Industry Analysis: The Fastener Supply Chain in Aerospace Industry

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Abstract

In a highly regulated industry such as the Aerospace it is impossible to have suppliers entering and leaving as they please. Entry barriers raise the importance of understanding the behavior of the entire supply chain system ranging from turbine engines to fasteners; any part can force the plane production to stop when there is a supply shortage. Nowadays, every purchasing order placed by Aerospace, from OEMs to high-tech suppliers, is followed thoroughly. In contrast, fasteners fall in the category of nuts and bolts for their "simplicity" and high volumes and often *they are taken for granted. This paper focuses on the fastener supply chain, developing a system dynamic model to show insights of its behavior and to set the base for a further improvement analysis.*

Keywords:
Fasteners, Supply Chain, Aerospace, System Dynamics, and Vendor-Managed Inventory

Introduction

The Aerospace industry is continuously facing risks and instability at every stage of its supply network. Operating in the volatile environment of Original Equipment Manufacturers (OEMs) such as Boeing, Airbus and Bombardier are directly affected by various factors including market uncertainty, global economic challenges, fluctuating oil prices, fierce competition, and ever-changing international politics. As a consequence of the recent global recession, many of the

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suppliers have exited the industry or have been forced to adjust their production capacity in response to the sharp fluctuations in demand. As a result, the aerospace Supply Chain (SC) has been tremendously fragmented.

However, over the past few years the industry started to bounce back and began a production ramp up to cope with the projected growing trends in demand. In part, this recovery is the result of new technology developments, lighter materials, and more fuel-efficient designs. This situation has shifted the pressure upstream in the SC, pushing suppliers to expand production capabilities and raising uncertainty whether the pipeline is prepared to keep pace with such a rapid change.

When talking about airplane parts, what are the first things that people think of? Turbine engines, electronic control devices, landing gear, seats, wings, to mention few… in other words the big, visible, high tech and expensive parts of the airplane. But even the production of a multimillion-airplane can be stopped due to the most costly insignificant part: a fastener. One piece that cost few cents can compromise the production of a several million dollars airplane. For instance, a Boeing 747 has more than six million parts, from which more than half are fasteners[2]. Under those circumstances, a widespread shortage of fasteners will disrupt the entire SC, increase lead times, create order backlogs, and end up in frequent changes in production rates. Furthermore, evolving industry practice and aerospace regulations are causing parts to become obsolete which in turn creates tremendous strains on suppliers' production capacities.

The recent economic downturn has forced fastener manufacturers in the market to consolidate. As a result, OEMs are now relying on fewer and larger suppliers who not only serve the aerospace industry but also supply to a wide range of sectors such as marine, construction, and automotive. For that reason, there is an increasing concern that fastener suppliers may not be able to accommodate their expected demand requirements for the next two years. Single source suppliers that were able to survive the industry's slowdown only increase the complexity of the supply base and intensify the fragility of the entire network.

Over the years, OEMs have been working closely with multiple distributors and third-party logistics (3PL) providers in an effort to mitigate risks, optimize forecasting, improve inventory management, and reduce costs. At the same time, industry-wide trends and polices such as vendor-managed inventory (VMI), strategic contract agreements, and collaborative relationship management are becoming instrumental in driving industry's dynamics and ensuring business continuity across the SC structure.

This Industry Analysis is aimed to understand the behavior of the fastener SC system by taking the interaction across different variables into consideration, identify scenarios that can create production stoppage, and explore ways to reduce the probability production stoppage.

[2] 747 Fun Facts. Boeing. Internet. July 2011.

Overview of the Fastener Supply Chain System

OEMs have two types of fastener suppliers: manufacturers and distributers. Each supplier varies in size and capability. Large fastener manufacturers such as Alcoa produce the majority of fasteners in the world. They have the capability to quickly increase their production capacity; however they serve multiple industries at the same time, therefore in case of demand increase, it will be difficult for them to adapt effectively and simultaneously across all industries. On the other hand, fastener distributors such as Anixter maintain inventory levels for multiple OEMs giving them the advantage to add demand volumes and increasing their purchasing power. Figure 1 illustrates how players interact in the SC of fasteners. For instance, "Manufacturer 1" not only supplies to all distributors, it also supplies to "OEM 1" directly, and the same behavior is shown from "Manufacturer 2" to "OEM 2", while "Distributor 3" only supplies to "OEM 2". These are few examples of the many forms that players connect among each other.

Information is shared across the SC by sending Purchasing Orders (POs) from OEMs to distributors and manufacturers. Since distributors don't produce any material – they only store it – once they receive a PO they forward it to manufacturers. In opposite direction, the material is shipped – in accordance to the POs – from manufacturers to distributors and OEMs as well as from distributors to OEMs. Fasteners are not exclusive to one industry; they are as much required in Aerospace as in Automotive or Machinery markets. Moreover, these markets are usually correlated thus when one's market demand improves, other industries' behavior follow the same pattern. This phenomenon raises the importance of the buying power of both the company and the market or industry. A better idea for each market purchasing power can be seen in figure 2.

Methodology

The main objective of this analysis is to understand the dynamics of the fastener SC system when shortage risk is involved and there is an abrupt demand growth. Likewise, it is important to identify ways to improve the performance of the system through scenario evaluations that consider the dynamic behavior caused by feedbacks and delays.

A system dynamics methodology was followed that enabled us to develop a model capable of tracking the behavior over time in response to changes in the system. At first, a meeting with Bombardier Aerospace (BA) supply chain experts was held to list and identify important variables and come up with the respective reference modes[3]. Then, a casual loop diagram (CLD) was created with the information gathered and follow-up meetings were arranged (feedback elicitation) to include BA's contacts in the process and to validate the system captured in the CLD. Finally a model was developed by taking into consideration the input from previous

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[3] David F Andersen and George Richardson, "*Scripts for group model building*" System Dynamics Review Volume 13 Number 2 Summer 1997

meetings, multiple interviews, workshops, and information obtained from other sources. ***Most of the quantitative information collected throughout this analysis was confidential, therefore was disguised.***

The model is comprehensive in scope, capturing the critical relationship between parameters such as production rates, supplier capacity, order demands, backlogs, inventory levels and capacities, including links in the SC (fastener manufacturers, fastener distributors, and aerospace OEMs). For analytical clarity the model is deliberately stylized in terms of the technical details of the existing SC elements, for example aggregates over most SKUs and market players.

The underlying tool is a practical computer-based simulation developed in Vensim. This tool will also be used to diagnose the various factors that are affecting the flow of fastener across the SC and to explore potential outcomes for alternative inventory management decisions and polices as well as other forms of coordination across the SC, under a variety of economic scenarios. The model is designed to develop and explore "what-if questions" rather than serving as a black-boxed forecasting tool. The current phase of analysis does not involve a detailed calibration to the entire SC and set the bases for further analysis in the future.

Model Description

Since numerous variables affect the fastener SC system. Considering all of them would create a complex model and complicate the analysis. Our model captures the essence of most representative supply chain actors: OEM, distributors and manufacturers. There are two types of manufacturer suppliers: major manufacturers who serve all market sizes/types and minor manufacturers who only supply to the OEM. Distributors bridge the gap between major manufacturers and the OEM by buying products from the former and supplying to the later. The model is based on the material flow shown on figure 3.

Our model also considers the effect of the demand of other aerospace OEMs and the rest of the industries requirements on common suppliers by calculating OEM's aerospace market share and the aerospace's market share in the fastener industry. If the company has a 50% of aerospace market share, according to figure 2 it will posses 7% share of the entire fastener industry. For the purpose of analysis we assumed that airplanes are built only with fasteners. This will set the boundaries to isolate the model to the fastener industry.

Our model represents each player as a subsystem except for "Other OEMs". Subsystems are connected by information flow upstream and material flow in the opposite direction. The OEM sends POs to their minor manufacturer, their major manufacturers, and their distributers who will forward the PO they just receive to their own suppliers – major manufacturers. Processed according to their capabilities, suppliers produce or receive the fasteners and then ship them to the OEM.

Airplanes are very expensive therefore it is not viable for any company to have a stock of airplanes waiting to be sold. This explains why aerospace is a "Make to Order" industry. A backlog order is where a "customer order received" is placed until the plane production stars.

This is commonly used in this kind of industries. When a demand increase occurs, it affects the OEM's backlog and triggers the reaction of the system to adapt to that change.
Purchasing orders are send from the OEM to its suppliers after considering its consumption rate and the forecast for the expected future demand. In a similar way, the distributor calculates their PO's quantities based on the received order and their own forecasted values before sending their POs to their suppliers – major manufacturers.
Contrary to OEMs, distributors behave like a "Make to Stock" type of industry mainly because they do not produce anything. To cover themselves from any demand volatility, they stock more inventory than needed. At the short run this seems to be an advantage, but it is not sustainable and later on the analysis will be demonstrated that produce noise in the system incurring in more costs.
Manufacturers adopt their production rate according to the POs received from OEMs and distributors. In addition, major manufacturers take into consideration demand from the other industries by including their demand volumes to the production rate. Because all the industries are correlated, the model considers that when there is a demand increase in one industry, the other industries will follow the same path. As a result, there is a huge demand increase at the major manufacturers "order receiving rate" that makes difficult to catch up with production for everyone despite their unique capacity adaptation characteristic. On the other hand, there is a delay for implementation of changes in manufacturing floor along with delay of realization of need to make those changes.

Detail Analysis:

<u>OEM:</u>

The model builds upon "policy structure diagrams of inventory and production"[4]. At the top of the system hierarchy, the OEM subsystem controls the input of demanded fasteners in the system and the output of shipped airplanes delivered to the customer (Figure 4).
The customer behavior is reflected in the system via "Customer Order Rate". When in equilibrium, this flow depends entirely on the company's market share of the industry – the market percentage of the company from the industry percentage of the fastener industry. One of the questions that the industry experts were curious about was to see if the industry would be able to keep up with an unexpected demand increase. In order to do so, the model includes two variables to create a step increase at specific time.
Every customer order received will pass through the "Customer Order Rate" and end up in the "OEM Backlog" stock and every order processed will flow out by "Order Start Rate". This outflow depends directly on a parallel material flow called "Production Start Rate" that

[4] John Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World. Boston: Irwin/McGraw-Hill, 2000. Print. Pages 709-723.

represents the production capacity of the company in terms of inventory availability. Once the production of an airplane is started, it flows to the “WIP” (Work In Progress) stock. Simultaneously, the backlog orders flow at the same rate to the “Started Backlog” stock. A WIP airplane is a Started Backlog Order. Finally, the “Shipment Rate” represents the airplanes delivered to customers.
As mentioned before, “Production Start Rate” represents the production capacity of the OEM in terms of inventory available and do not depend on the production capacity installed at their facilities (Eq. 1). The larger the OEM Backlog stock is, the larger the PSR will be, as long as there is available inventory. Additionally, if the OEM is able to reduce their Production Start Time the PSR will also increase if and only if there is available inventory to do so.

Equation 1:

$$Production\ Start\ Rate = \frac{OEM\ Backlog}{Production\ Start\ Time} \times Actual\ Stoppage$$

The importance of “Production Start Rate” resides in the inclusion of the “Actual Stoppage” variable in its calculation as a result of the “Actual Stoppage Loop”. This loop certifies that there are enough fasteners in stock to cover the Required Inventory for Expected Production Start in the Critical Time Horizon (Required Inventory for EPS in CTH). The inventory validation loop begins tracking any change in the “Production Star Rate” by comparing it with the “Expected Production Start Rate”; if there is any discrepancy the stock will adapt in the “ESPR Average Time” period through the “Change in EPSR rate”. Afterwards, the system adapts the expected airplanes per month to cover the “Expected Production Start Rate in the Critical Time Horizon” and then convert the units from airplanes to fasteners at the “Required Inventory for EPS in CTH” variable. The next step in the loop is to calculate the “Probability of Reaching a Critical Point” as shown on Eq. 2.

Equation 2:

$$PRCP\ = Table\ of\ Stoppage(XIDZ(\frac{Required\ Inventory\ for\ EPS\ in\ CTH}{Fastener\ Inventory}, 1))$$

It exist a major reliability to some fasteners more than others reason why by using a “Table of Stoppage” it is possible to consider a reliable value to continue production. The Table of Stoppage – as shown on Figure 5 – was validated by industry experts considering the system major assumptions and proved through evaluation of past scenarios.

At the end of the loop “Actual Stoppage” compares the “Probability of Reaching Critical Point” to the “Actual Stoppage Point” resulting in a “Go-or-No Go” value [1,0].

Equation 3:

$$Actual\ Stoppage = IF\ THEN\ ELSE(Probability\ of\ reaching\ critical\ point \geq\ Actual\ Stoppage\ Point, 0,1)$$

The OEM subsystem sends their Purchasing Orders to its suppliers with the "OEM Fastener Order Rate" variable. It has been said that the "Fastener Inventory" stock increases with the "Fastener Receiving Rate" and decreases with the "Consumption Rate". Similar to the "Expected PSR (Short term)" stock mentioned in the Actual Stoppage loop, the OEM calculates the "OEM Expected Order Rate" as some sort of forecast considering the current rate values and comparing it to any changes in the "Customer Order Rate. Then, the stock value – plus a safety stock – is compared to the "Fastener Inventory" resulting in "Adjustment for inventory". As shown on Eq. 4, the OEM will order the "OEM Expected Fastener Consumption Rate" in addition to any required adjustment.

Equation 4:

$$OEM\ Fastener\ Order\ Rate = MAX(0, \frac{Adjusment\ for\ Inventory}{Fastener\ Inventory\ Adj\ Time} + OEM\ Expected\ Fastener\ Consumption\ Rate)$$

<u>Distributor:</u>

Distributors play a vital role in the system by shipping 50% of the "Fastener Receiving Rate" to the OEM and an even more critical role when there is a short-term market fluctuation. Introducing distributor in the supply chain not only decreases the inventory holding cost of the OEM but also gives the buying power to distributor among the different OEM demand to decrease the cost of ownership of the fasteners from Manufacturer. Since they hold the inventory for the OEM its model is similar to a general "policy structure diagram" model. Contrary to the OEM, instead of "Make to Order", distributor's model is "Make to Stock". Based on their received orders, they place their orders to Major Manufacturers and ship to the OEM based on current demand and expected growth in future.

Manufacturer:

Major and minor manufacturers are the last subsystems in the supply chain model. They receive raw material from the mills and produce fasteners for the industry. As mentioned, one of the characteristics of manufacturers is their ability to adapt their capacity. Figure 8 shows the basic dynamics of the fastener manufacturers in a casual loop of capacity.

In the CLD the “Backlog” stock has as an inflow the order rates and as an outflow the “shipment rate”. This flows control the level at which the backlog stock can be found at any given time.

When backlog is built-up it creates delivery delays, which will generate pressure to expand the manufacturer’s capacity in order to improve the shipment rate. New facilities are acquired to adjust to the actual capacity with the desired shipment rate. This set of variables creates a balancing feedback loop that tends to control the “delivery delay”. A weaker balancing loop controls the “utilization” of the capacity.

Taking a step further away, a higher fastener order rate will not only affect the backlog but also will increase the expect order rate, which in turn will exert more pressure on fasteners manufacturers to expand capacity. The figure 9 illustrates the final casual loop for manufacturer. Based on the concept of Economies of Scales, the manufacturer with higher capacity has higher revenue and as a result has higher ability to expand its capacity in less time. With this in mind the model differentiates major manufacturers from minor ones. In addition, learning capabilities for new employee and new machinery should be taken to the account in the form of delays.

Transferring the previous CLD to a stock and flow diagram, the “Manufacturer WIP” will have “Manufacturer Production Start Rate” as the raw material inflow. This rate is driven by Capacity and the Utilization, which is effected by Capacity and Desired Production Start Rate. The “Desired Production Start Rate” can be found in typical manufacturing model as a result of “Desired Production” and “Adjustment for WIP”. (Refer to Major Manufacturer Model in Appendix).

A short-term solution for changes in the “Desired Production Start Rate” would modify the “Utilization” that affects the “Manufacturer Production Start Rate”. At the long term, there should be a change in capacity that will be triggered by “Pressure to Expand Capacity”. The manufacturer will start to build up capacity as a consequence of the “Capacity Adjustment” at a “Capacity Acquisition Delay” and later installed capacity at a “Capacity Installation delay”.

Results

The model starts at equilibrium only to receive a shock in the "customer order rate" and analyze the resulting behavior. For each of the 3 simulations the shock is represented by a step increase of 10%, 20% and 30% respectively at the 24th month. The graphs in figure 11 show the resilience experienced by the OEM subsystem after the shock demand at each simulation. The step increase presented on the "Customer Order Rate" produces more backlog orders and consequently, a goal-seek increase behavior on the work in progress (WIP). Since more production demands more from the inventory the "Expected Order Rate" increases until reaching equilibrium.

During the 30% increase simulation the system presents stoppage months after the demand shock was introduced. In order to analyze the details of this event we looked at different variables in every subsystem of the model. Although the Inventory level of OEM should increase accordingly to satisfy the new demand, information and material delay produce an over shoot and an under shoot on the inventory levels.

Behind the production stoppage is the behavior of the suppliers and its reaction to demand changes (Figure 12). On one hand, distributors are capable of supplying fasteners at the same rate in every simulation despite the fact that their inventory levels fluctuate. Distributors' business model is to have material available every time is needed by customers and since they don't produce anything, they need to assure they have enough inventory considering the manufacturers delivery delay. This extra inventory consideration is what keeps distributors shipping at the same rate without affecting its delivery delay. On the other hand, manufacturers are not able to produce enough fasteners to keep shipment rate constant extending its delivery delays across the system resulting on production stoppage.

Capacity represents a major difference between suppliers, while manufacturers are constrained to their machines capacity; distributors only need to store the ordered product. This explains why "Distributor Inventory" overshoots and "Manufacturer Inventory" behaves different.

Comparing the expected order rates across the supply chain explains the influence of information delay on the system (figure 13). Contrary to material delays, there is no capacity constrain in the information that can be shared. Therefore, manufacturers expected order rate can overshoot and manufacturer's inventory won't overshoot. Between "Customer Order Rate" and "OEM Expected Order rate" there is a 6 months forecast delay – explaining the gradual growth until equilibrium. As mentioned before, distributor needs to counteract their lack of production capability by storing inventory, making "Distributor Expected Order Rate" more sensible to changes. Upstream, manufacturers have their own "Manufacturer Expected Order Rate" but by the time they receive the information, it already has the influence of the expected order rate of distributors and OEM adding noise to the system.

Vendor Managed Inventory Policy

Vendor Management Inventory (VMI) is a distribution channel operation system where the manufacturer/vendor monitor and manage the inventory at distributor/retailer. In a VMI partnership, the distributor makes main inventory replenishment decisions for the OEM. The vendor monitors the buyer's inventory levels physically or via electronic messaging and makes periodic resupplies decisions regarding order quantities, shipping, and timing[5]. The inventory policy demands suppliers to replenish inventory for OEM and supply in cycles. Suppliers set a target inventory for manufacturers accompanied with more frequent inventory cycles of complement and joint distribution to achieve economic benefits.

The VMI policy included in the model shifts the forecast information from OEM to the distributor representing vendor access to the buyer's inventory levels and reducing information delays. Distributors will know exactly how many fasteners are on stock and how many are needed to continue production. The information confidence reduces overshoot in distributor order rate and is reflected even at the manufacturers expected order rate. The consolidation of order rates help avoid the stoppage presented on previous simulations, at the same time lower the inventory level required by the distributors. Figure 14 exhibit the distributors inventory levels drop compared to the previous simulations. In addition, the manufacturer visibility improves resulting in faster inventory adaptability. Manufacturers also acquire new capacity more effectively reproducing less variation in delivery delays. Overall, we can see significant improvement in the supply chain by comparing figure 13 with figure 15, where variability of the bullwhip effect it is reduced.

Conclusions and Future actions

The model represents the fastener supply chain dynamics, making possible to analyze its behavior based on the information provided by industry experts. In addition, the robustness of the model allows testing different policies and scenarios representing plausible outcomes. For instance, increasing the fastener safety stock will save the company stoppages' fees at expense of adding more inventory carrying costs. Modifying the time to average order rate changed the forecasted fasteners either increasing volatility or reducing response time presenting stoppage in both scenarios. Alternative policies were discussed based on simulation results. The insights gain on each simulation help identify what variables influence the system more than others.

As a result, information delays were identified as an important variable and selected to control the performance of the system. The selection was made considering experts' feedback and implementation feasibility. This is shown in the model in the performance improvement of the Vendor Management Inventory simulations.

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[5] Allan N. Portes, and Ghilherme E. Vieira, *"The Impact Of Vendor Managed Inventory (VMI) On The Bullwhip Effect In Supply Chains."*

In conclusion, distributors play a critical role in the supply chain and the OEM should establish strategic sourcing relations to improve the confidence of the information sharing. Further steps are needed to improve the sensitivity of the system. The current stage model was designed with the intention of introducing executive decision-makers to System Dynamics and to give them the capability to explore scenarios of their own, challenge the underlying assumptions, and examine effectiveness of combining policies.

Figures:

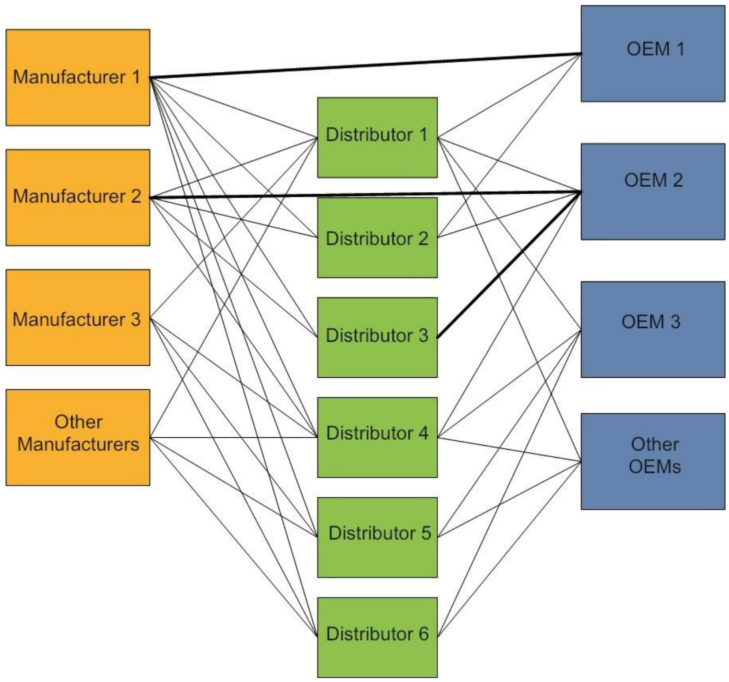

Figure 1: Fastener Supply Chain interaction

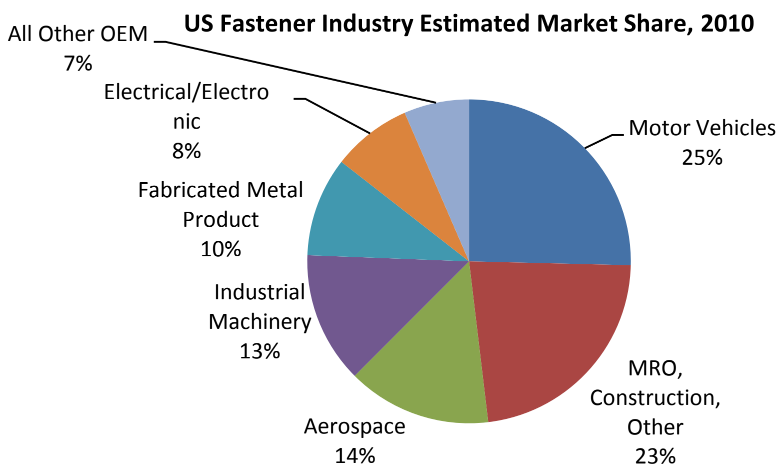

Figure 2: Fastener Industry market segmentation[6]

[6] Industrial Fastener Institute. Annual Report 2010. Printed. July 2011.

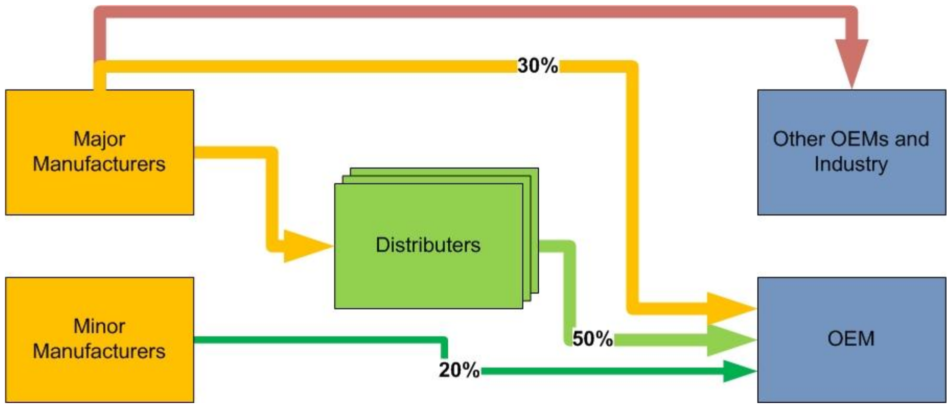

Figure 3: Material Flow Model Overview

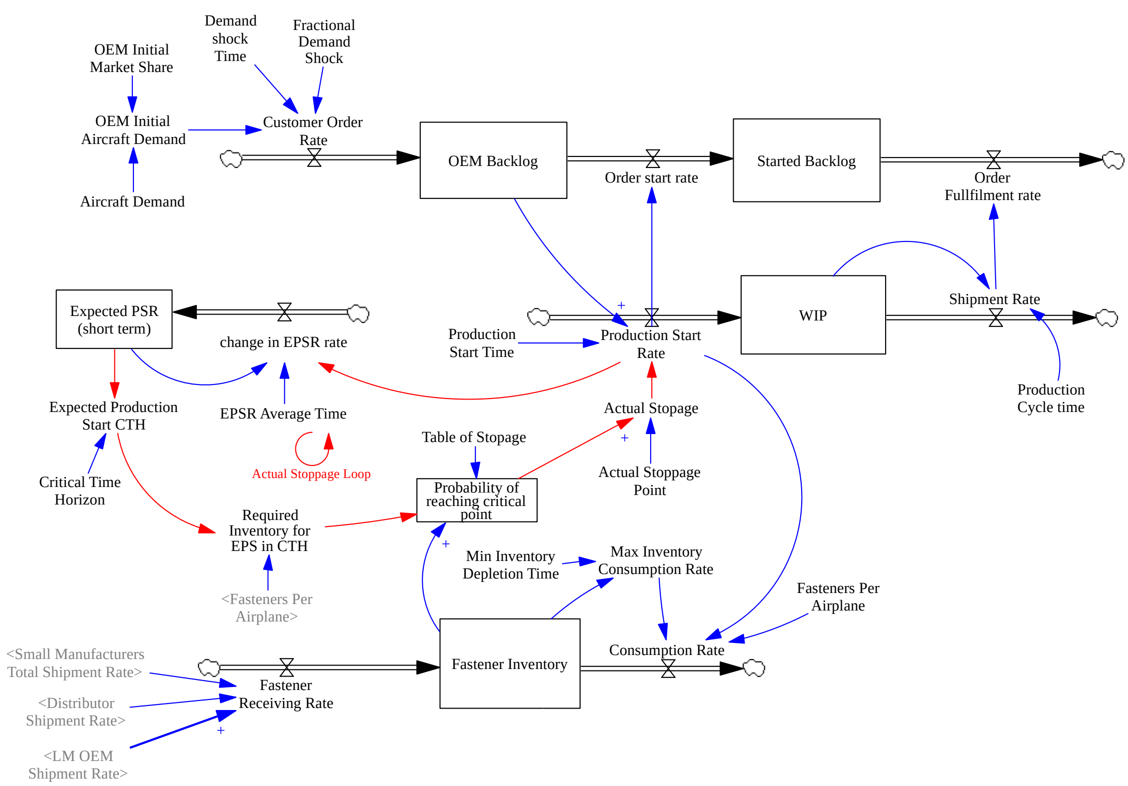

Figure 4: The OEM Model – Policy Structure Diagram

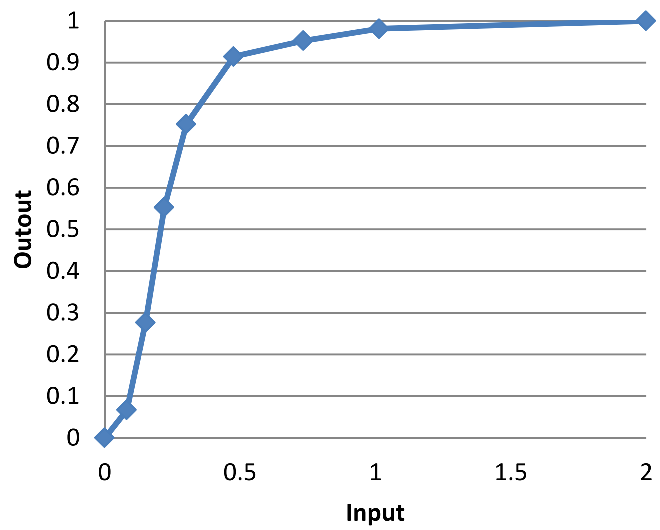

Figure 5: The Table of Stoppage

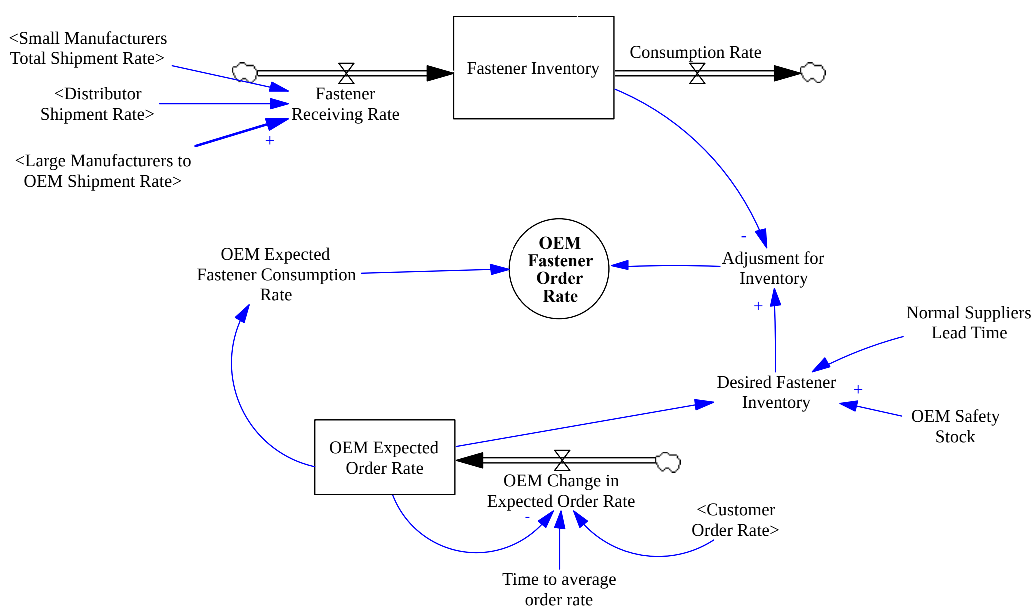

Figure 6: The OEM Model – Order Structure Diagram

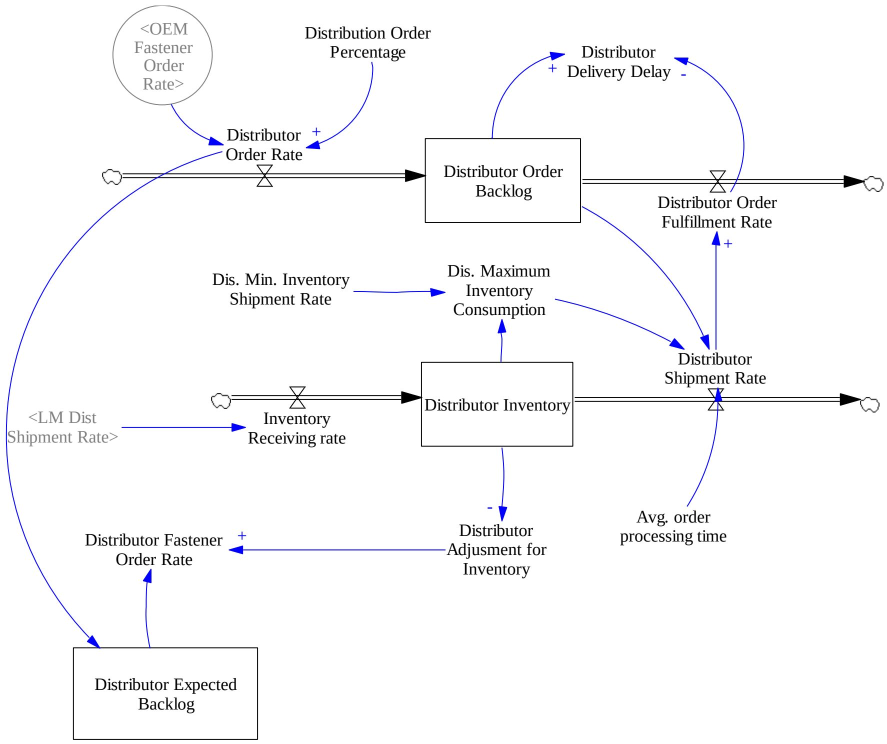

Figure 7: The Distributor Model – Order Structure Diagram

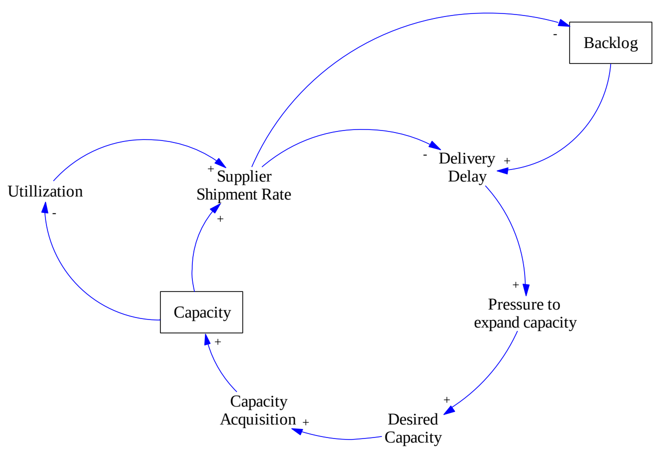

Figure 8: The Manufacturer First Causal Loop Diagram

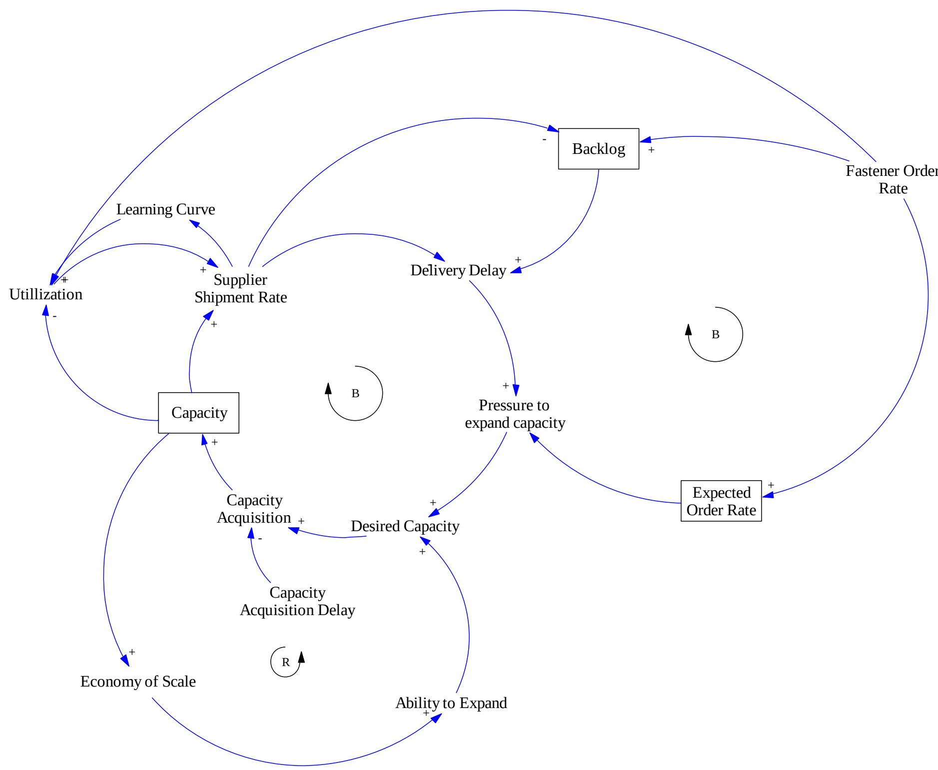

Figure 9: The Manufacturer Second Causal Loop Diagram

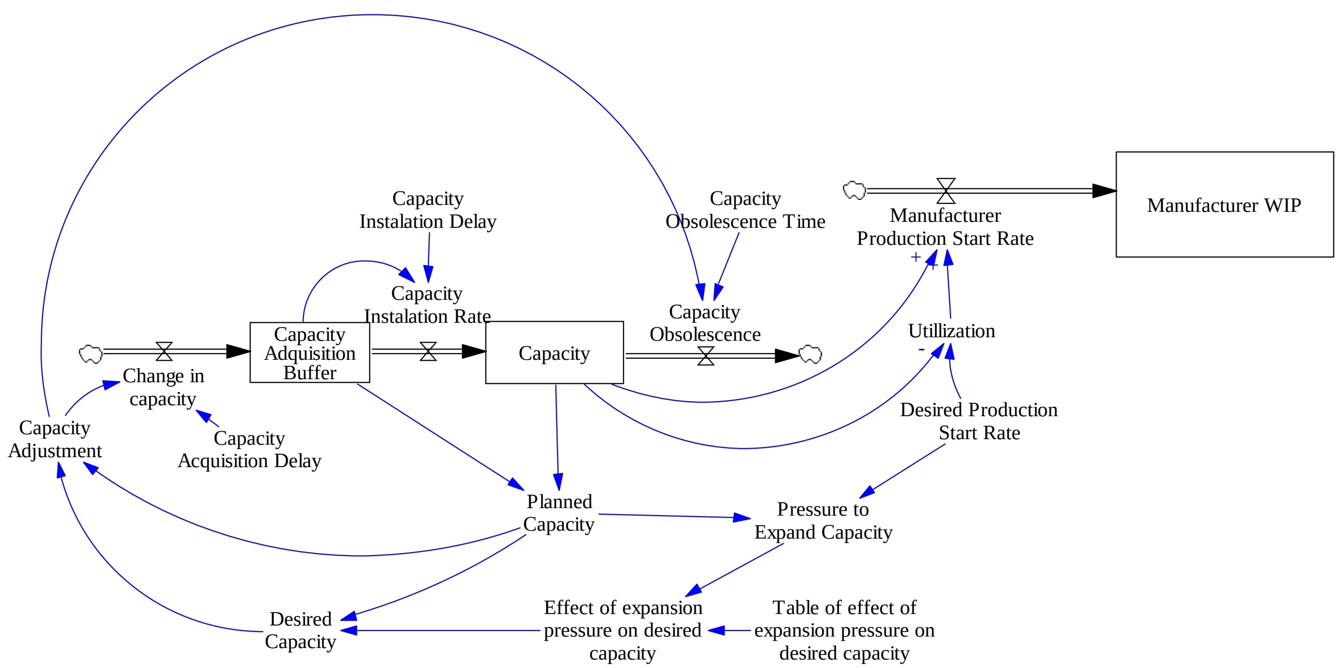

Figure 10: The Manufacturer Model– Capacity Acquisition Diagram

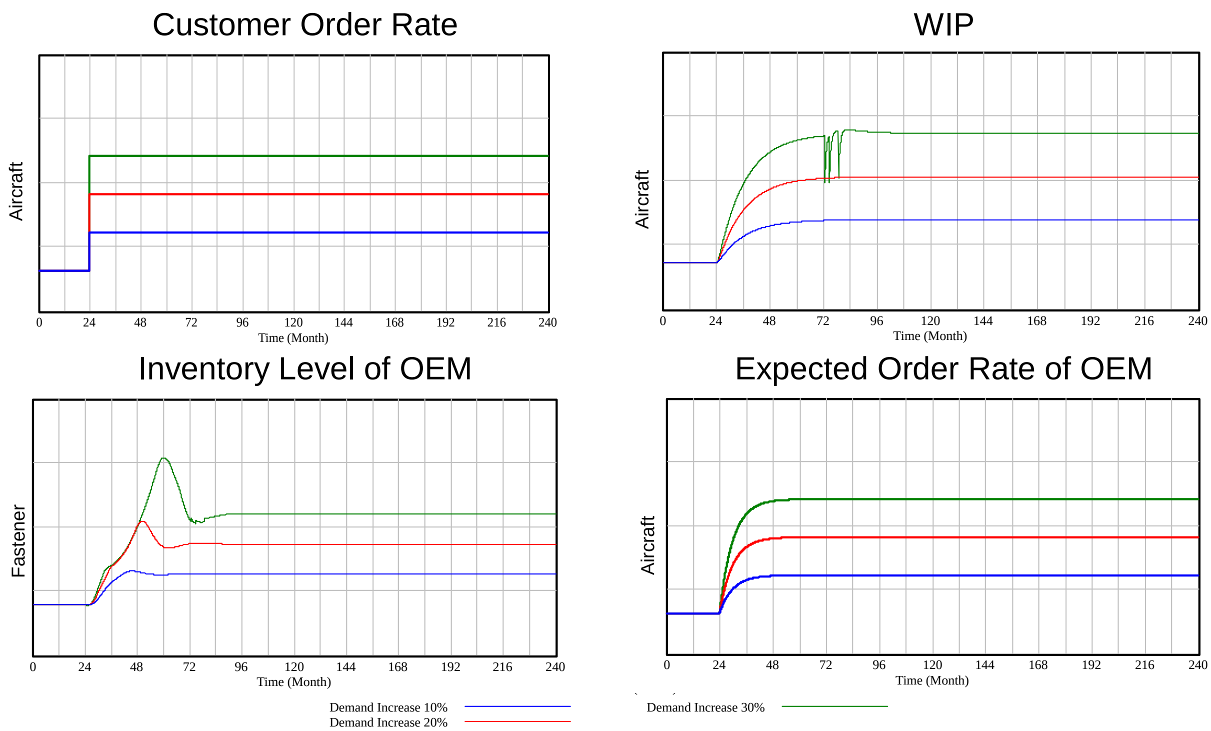

Figure 11: The Simulation Results of Step Increase in Demand

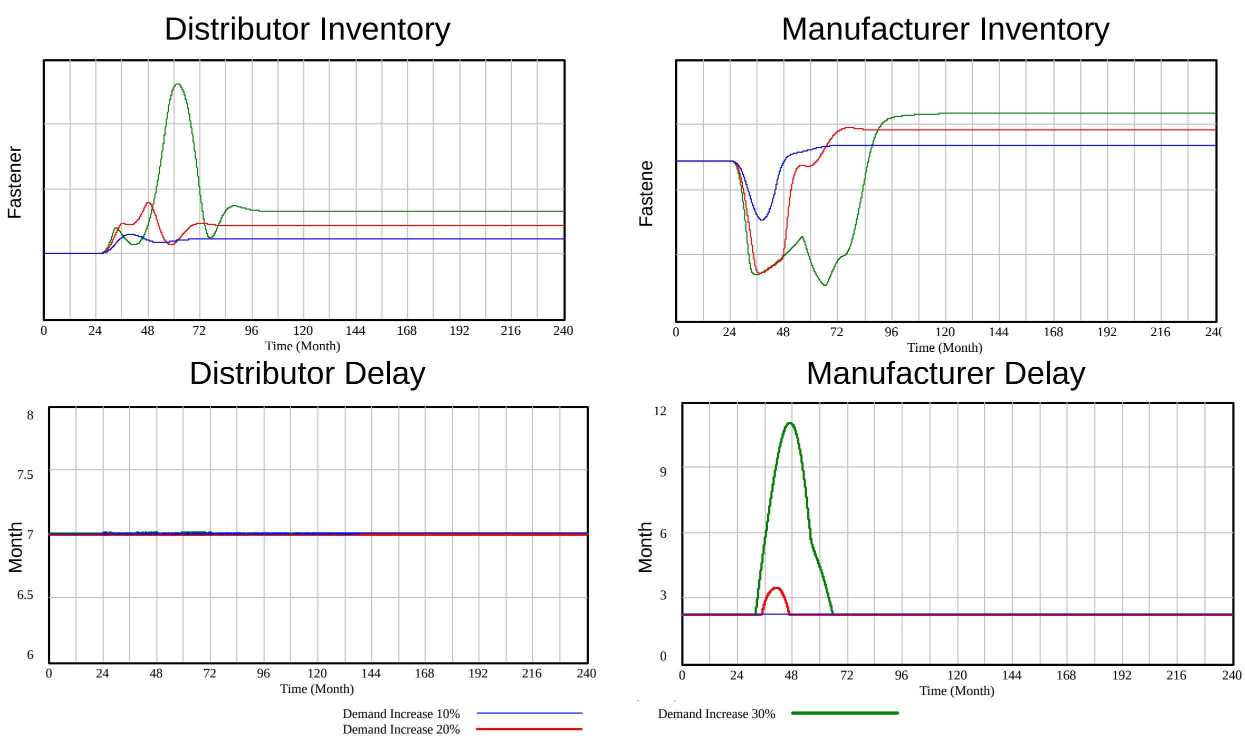

Figure 12: The Simulation Results of Step Increase in Demand

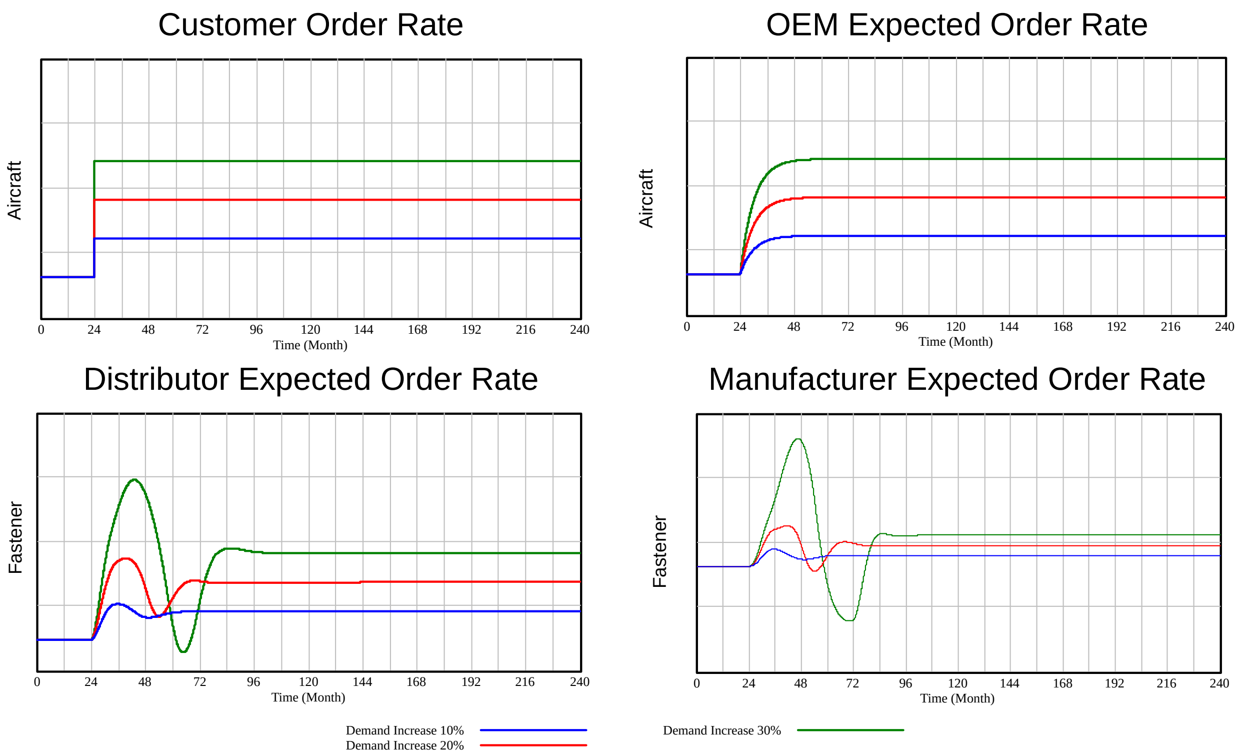

Figure 13: The Simulation Results of Step Increase in Demand – Bullwhip effect

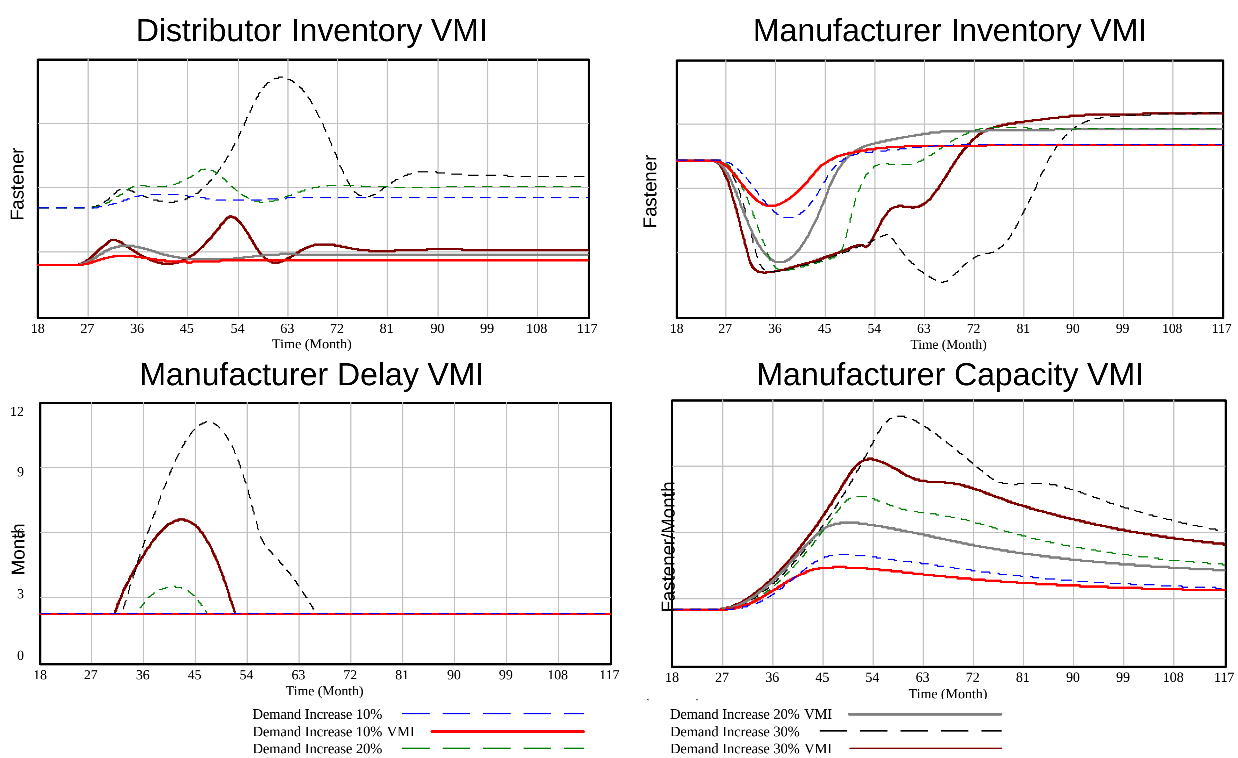

Figure 14: The Simulation Results of Step Increase in Demand – VMI

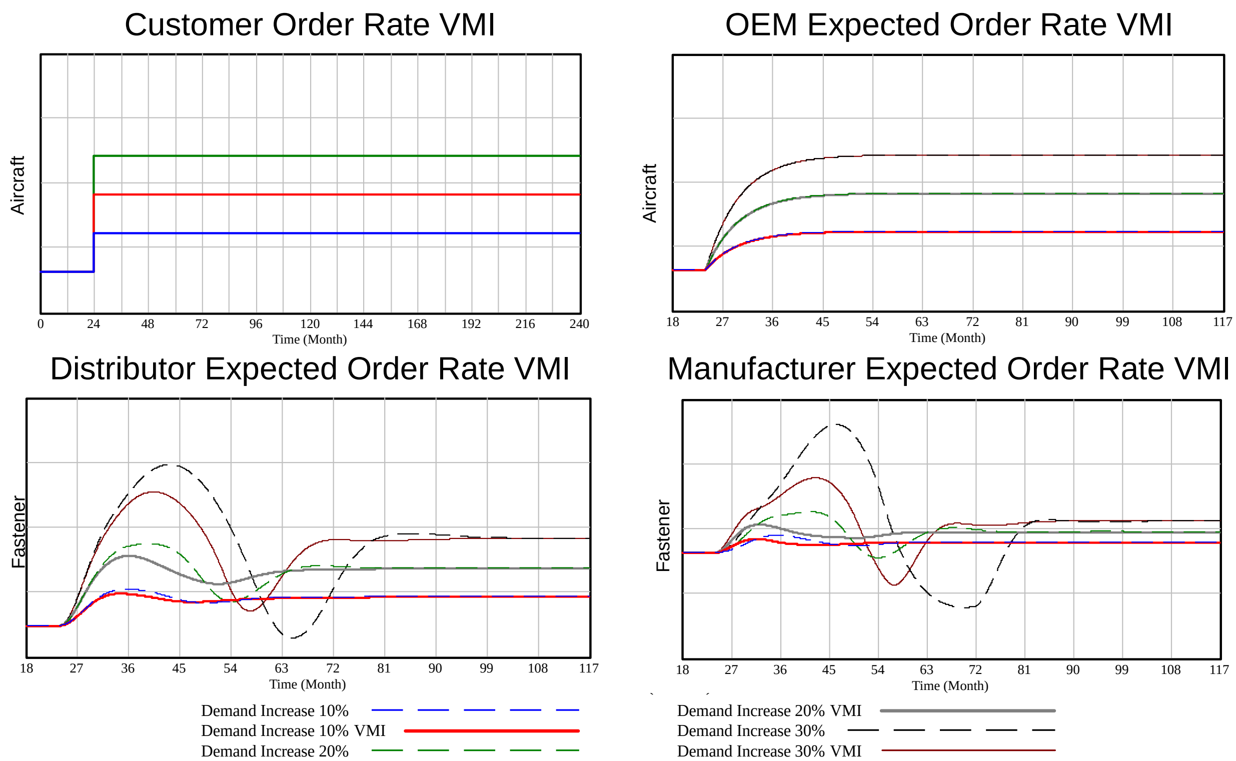

Figure 15: The Simulation Results of Step Increase in Demand – Bullwhip effect – VMI

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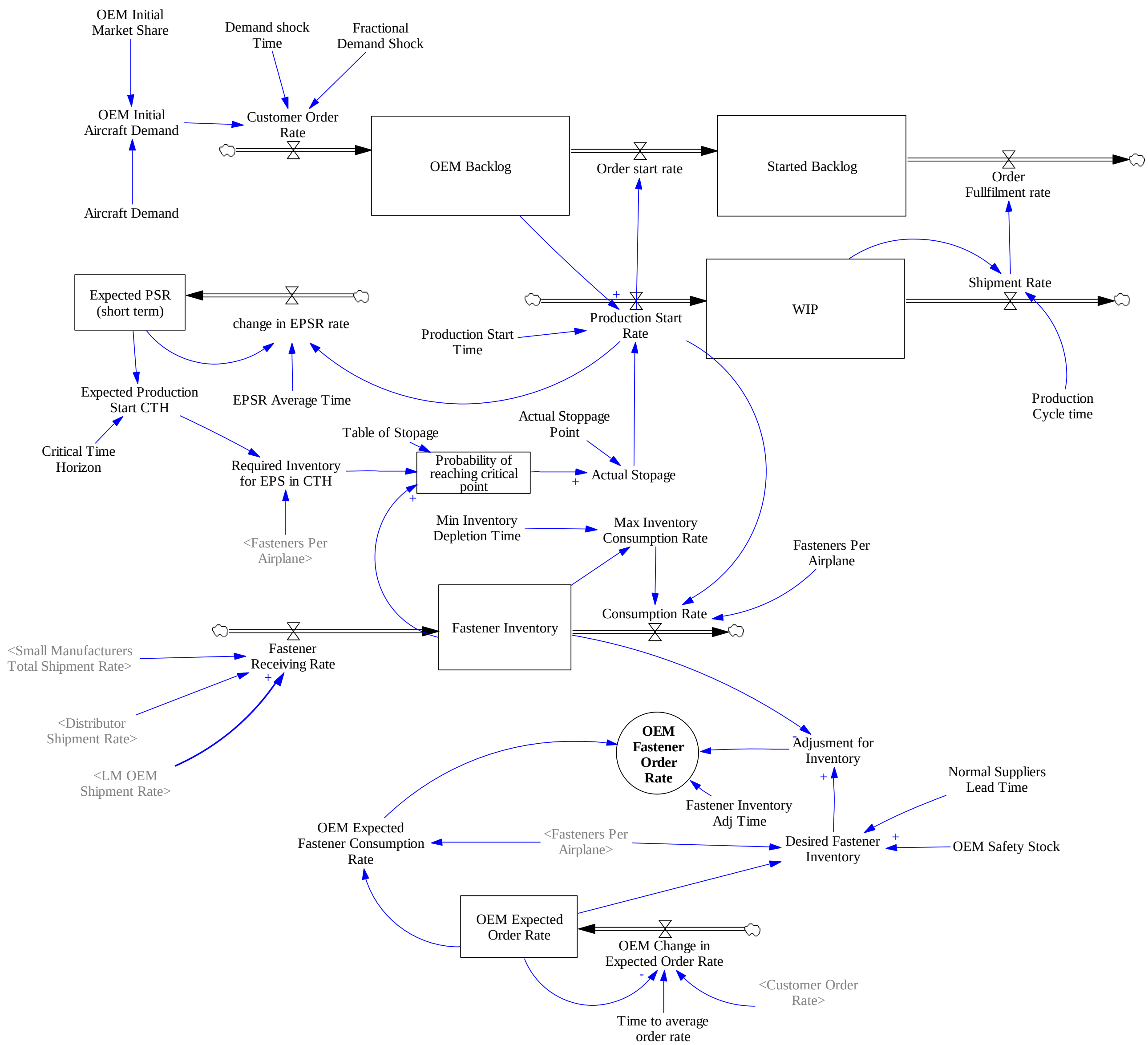
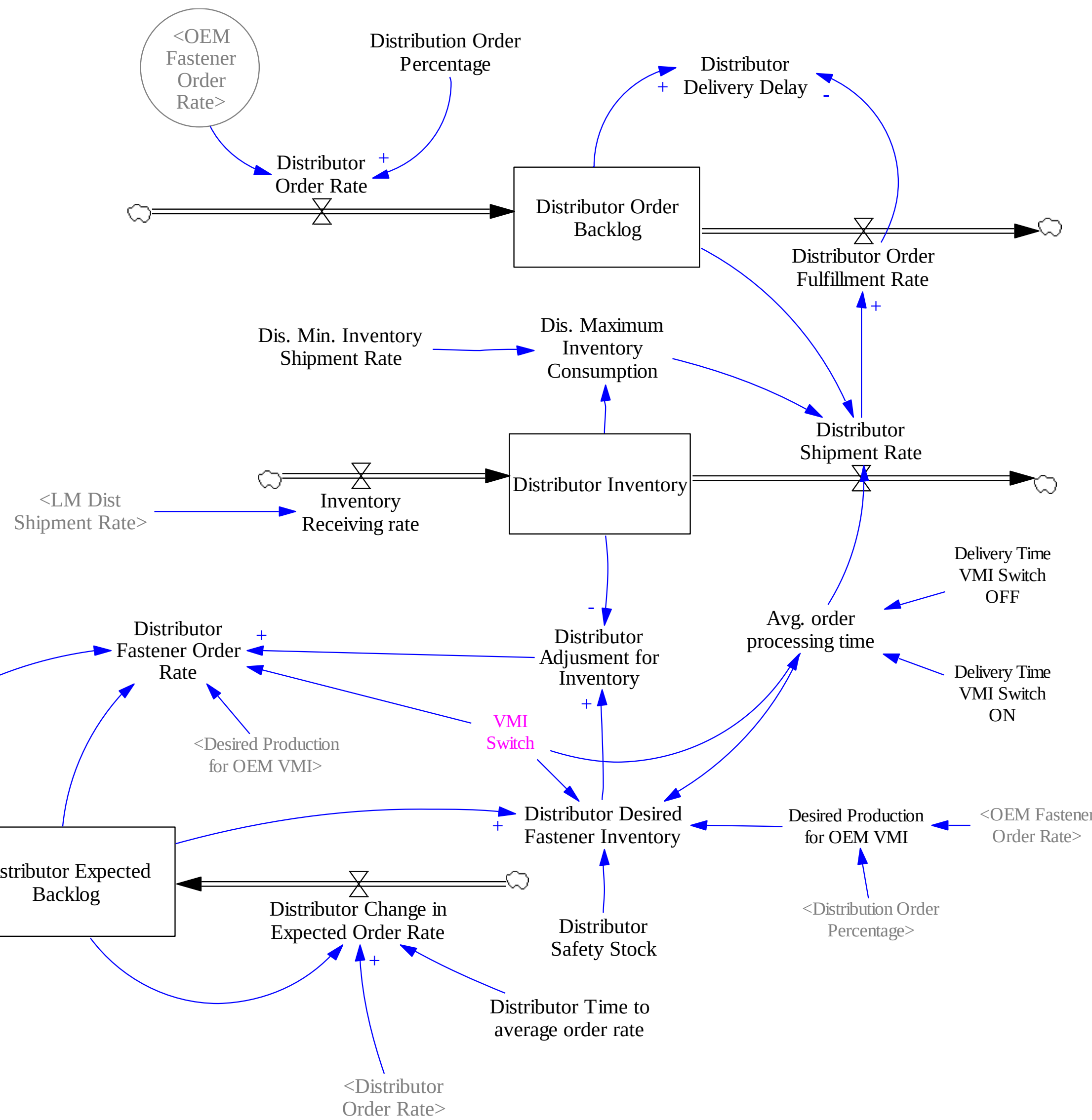
Appendix

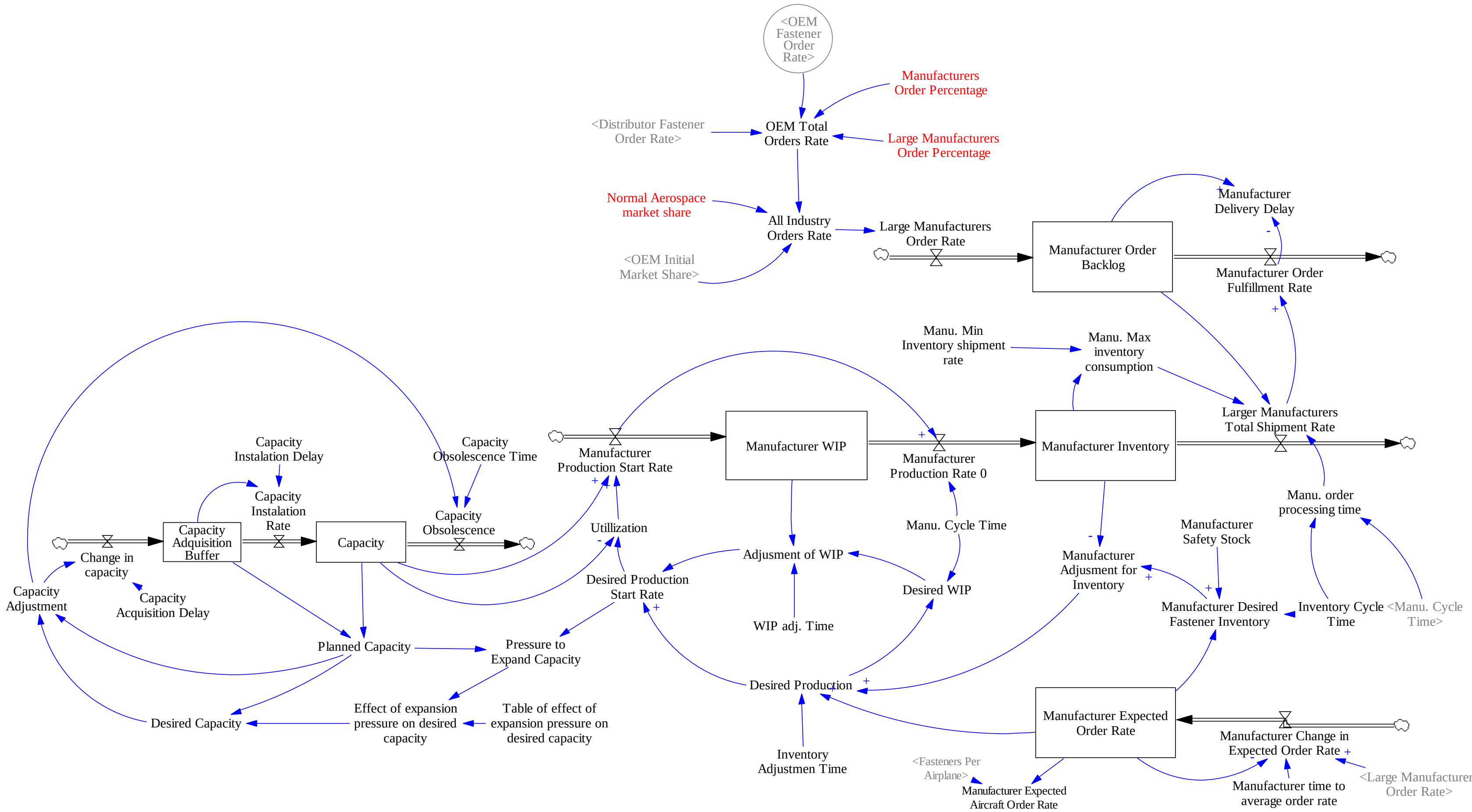
OEM Model:



Distributor model:



Major Manufacturer Model:



Minor Manufacturer Model: