web-based to allow easy access by customer-support staff.

These models provide a theoretical approach to understanding the different elements of the supply chain. Aside from these analyses, ground work should be done to understand the physical flow of components. Particular attention should be paid to the transaction points of the supply chain (e.g. transferring of components from the shipping company to 3PL, and transferring from the 3PL to the warehouse manager). This would validate the model's recommendation and ensure its applicability in the real world.

5.2 Building upon Supply Chain Framework for Startup Companies

Our supply chain framework for startup companies was based on our work with XL Hybrids, interviews with industry professionals and academics, and literature review. We believe that this framework is reasonably robust as we have tried to distill insights that would be applicable to most startup companies. However, more work can be done to validate these insights and provide extensions to the model.

First, startup companies should be encouraged place more emphasis on supply chain design when planning their business. If startup companies are willing to apply the framework, they will be able to provide feedback on improvements to the models. Second, more interviews and surveys should be done across established companies. This would allow us to strengthen our framework based on lessons obtained from the successes and failures of these companies. Finally, while the supply chain framework is targeted at startup companies in general, there could be insights that are industry-specific. Extensions to the framework should be added to give a more comprehensive supply chain perspective to startup companies.

List of Terms

Term	Description
3PL	3rd Party Logistics provider
Assemble-to-Order Process	Assemble-to-order involves performing the conversion after the customer order has been received.
Battery	The battery is one of the key components in the hybridization process. The battery charges and stores the energy when the vehicle is breaking and transmits energy to the controller and motor to engage the hybrid motor in order to add power back into the driveline.
Bay	The bay is a compartment in the facility where the hybridization process is performed. A bay will consist of a lift to raise the vehicles. There is a limit to the number of bays that we can have in conversion center which we set to 3
Capacity Planning	Capacity planning involves planning the required capacity to meet a service and production level. For XL Hybrids this means the capacity required to hybridize vehicles in order to meet demand. There are 4 ways for XL to increase capacity: Increase shifts, bays, facilities, and mobile teams.
Carrying Cost	The carrying cost is the inventory carrying cost which we set to 20% which is essentially the cost of having 1$ of having money tied up in inventory over a year.
Controller	The controller is one of the key components in the hybridization process. It is the brain that controls when the electric motor should engage, and when the battery should charge versus discharge
Conversion	The process of Hybridizing a vehicle. 1 Conversion= Hybridizing 1 vehicle
Conversion Center	A conversion center is the same as the facility. This is a location where XL Hybrids will hybridize vehicles. It is similar to a regular vehicle service center
Conversion Kit	A conversion kit is a bundle which includes the motor, the battery, and the electric motor which are needed to Hybridize a vehicle. We believe that the warehouse would be able to break down the 3 key components are re-package them into kits to facilitate the storage and conversion process for XL Hybrids
Demand	Demand is based on projected sales given to us by XL Hybrids. Additionally, we created scenarios with different demand to stress test our models.
Electric Motor	The electric motor is also one of the key components. Surplus power gained through braking is drawn from the rear differential via belt drive and powers the

	motor which charges the battery. The motor is then powered by the battery to add power back into the driveline. This assist improves fuel efficiency.
Facility	A facility is a conversion center. A facility is similar to regular vehicle service center. (mechanic's)
Mobile Team	Mobile team is a team that can perform the hybridization from a mobile van that goes to the customer and performs the conversion(s) at the customer site. This prevents the need for customers to deliver their vehicles to an XL Hybrids conversion center.
Optimization Model	Optimization models were developed using Microsoft Excel with Risk Solver Add In to find solutions to minimize costs associated with production planning and capacity expansion
Order Cost	This is the fixed cost associated with every order
Outsource	Outsource involves contracting out a portion of the business to a 3rd party. For example, outsourcing warehousing involves using a 3PL to warehousing without XL Hybrids needing to invest any capital into warehousing.
Production Planning	It is a schedule of when and how much production should be carried out based on forecasted sales or demand. It involves smoothing out the demand for production. For XL Hybrids this is the schedule of when and how many vehicles should be hybridized.
Safety Stock	This is the stock required to against uncertain transportation and demand. We set this number to 1.3 times the next months expected demand. (The travel time for the
Sales Cycle	The sales cycle is the time from when customers submit an order with XL Hybrids to when conversion of the fleet of vehicles has to be completed. For XL Hybrids this is 6 months.
Shifts	Technicians at the conversion centers will be working with 8 hour shifts. There is the possibility to add additional shifts to increase output from the conversion centers per week. The maximum number of shifts is 3. (24 hours in a day)
Silver Meal Heuristic Model	A Heuristic model to estimate an inventory mode given variable demand.
Simulation Model	Simulation model was used for the transshipment versus the warehousing decision. The simulation model ran multiple scenarios and determines the best order quantity and the associated lower costs for both warehousing and transshipment.

	Having the scenarios ran alongside each other enabled us to do a direct comparison.
Three Critical Components or Key Components	These comprise of the motor, controller and the battery.
Transshipment	Transshipment involves breaking the shipped goods from the supplier once they have reached the USA into individual shipments to the conversion centers without being held at a warehouse. In this case, the inventory will be held at the conversion centers, and in-transit.
Warehousing	Warehousing involves using a public warehouse to store inventory of the battery, the controller, and the motor.
XL Hybrids	Startup company that converts conventional, gas-powered commercial taxis vehicles into hybrids, allowing the customer to improve fuel efficiency of their vehicle.

References

Ananth, I., Vinayak, D., & Zhengping, W. (Feb, 2003). A postponement model for demand management. *Management Science, 49*(8), 983-1002.

Bolten, E. F. (1997). Chapter 2: Warehouses, leasing and storage costs. (pp. 8-16) American Management Association International.

Byrnes, J. (2010, March 8). Senior Lecturer, Massachusetts Institute of Technology. (M. Causton, & J. Wu, Interviewers)

Chan, F. T. S., Kumar, N., & Choy, K. L. (2007). Decision-making approach for the distribution centre location problem in a supply chain network using the fuzzy-based hierarchical concept. *Proceedings of the Institution of Mechanical Engineers -- Part B -- Engineering Manufacture, 221*(4), 725-739.

Christiansen, M., Fagerhold, K., & Ronen, D. (Feb, 2004). Ship routing and scheduling: Status and perspective. *Transportation Science, 38*(1), 1-18.

Hamdan, A., & (Jamie) Rogers, K. J. (2008). Evaluating the efficiency of 3PL logistics operations. *International Journal of Production Economics, 113*(1), 235-244.

Hoyt, D. (2006). *FedEx and environmental defense: Building a hybrid delivery fleet* No. SI-82)Stanford Graduate School of Business.

Hu, X., Duenyas, I., & Kapuscinski, R. (2007). Existence of coordinating transshipment prices in a two-location inventory model. *Management Science, 53*(8), 1289-1302.

Hu, J., Munson, CL., Silver, EA. (2004). A modified Silver-Meal heuristic for dynamic lot sizing under incremental quantity discounts. *Journal of the Operational Research Society, 55*, 671-673.

Jan, O., Martin, R., & Joakim, W. (2001). Long-term capacity management: Linking the perspectives from manufacturing strategy and sales and operations planning. *International Journal of Production Economics, 69*, 215-225.

Jones, J. R. (1972). Operational characteristics pertaining to public warehouses. *Transportation Journal, 11*(3), 23-30.

Lebl, B. (2010, March 9). Supply Chain Manager NxStage. (M. Causton, & J. Wu, Interviewers)

L, Cheng, E, Subrahmanian., & A, Westerberg. (2003). Designing and planning under uncertainty: Issues on problem formulation and solution. *Computers and Chemical Engineering, 27*, 781-801.

Olhager, J. (2002). Supply chain management: A just-in-time perspective. *Production Planning & Control, 13*(8), 681-687.

Olhager, J., Rudberg, M., & Wikner, J. (2001). Long-term capacity management: Linking the perspectives from manufacturing strategy and sales and operations planning. *International Journal of Production Economics., 69*(2), 215.

Pan, J. C., & Yang, J. (2002). A study of an integrated inventory with controllable lead time. *International Journal of Production Research, 40*(5), 1263-1273.

Porter, Micahel E. (1985) *Competitive Advantage – Creating and sustaining superior performance.* The Free Press

R. Lesonsky. (2001). *Start your own business, 2nd edition: The only start-up book you'll ever need.* Entrepreneur Press.

Richard, W., John, P., & Jeffrey, W. (Jan, 1999). JIT manufacturing: A survey of implementations in small and large U.S. manufacturers. *Management Science, 45*(1), 1-15.

Sampath, R., & Jayashankar, S. (2001). A coordinated production planning model with capacity expansion and inventory management. *Management Science, 47*(11), 1562-1580.

Sheryl, K. (1989). Yield management: A tool for capacity-constrained service firms. *Journal of Operations Management, 8*(4), 348-363.

'Silver, E., 'Pyke, D., & 'Peterson, R. (1998). *Inventory management and production planning and scheduling* (Third ed.). 111 River Street, Hoboken, NJ 07030: John Wiley & Sons Inc.

Sunil, C. (2003). Designing the distribution network in a supply chain. *Transportation Research Part E, 39*, 123-140.

Taylor, J. (2010, March 9). VP of Supply Chain NxStage. (M. Causton, & J. Wu, Interviewers)

Tompkins, J. A., Simonson, S. W., Tompkins, B. W., & Upchurch, B. E. (2006). Relationships: The key to outsourcing success. *Logistics Management, 45*(7), 13T-22T.

Yulin, H., & Xinping, C. (2009). Wind turbine generator systems. the supply chain in china: Status and problems. *Renewable Energy, 34*, 2892-2897.

Appendix

Appendix I: Input Parameters into Production Planning and Capacity Expansion Models

Capacity Planning Inputs	Cost		Units	Sort
Minimum Number of Bays/ Facility		1	Bays/Facility	A Facility
Cost of Opening a Facility	$	99,023	$	A Facility
Employees per Base Facility		4		A Facility
Cost of Bringing Vehicle to Facility		200	$/vehicle	A Facility
Facility Operating Cost		100	$/Bay per Month	A Facility
Cost of Setting up bays	$	12,000	$/Bay	Bay
Maintenance Cost		500	$/Bay per Month	Bay
Max Capacity Per Bay per Shift		3	Conversions/bay/Shift	Bay
Max # of Bays per Facility		4		Bay
Customer Service/Sales Support Employees		2	employee/bay/shift	Bay
Vehicle Technicians per Bay		3	Technicians Per bay per shift	Bay
Customer Service/Sales Support Salary + Benefits	$	4,875	$ Per Person per Month	Employees
Technician Salary	$	5,850	$ Per Person per Month	Employees
Working Days Per Week		5	Days/Week	General
Weeks Per Month		4	weeks/month	General
Capacity per Mobile Team Per Shift		2	Conversions/Shift	Mobile
Mobile Team Operating Cost		2550	Cost per Team per Month	Mobile
Lump Sum Cost per Mobile Team		30000	Cost per Team	Mobile
Technicians per Mobile team		3	Technicians per mobile team	Mobile
Customer Service/Sales Support Employees (Mobile Teams)		2	employee/Mobile Team/Shift	Mobile
% of Capacity that needs to be mobile teams	20%		%	Mobile
# of Mobile Teams per Facility		10	Mobile/Facility	Mobile
Cost of Being Late		100	Cost per late vehicle per week	Production Plan

Appendix II: Input Parameters into Warehousing/Transshipment Model

Parameter	Value Assigned
Number of months of demand smoothed	6 months
Conversion center storage capacity	7 pallets per conversion center
Safety stock	20% for warehouse 40% for transshipment
Warehousing storage space cost	$10/pallet/month
Warehousing order cost	$25/order
Warehousing handling cost	$15/pallet
Weighted average cost of capital	20%
Maximum number of months of demand of inventory to stock	3 months