# The Dynamics of the Government Supply Process For High-Value Spare Parts

***Abstract***

*Supply chains providing high-value parts to the Government have been plagued by both shortages and excess inventory. In many of these supply chains, a computerized government process calculates recommended orders for both new and overhaul parts. A research effort was undertaken to understand the mathematics of this process and its impact on supply chain performance. A system dynamics model of the supply chain was developed that incorporates the equations of the requirements determination process. The model revealed that the process worked appropriately for constant demand and responded well to a ramp-up in demand. It was found, however, that in the face of varying demands substantial bullwhip was produced in the supply chain. Moreover, it was shown that the ordering process is extremely sensitive to common data errors such as the production lead-time and that production constraints, not included in the ordering algorithms, created deep and prolonged shortages. On going research is developing improvements to the formulation of the ordering process and developing supply chain strategies for the next five years under differing demand scenarios.*

## Introduction

At the heart of many government and defense supply chains for high-value parts is a process known as the Requirements Determination System or the Supply Control Study. (Rosenman, 1964) This computerized process is used to determine the recommended buys for new parts and the recommended number of parts to undergo repair and overhaul. The supply chain control system compares current levels of inventory, including due-ins and due-outs, with anticipated needs to calculate recommended buy and repairs. Since the procurement of new spares and the overhaul of damaged spares leads over time to changes in inventory, the system truly functions in a feedback control fashion to manage the supply chain. Figure 1 presents an overview of this process.

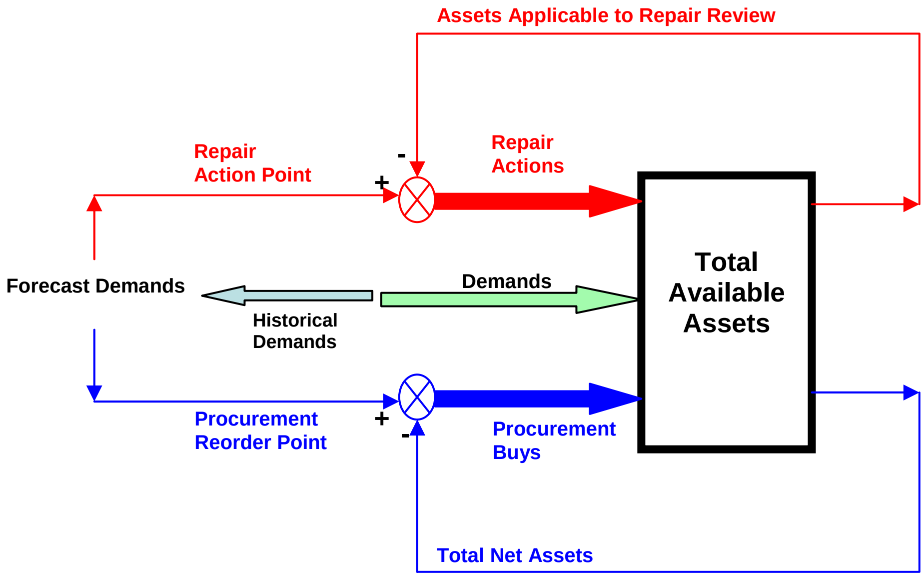


**Figure 1. Overview of Supply Chain Control Process**

In the computer-based process for determining recommended orders, many data elements are actually included in the calculations for recommended procurement buys and repair actions. Inputs to the requirements determination include average historical demand rates, procurement and repair lead-times, return and scrap rates of worn and damaged parts, inventory on-hand, due-ins, due-outs, and desired safety levels. In the computerized requirements determination process, the required data for a particular part such as a transmission, helicopter blade, etc. is extracted from government databases. Figure 2 presents the detailed supply chain and production data used to calculate the recommended procurement buys and repair actions for each high-valued part.

The requirements determination algorithms were embedded in a number of large government data systems such as the Commodity Command Standard System in the late nineteen sixties and have been used continually since the early seventies.

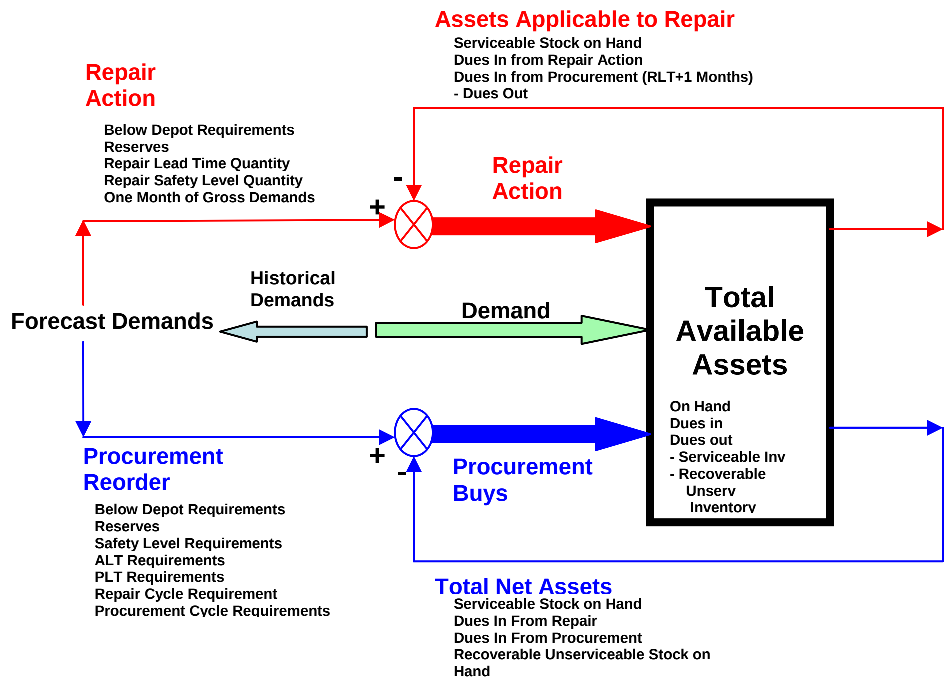


**Figure 2. Data Feeds Used in Supply Chain Management**

Difficulties with the requirements determination process, however, and performance problems with the associated supply chains have been reported on an on-going basis for decades. Rosenman (1981a) reported on the instabilities in the system and the frequently observed flip-flops in recommendations from one calculation to another. Rosenman (1981b) also noted an "uneasiness about how well this system might respond" to sudden changes in demand level. The Government Accountability Office (GAO) has made frequent reports to Congress on the problems with the requirements determination process and related supply chain performance. These problems have been identified as arising from both the analytic process and its sensitivity to inaccurate data. In 1981 the GAO found substantial overstatement and understatement of requirements "because requirements computations were based on inaccurate delivery, administrative, and production lead-times." (GAO 1981) In 1990, the GAO reported problems because item managers "accepted the inventory levels determined by a computer" and that the "database that item managers relied upon to make retention decisions included inaccurate data and lacked some necessary data." (GAO 1990) Moreover, the systems "were based on management processes, procedures, and concepts that have evolved over time but are largely outdated." (GAO 1998) GAO has identified management of inventory "as a high-risk area since 1990 due to ineffective and inefficient inventory systems and practices." (GAO March 2007) Additionally the GAO found that the government is experiencing difficulties estimating acquisition lead times to acquire spare parts and this hinders "their ability to efficiently and effectively maintain spare parts inventories..." (GAO July 2007) In short, GAO has repeatedly stated that the government has "wasted billions of dollars on excess supplies, burdened itself with the need to maintain them, and failed to acquire the tools or expertise to manage them effectively." (Thorne, 1999) Numerous studies have reflected similar conclusions and have included suggestions for possible resolutions to these problems, including Gansler and Luby (2003), Abramson and Harris (2004), and Folkeson and Brauner (2005). These difficulties continue to exist and afflict the current supply process, however.

Because of the many problems in supply chain performance, especially the prevalence of shortages in high-value spare parts, a research program was initiated to investigate the dynamics of the system. The objectives of the program were to: examine the impacts of the calculated recommendations of the supply control study under a variety of time-varying demand conditions; assess the impacts on supply chain performance of inaccurate data in the calculation of the recommended buys and overhaul; determine any contribution of the process in the creation of a bull-whip effect; and project supply chain performance in the face of real world production capacity constraints not included in the supply control study.

**Analytical Approach**

Because of the feedback nature of the requirements determination process described above, System Dynamics is an appropriate technique for analyzing the impacts of the embedded control processes and investigating the resultant supply chain performance. System Dynamics has been used to analyze supply chains from its very beginning as a modeling and simulation tool for policy analysis. Forrester's (1958) groundbreaking article in the Harvard Business Review demonstrated fundamental supply chain dynamic behavior such as how small changes in retail sales and promotional activity can lead to large swings in factory production, i.e., the so-called bullwhip or Forrester effect. Forrester (1961) also included a supply chain model and demonstrated various modes of behavior. More recently, Sterman (2000) has addressed supply chains with several models and case studies. Huang and Wang (2007) addressed the bullwhip effect in a closed loop supply chain using a simple model based on Sterman's (2000) structure. Schroeter and Spengler (2005) addressed the strategic management of spare parts in closed-loop supply chains. Simchi-Levi (2008) and Lee (1997) both analyzed the generation of bullwhip. Finally, Angerhofer (2000) presents a thorough discussion of system dynamics modeling in supply chain management. The objective of the current research is to capture the actual algorithms of a government procurement process, embed this procurement or ordering process within a systems dynamic supply chain model, and assess the impacts and performance of the process and supply chain.

**Model Description**

The model that has been developed is a detailed and dynamic version of the structure presented in overview in Figure 2. The model is intended to simulate the behavior of the requirements determination process and supply chain performance under a variety of demand and input assumptions. An overview of the major flows in the model is shown in Figure 3. Demand information flows to the control process to be used along with inventory data in the calculations that drive new production and overhaul actions. Parts that are removed are returned in a flow to the overhaul sites to be reworked. Orders for new parts flow to the commercial new production facility. If production capacity is available, these orders enter production and after a manufacturing or production lead-time flow into inventory. If production capacity is not available, these orders enter a backlog and wait until capacity is available. Orders for overhaul are allocated between government depots and commercial overhaul facilities. If overhaul capacity is available and a returned part is also available, overhaul is initiated. If capacity or a returned part is not available, the order enters a backlog until there is both capacity and returned part availability. Parts complete the overhaul process after a repair lead-time and flow into the inventory system and then into use. The focus of the model is to understand how the ordering process within the supply control study affects the dynamics and performance of the actual real-world supply chain.

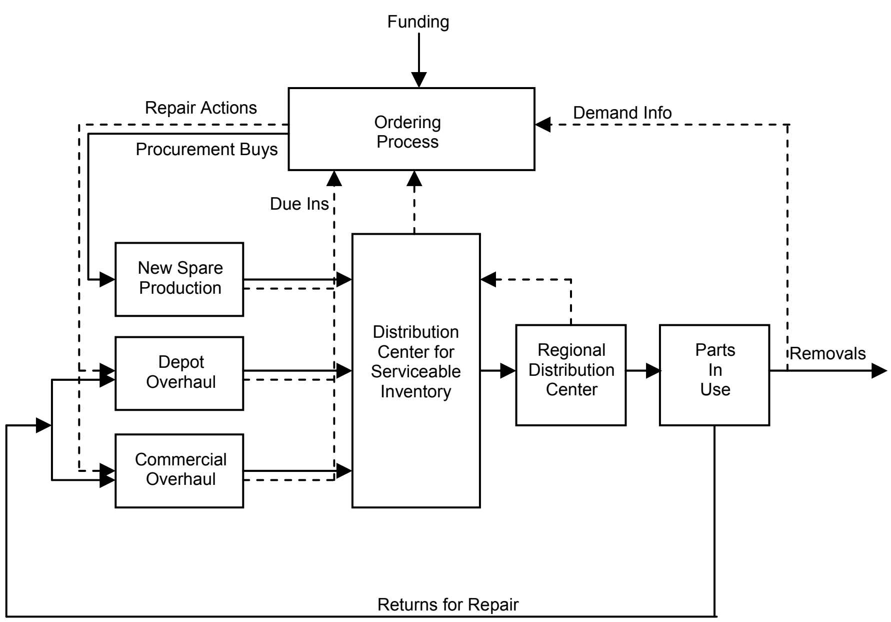


**Figure 3: Overview of Model Flows**

In the supply control process, recommended orders for new parts are calculated as the difference between the Procurement Reorder Point (the minimum amount of stock that should be available to meet demands until the next scheduled order) and the Total Net Assets. The recommended order is the difference between these values plus the Procurement Cycle Requirement, the amount of inventory necessary to meet demands until the next scheduled order (see Figure 4).

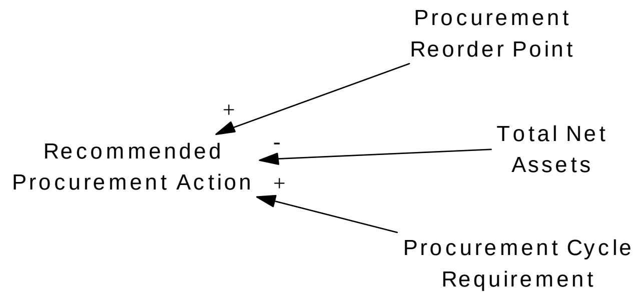


**Figure 4: Recommended Procurement Action**

In this process, Total Net Assets is calculated by summing the available inventories, the items due in from the procurement and repair processes, and subtracting the number of items due out. This is shown in Figure 4. The Procurement Reorder Point is determined by the necessary safety levels and inventory requirements to sustain inventory levels through the next scheduled purchase. This second level of data input to the controller is shown in Figure 5. As shown in Figure 5, the New Spares Completion Rate flows into the Serviceable Inventory, and New Spares WIP and Orders Awaiting Production start are components in the calculation of Due-Ins From Procurement.

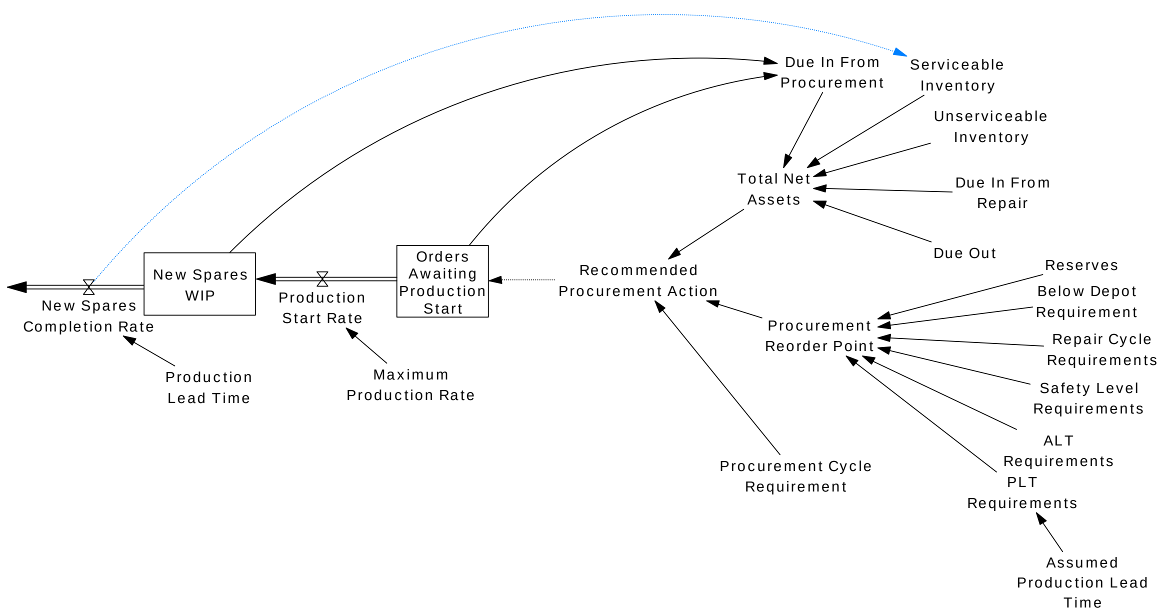


**Figure 5: Second Level of Calculations for Recommended Procurement Action**

Figure 6 presents the third level of variables that are used in the calculation for Recommended Procurement Action. Note in Figure 6 that the Procurement Reorder Point is strongly determined by average historical demands. In the actual process, this averaging is typically for twenty-four months.

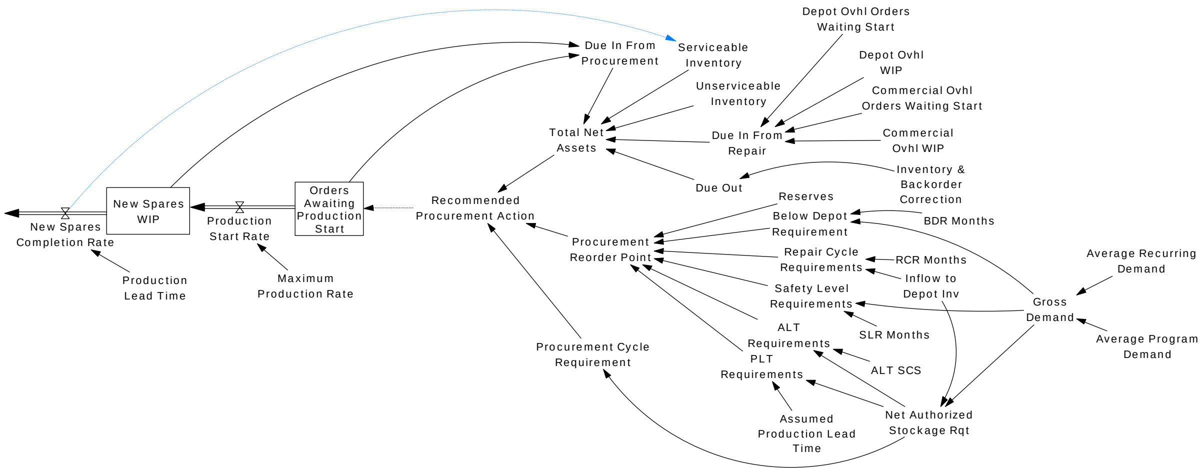


**Figure 6: Echelons of Variables in the Procurement Ordering System**

Calculation of the Recommended Repair Action is somewhat different from the calculation for recommended purchase of new spares. The key difference is that repair and overhaul can only proceed if there is a worn or damaged part available on which to work. This availability is determined by the effectiveness of the reverse logistics flow (there is an assumed loss rate) and the percentage that must be scrapped due to excessive wear or damage. The supply control process calculates a Maximum Recommended Repair Action by taking the difference between the Repair Action Point and the Assets Applicable to Repair Review. This Maximum Recommended Repair Quantity is the compared to the on-hand unserviceable inventory and the minimum of these two variables is then the Recommended Repair Action. (See Figure 7 and Appendix).

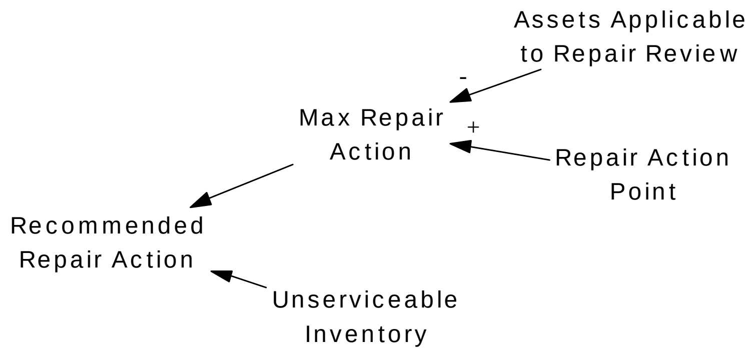


**Figure 7: Recommended Repair Action**

Once a repair is recommended, the cost of the repair is calculated to determine whether sufficient funding is available. Upon available resources, the repair quantity then may be allocated for depot overhaul and/or commercial overhaul sites. After an item has been repaired, it is added to the Serviceable Inventory and the calculation of Assets Applicable to Repair Review. The second tier of variables used in the calculation of the maximum recommended repair action is shown in Figure 8. Feedbacks from the repair actions to inventory and due-ins are illustrated in blue dashed lines on Figure 8.

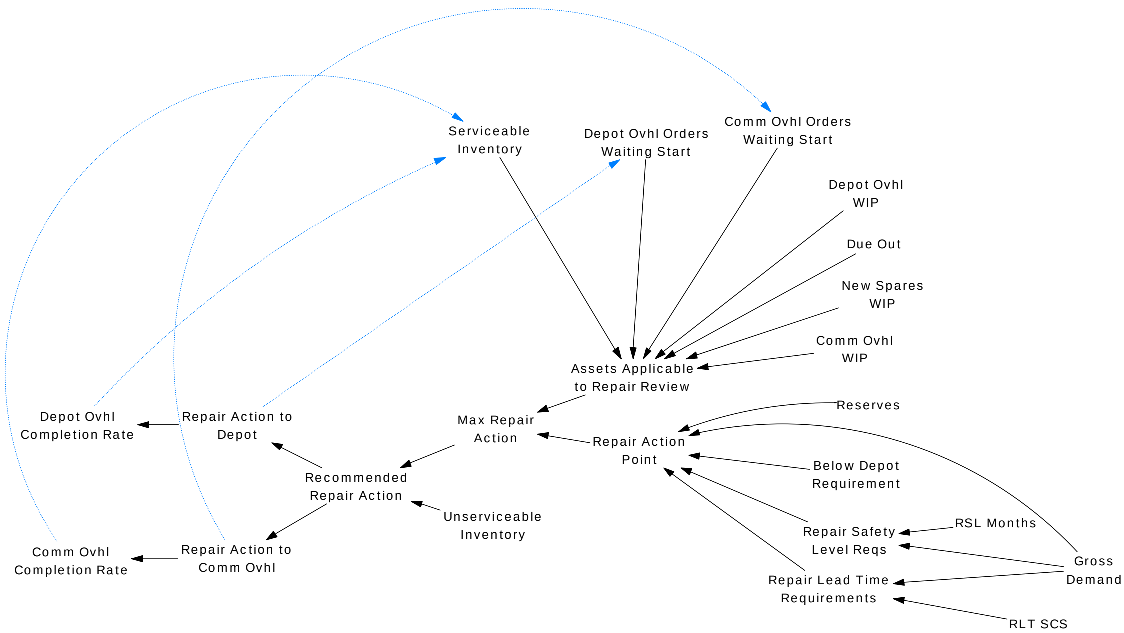


**Figure 8: Echelons of Variables in the Current Repair Ordering System**

As shown in Figure 3, the model includes a central inventory distribution center as well as a regional distribution center. The requirements determination process as described above replenishes the central inventory of serviceable parts. This central inventory then replenishes the regional inventory. The regional center places orders to the central distribution center as shown in Figure 9. This section of the model is similar to the structure incorporated in other System Dynamics supply chain related models (Sterman, 2000) in which desired inventory coverage is based upon historical demand.

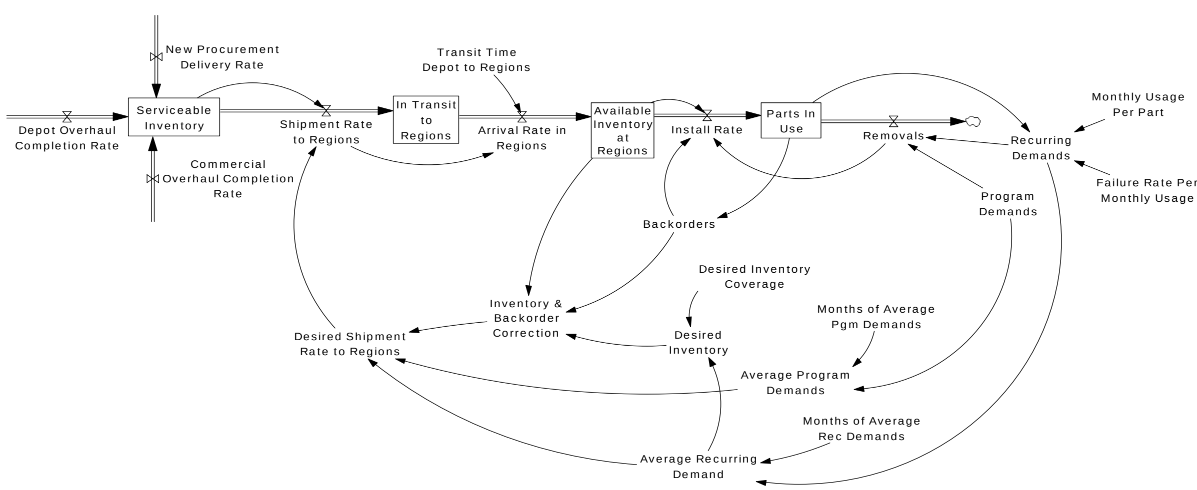


**Figure 9: Ordering Process from Regions to Central Inventory**

Finally, Figure 10 presents an overview of the closed loop, reverse logistics process in the model. Part removals (demands) are generated based upon the number of parts in use, the monthly hours of operation, and a failure rate per part per hour of monthly use. Some of these removed parts are lost or are too damaged to be repaired. The remainder is returned for close inspection and evaluation. Some of these parts are scrapped. The remainder is then divided between commercial and government depot overhaul facilities. These are then matched with a repair order and upon completion are ready for re-issue.

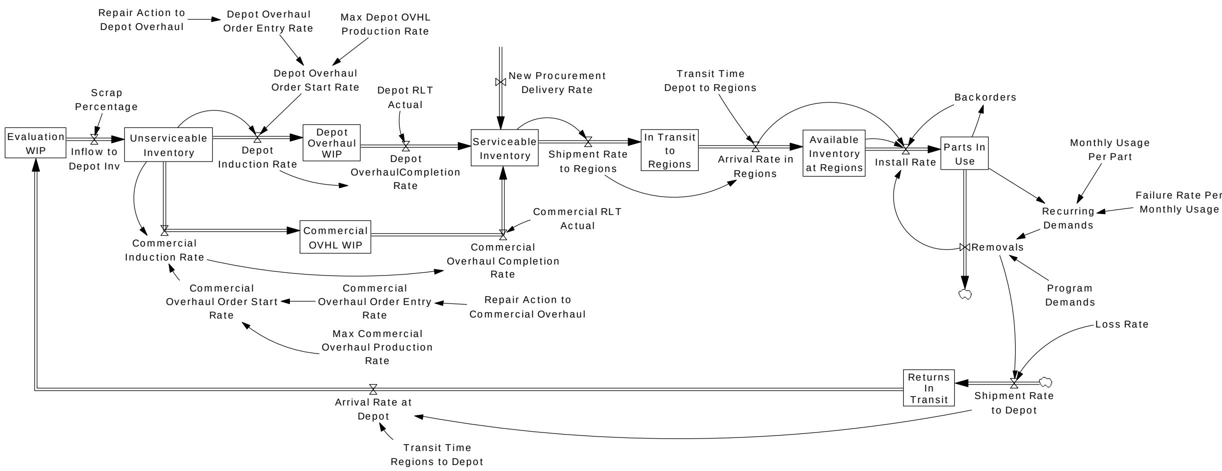


**Figure 10: Demand and Return Process**

## Analysis and Simulation Results

Key objectives of the analysis were to: (i) ascertain the robustness of the requirements determination and supply control process in facing alternative demand profiles, (ii) assess the potential of the requirements determination process for creating bull-whip in the supply chain, (iii) determine the sensitivity of the supply control to inaccurate data and (iv) evaluate impacts of real-world production and overhaul capacity constraints. The model described has been parameterized for a number of specific high value parts and has been used to simulate the behavior and performance of the supply control process and the supply chain for these particular parts. The following cases are presented with a simulation time covering 2001-2012:

Case 1: Constant Demand
Case 2: Ramp Up in Demand beginning in 2003
Case 3: Oscillation in Demand
Case 4: Error in Assumed and Actual PLT in 2004
Case 5: Ramp Up in Demand in 2003 with Production Constraints
Case 6: Ramp Up (2003) and Down (2009) in Demand with
Production Constraints
Case 7: Ramp Up (2003) and Down (2009) in Demand with
Production Constraints and Error in Assumed PLT

Cases 1 and 2 were used both in the validation of the model and to verify that the requirements determination process generated appropriate orders in response to constant demand and a near step ramp-up in demand to a higher constant level. Case 3 was conducted to determine whether the governmental computerized ordering process and related supply chain exhibited the bullwhip effect. Because numerous reports, for example, GAO (1981) and GAO (July 2007), have indicated that certain data, such as production lead-time, used in the ordering process is often incorrect, Case 4 investigates the impact of incorrect production lead-time on the ordering process and supply chain performance. Moreover, because the governmental ordering process does not include the potential for production capacity constraints, Case 5 examines the behavior of the supply control process and the ability of the system to meet rising demand in the presence of capacity constraints. Finally, Cases 6 and 7 examine "real world" scenarios involving shifting demand, production constraints, and data errors.

Case 1 assumes a constant demand of fourteen parts per month. For certain high value parts, this is a realistic monthly demand. These are not high volume consumer product supply chains. Constant demand provides one test of validation and offers a suitable base case for comparison to subsequent cases. It is assumed in Case 1 that there are no production capacity constraints. Production lead-time is assumed to be twenty-two months and repair lead-time is assumed to be eleven months, typical values for this type of part within the government supply chain. Importantly, the PLT and RLT assumed for the requirements determination are equal to the actual values. No errors are assumed in input assumptions. Simulation output for Case 1 is presented in Figures 11-14. Inventories remain at a constant level throughout the simulation time period; as items are removed and demands are generated, orders are created and items replaced on a regular basis, establishing equilibrium within the system (see Figure 11). Similarly, the key rates within the model remain constant (see Figure 12). The completion rates of the two overhaul sectors combined with the new production completion rate are equivalent to the removals; hence, demands are met as necessary. Note also that the Shipment Rate to Regions overlaps with the Removal Rate in Figure 12, showing the demands are being met as needed. The recommended repair quantity is limited by the amount of unserviceable inventory on-hand, as shown in Figure 13. Of the fourteen parts removed monthly, it is assumed that 85% are returned for repair, and of those, 35% are scrapped as non-reparable. This constrains the repair action to roughly eight per month. Unserviceable Inventory coincides with the Repair Action in this graph, while the Max Repair Action value is much higher (see Appendix for definitions). This limitation in the repair process is a common occurrence (Folkeson 2005), which is one of the factors that hinder the responsiveness of the supply chain to dynamic conditions, such as those presented in subsequent cases. The recommended procurement action does not have such a restriction, however, and procurement orders are placed on a regular basis according to the Procurement Cycle Requirement (see Figure 14). As parts are removed from serviceable inventory, Total Net Assets decline and eventually the value dips below the Procurement Reorder Point. A buy is generated at this point, and the increase in the due-ins from procurement increases the Total Net Assets above the Reorder point and the buy process is halted. Even in the face of constant demand, the process creates a periodic buy action. This is shown in Figure 14.

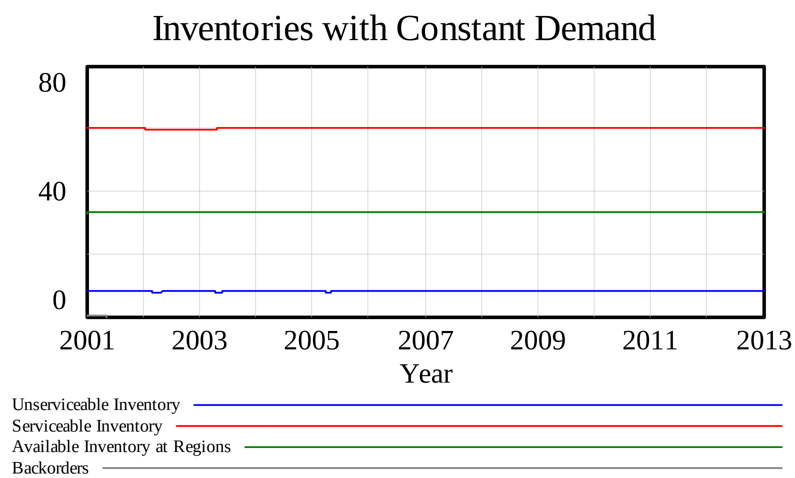


**Figure 11: Case 1, Constant Demand**

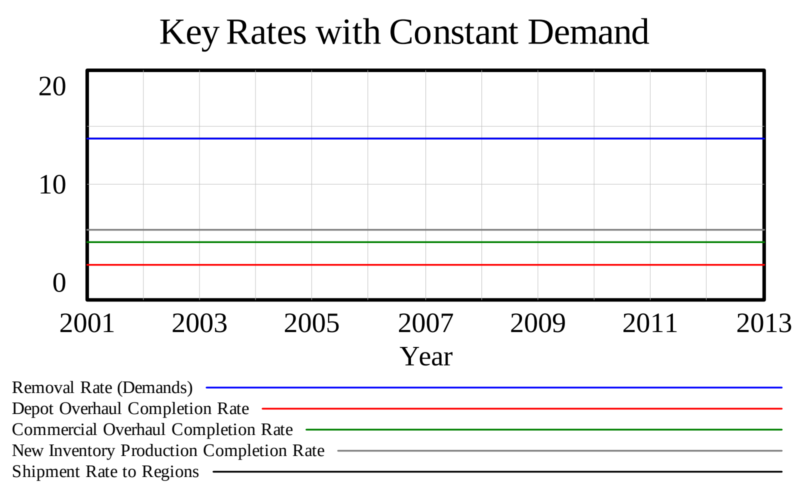


**Figure 12: Case 1, Constant Demand**

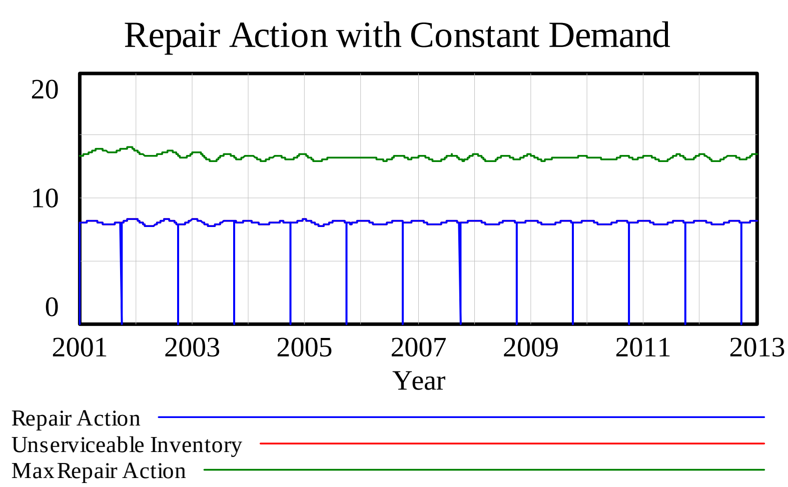


**Figure 13: Case 1, Constant Demand**

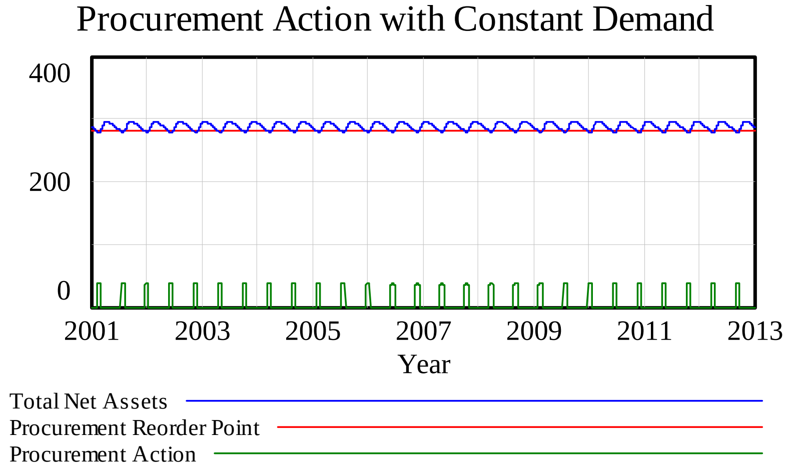


**Figure 14: Case 1, Constant Demand**

It is important to note at this point that both the Recommended Procurement Action and the Max Repair Action are determined as the difference of two large numbers. This makes the resultant recommendation very sensitive to noisy data. (It is well known that the distribution of a difference of two normally distributed variants X and Y with means and variances ($\mu_x$, $\sigma^2_x$) and ($\mu_y$, $\sigma^2_y$ ), respectively is given by is another normal distribution having mean $\mu_{x-y} = \mu_x - \mu_y$ and variance $\sigma^2_{x-y} = \sigma^2_x + \sigma^2_y$) (http://mathworld.wolfram.com) For example, in Figure 13, the Procurement Reorder Point (being demand driven) is constant at 280. The Total Net Assets varies between 278 and 295 with an average value of roughly 286. Thus the mean of the difference is about six. If the two large numbers were each to have a standard deviation of 30, that is, roughly 10% of their means, then the difference - the recommended procurement action- would have a mean of six with a standard deviation of roughly forty-two. It is no wonder that Rosenman (1981) noted instabilities in the requirements determination process very early in its usage. This is an important finding within the modeling process.

Case 2 examines a ramping up of demand over a twelve month period from fourteen parts per month to eighteen per month. All other assumptions are identical to Case 1. In this example, the increase in demand by four units per month over the course of the year 2003 results in the depletion of serviceable inventory (see Figure 15). During this time when serviceable inventories are depleted, backorders build. The requirements determination process and supply control system do lead to inventory recovery but it takes approximately two years to work-off all the backorders and to begin to build reserve inventory levels once again. The delays in the system are apparent in the Key Rates graph in Figure 16. Demand begins to increase at the beginning of 2003, but the production completion rates do not begin to rise until 2004. This is due to the averaging of demand, the acquisition lead-time, the production lead-time, and the repair lead-time. The supply control process uses new procurement as a primary method of meeting increased demands due to the limited availability of unserviceable items on hand for overhaul. The Unserviceable Inventory coincides with the Repair Action again in the graph in Figure 17. Although the recommended repair (Max Repair Action) is much higher, there is not enough repairable stock on-hand to meet this recommendation. The

Procurement Action, on the other hand, continues to ensure the Total Net Assets on-hand do not dip far below the Procurement Reorder Point, which increases as demand rises in 2003 (see Figure 18). Accordingly, the periodic behavior is seen again in this case. Importantly, Cases 1 and 2 verify that the recommended procurement and repair actions of the requirements determination process are appropriate and do lead to the necessary orders in the case of constant demand and a step-up in demand.

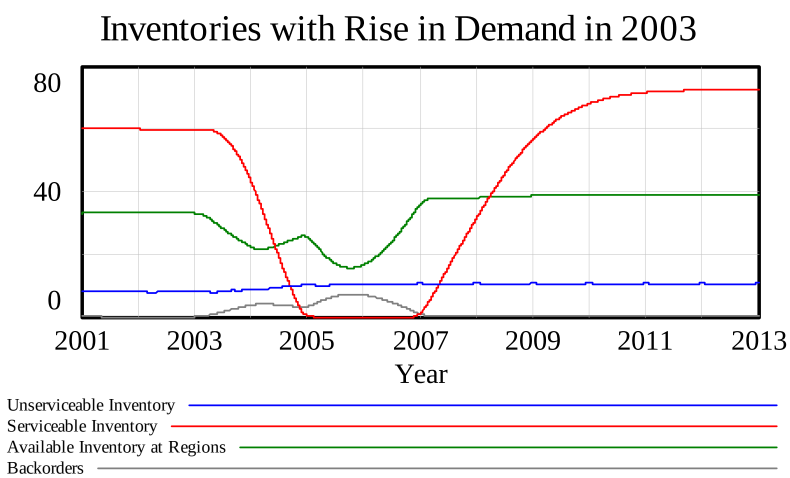


**Figure 15: Case 2, Ramp Up in Demand in 2003**

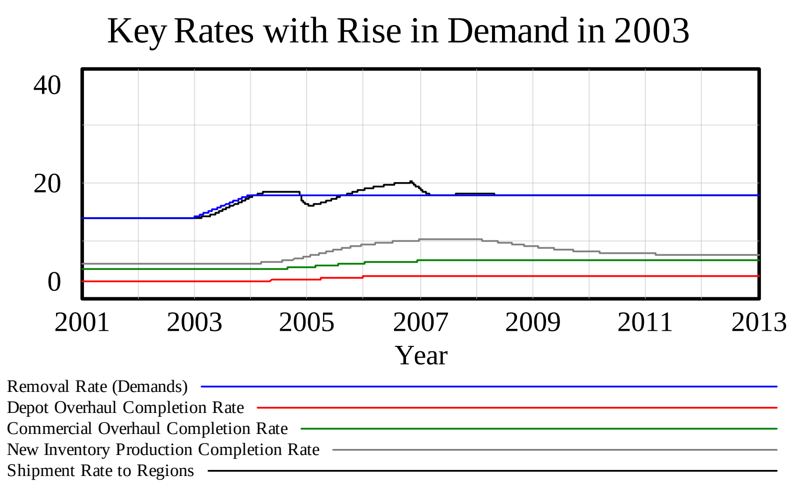


**Figure 16: Case 2, Ramp Up in Demand in 2003**

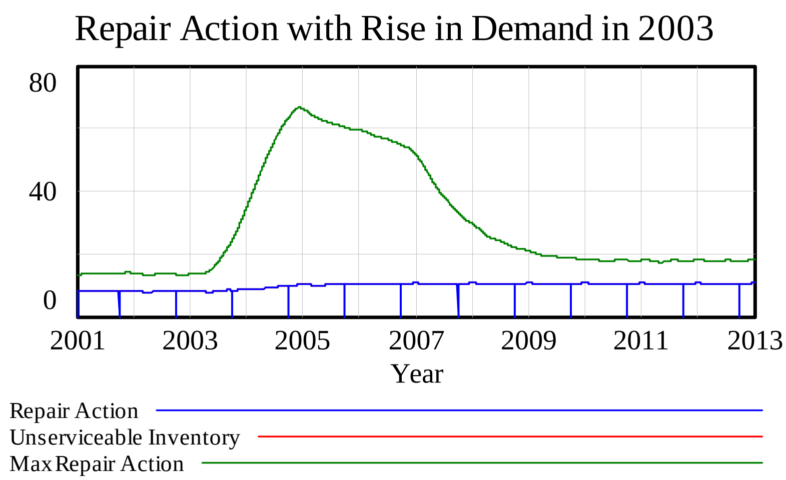


**Figure 17: Case 2, Ramp Up in Demand in 2003**

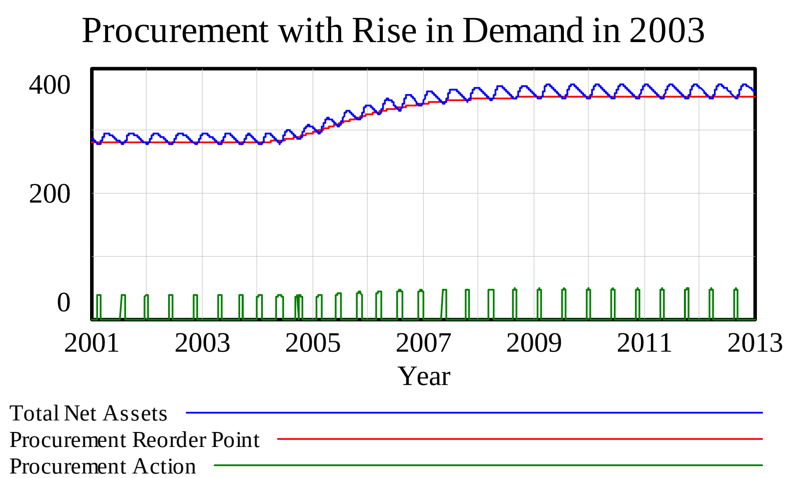


**Figure 18: Case 2, Ramp Up in Demand in 2003**

Case 3 is designed to examine whether the requirements determination process leads to bullwhip behavior in the supply chain. The input assumptions creating demand for parts removal is assumed to be sinusoidal with periods of two, four and eight years. The average demand is the same as Case 1 at 14 units a month. The sine waves oscillate ±20% around 14 units per month. (see Figure 19). As in the prior two cases, this case assumes no production capacity constraints (as always, repair is constrained by availability of unserviceable parts) and input assumptions for PLT and RLT are equal to actual lead-times. With these assumptions, the new spare production rate becomes extremely volatile for the longer fluctuation periods, varying as much as 40% in the 8-year oscillation period (see Figure 20). As a result, the amount of unserviceable inventory returning to be refurbished also becomes variable, with drastic spikes occurring primarily in the 4 and 8-year cycles (see Figure 21). Due to this volatile nature within the unserviceable inventory, depot and commercial overhaul rates also fluctuate accordingly (see Figures 22-23). In the 4 and 8-year oscillation period cases, these overhaul completion rates vary by as much as 30%. The highly varying production and overhaul rates cause significant changes in the serviceable inventory available for issue (see Figure 24). At times, as a result of this bullwhip effect, there is no serviceable inventory available in the 8 year oscillation cycle. Hence, the available inventory varies by as much as 100%. This case with no production constraints clearly demonstrates that the algorithms of the supply control process lead to bullwhip effects within the government supply chain. In the event that production constraints are considered, this behavior is still readily apparent. Although constraints are present in the real system, the current government ordering process does not take these constraints into consideration when recommending a purchase or an overhaul. The impacts of this are investigated in Case 5.

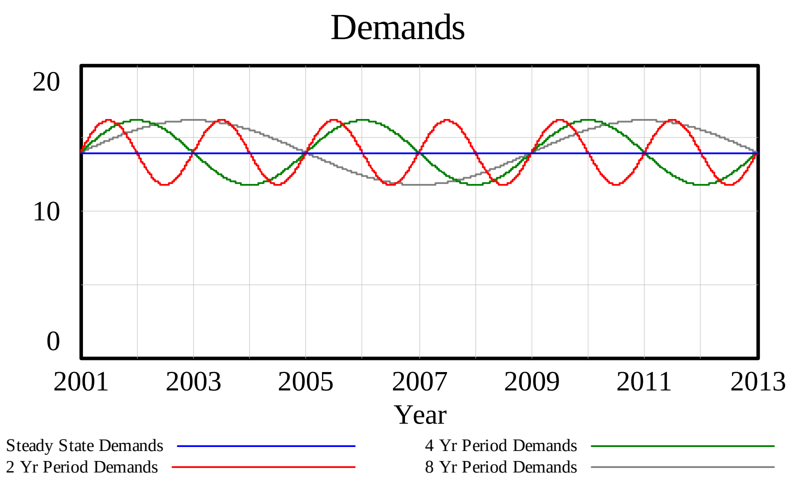


**Figure 19: Case 3, Demands with Oscillation Variance of 20% in Varying Time Periods**

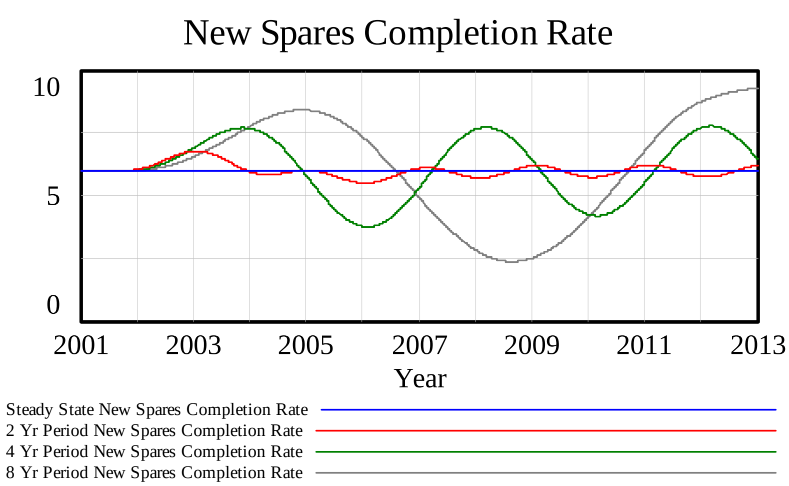


**Figure 20: Case 3, Affect of Oscillating Demands on New Spares Completion Rate**

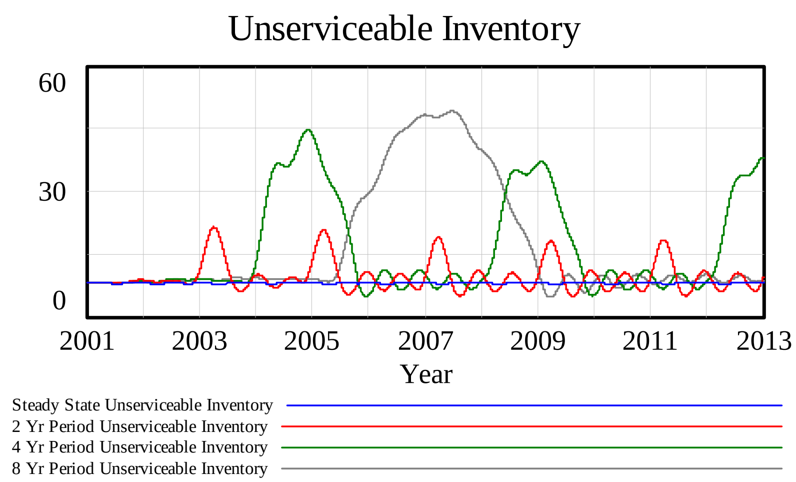


**Figure 21: Case 3, Affect of Oscillating Demands on Unserviceable Inventory**

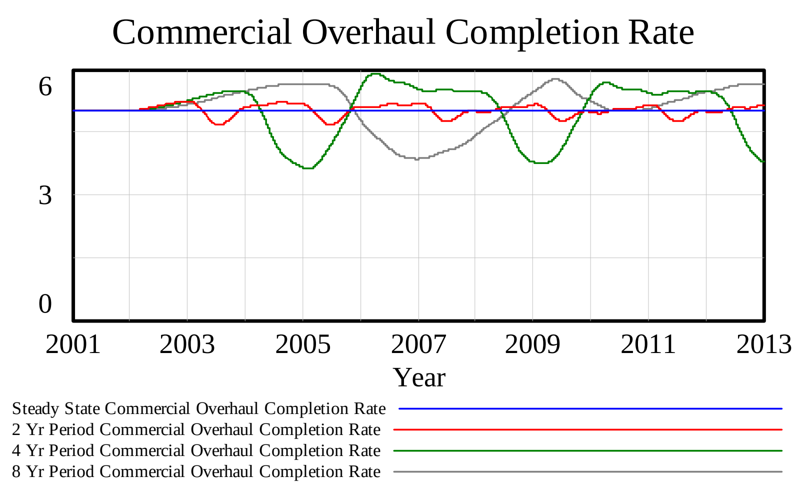


**Figure 22: Case 3, Affect of Oscillating Demands on Commercial Overhaul Completion Rate**

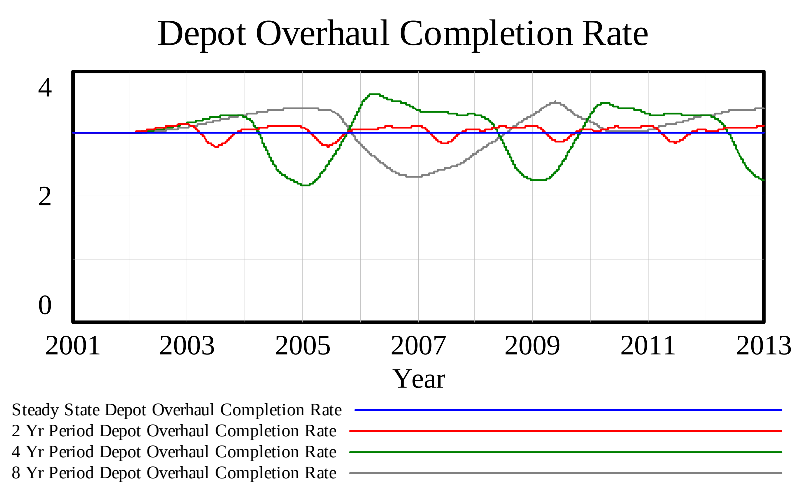


**Figure 23: Case 3, Affect of Oscillating Demands on Depot Overhaul Completion Rate**

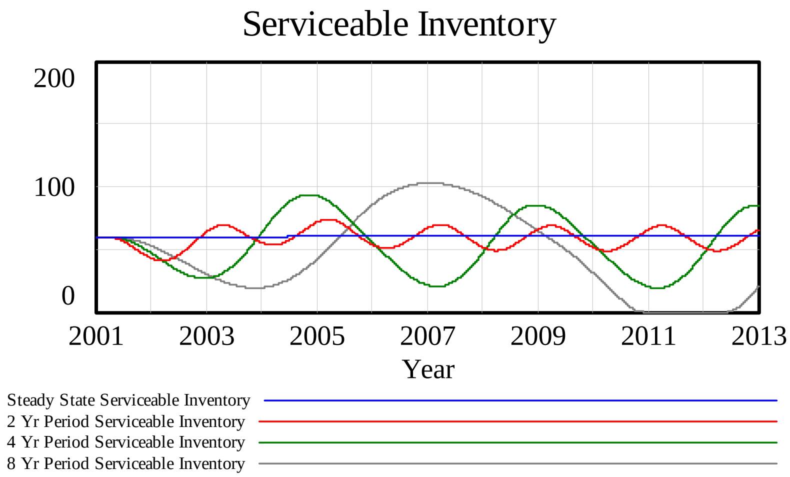


**Figure 24: Case 3, Affect of Oscillating Demands on Serviceable Inventory**

Another situation that causes potential for significant problems within the government ordering system is data inaccuracies. This is especially true for production lead times. Case 4 examines this issue through two examples in which the actual production lead time increases from 22 months to 32 months in 2004. This situation developed for many high-value spare parts due to rapidly rising lead times for certain raw materials such as aerospace steels and titanium. In the first example, the assumed PLT in the requirements determination calculation remains at 22 months for the entire period even though the actual jumps to 32 months during 2004. In the second example, the assumption in the government ordering system is corrected a year later and increases to 32 months in 2005. (This so-called “learning case” would almost certainly be the result of human intervention in the process because the data process itself would take much longer to identify the increase.)

When the production lead-time increases, the new production completion rate immediately declines (see Figure 25). If the government ordering system does not adjust the error in assumed PLT, the system continues to place orders with the assumption that the new spares will be delivered much sooner than will actually occur. As a result the new spare production completion remains depressed. If the government ordering system adjusts its expected lead-time accordingly, then the system compensates by ordering additional new parts, creating an increase in new spare completion rate. Over time, this increase in orders and new spare production enables a recovery of inventory to eventually begin (see Figure 27).

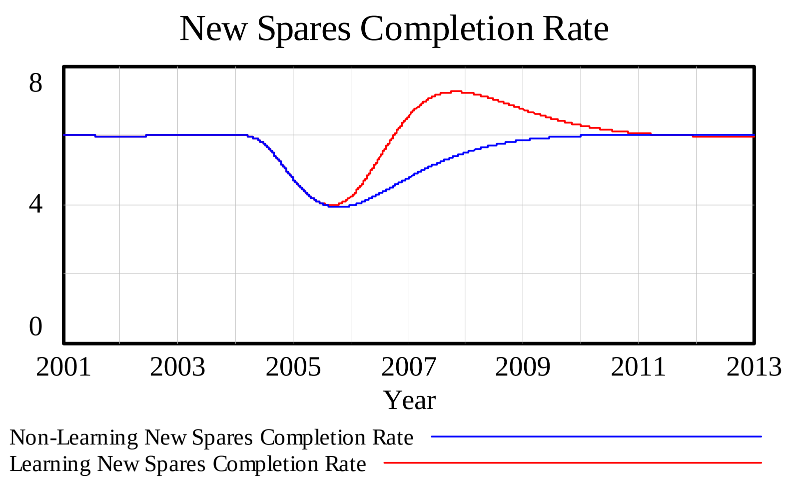


**Figure 25: Case 4, Affect of Increase in PLT on New Production Completion Rate**

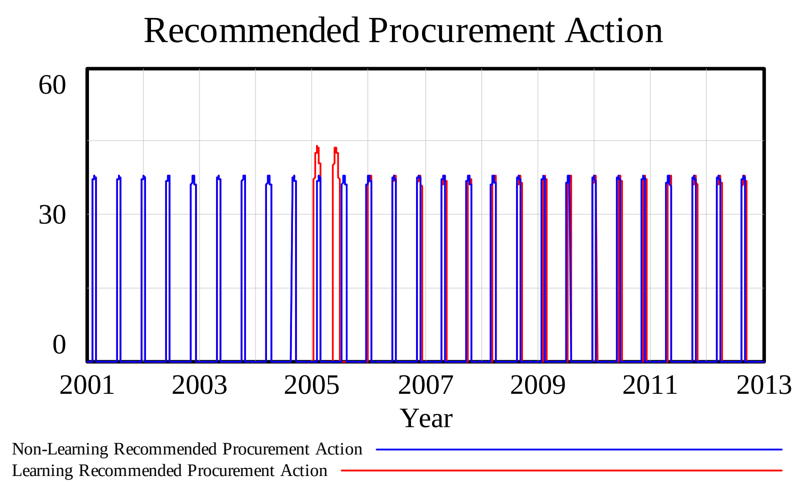


**Figure 26: Case 4, Affect of Increase in PLT on Recommended Procurement**

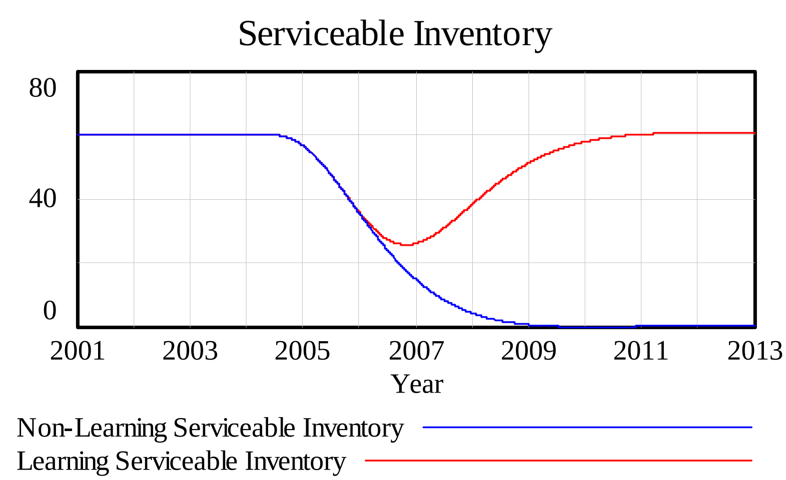


**Figure 27: Case 4, Affect of Increase in PLT on Serviceable Inventory**

Another problem that arose in supply chains for high-value spare parts during 2005 and 2006 was a rapid rise in backorders arising from capacity constraints in the production of new parts and in overhaul. The requirements determination process was generating orders but manufacturing could not keep pace. Case 5 examines supply chain performance under such production constraints. Case 5 assumes the same increased demand assumptions as Case 2, but additionally assumes a maximum depot overhaul capacity of six parts per month, a maximum commercial overhaul capacity of ten parts per month, and a maximum new production capacity of eight parts per month. (These constraints in practice were typically created by lack of tooling and labor.) Under these assumptions, backorders increase and inventories are depleted and only recover after two to three years as may be seen in Figure 28. Both new spare production rate and overhaul rate increase to their maximums and remain at those levels for the simulation period. (Figure 29) The recommended repair action substantially exceeds both the maximum overhaul capacity as well as the availability of unserviceable parts to undergo overhaul. Repair Action is still limited by the Unserviceable Inventory on-hand, which coincides with the Repair Action on the graph (see Figure 30). In Figure 31, the Procurement Reorder Point increases in response to the increased demand and orders for new spares also increase. Delivery, however, is constrained by the production limits and supply chain performance suffers.

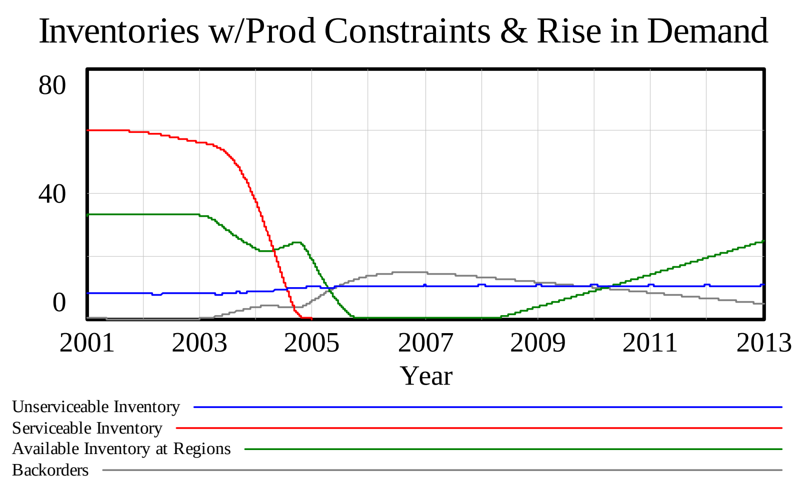


**Figure 28: Case 5, Ramp Up in Demand in 2003 with Overhaul and Production Constraints**

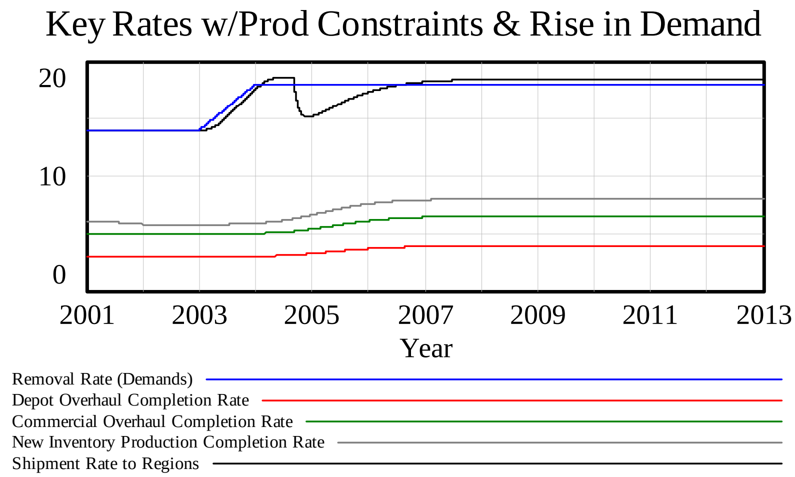


**Figure 29: Case 5, Ramp Up in Demand in 2003 with Overhaul and Production Constraints**

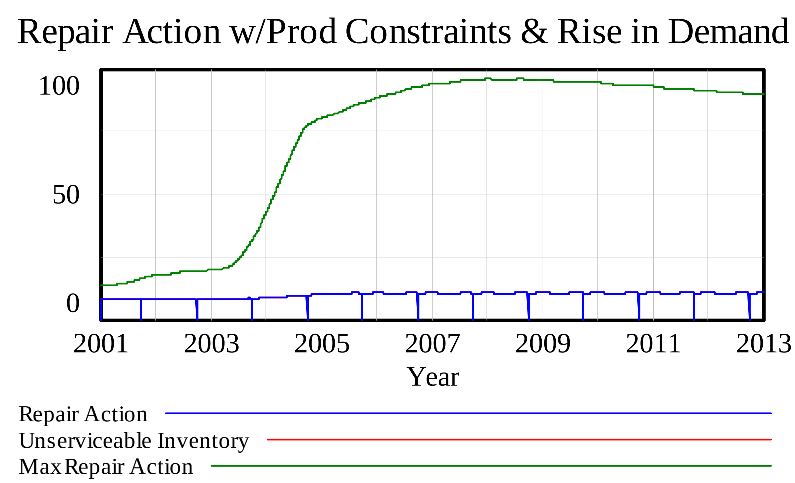


**Figure 30: Case 5, Ramp Up in Demand in 2003 with Overhaul and Production Constraints**

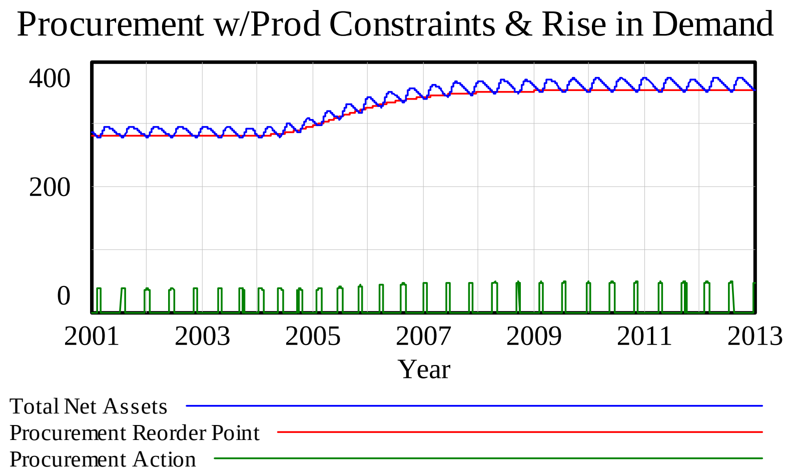


**Figure 31: Case 5, Ramp Up in Demand in 2003 with Overhaul and Production Constraints**

The model is now being used to examine and develop supply chain strategies for 2009 and beyond under alternative assumptions for future demand rates as well as changes in other conditions such as production lead times. Case 6 maintains the same assumptions as the previous case, but in addition to ramping up the demand in 2003, demand is reduced to the 2003 levels over a two-year period beginning in mid-2009. As demand ramps down in 2010, the system overshoots. Backorders are rapidly worked-off, inventory grows rapidly, and an excess of stock is created (see Figure 32). This is due to both the long production lead times as well as the averaging of demand in calculating the requirements and recommended orders. As may be seen in Figure 33, production and overhaul completion rates only begin to decline some time after demand has dropped. When the demand decreases and inventory builds, new procurement orders take place less frequently (see Figure 35).

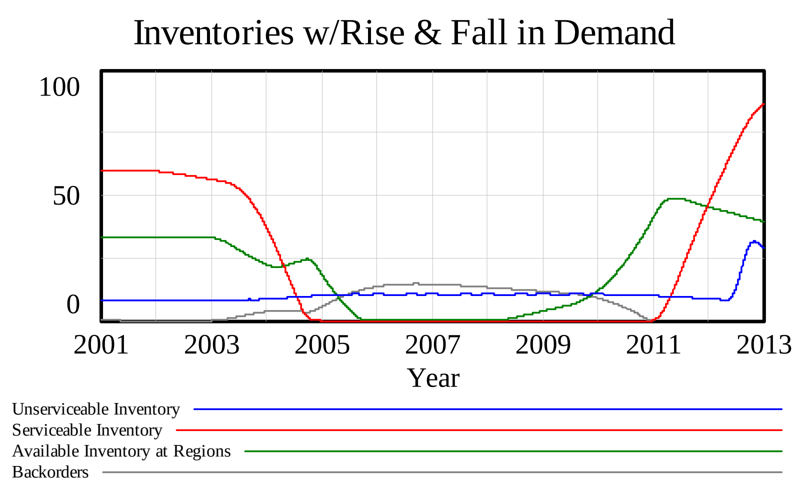


**Figure 32: Case 6, Ramp Up (2003) and Down (2009) in Demand with Overhaul and Production Constraints**

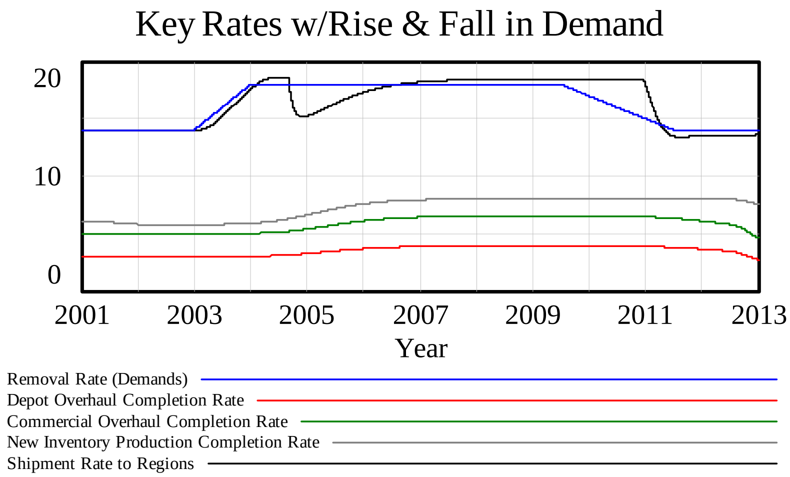


**Figure 33: Case 6, Ramp Up (2003) and Down (2009) in Demand with Overhaul and Production Constraints**

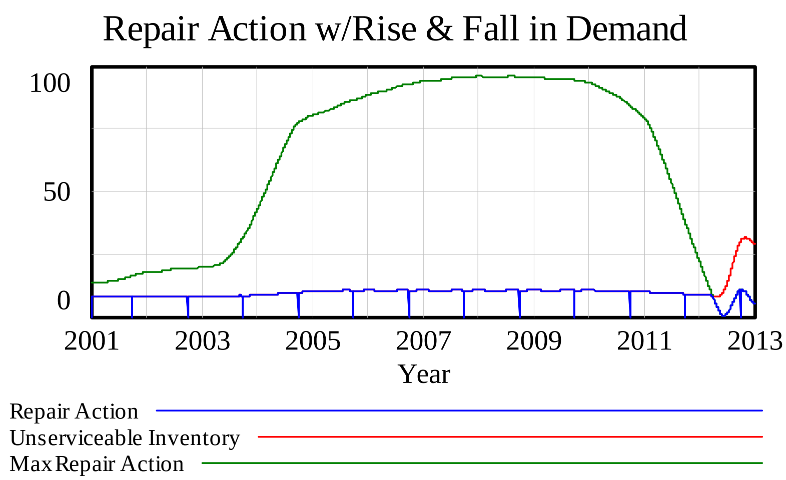


**Figure 34: Case 6, Ramp Up (2003) and Down (2009) in Demand with Overhaul and Production Constraints**

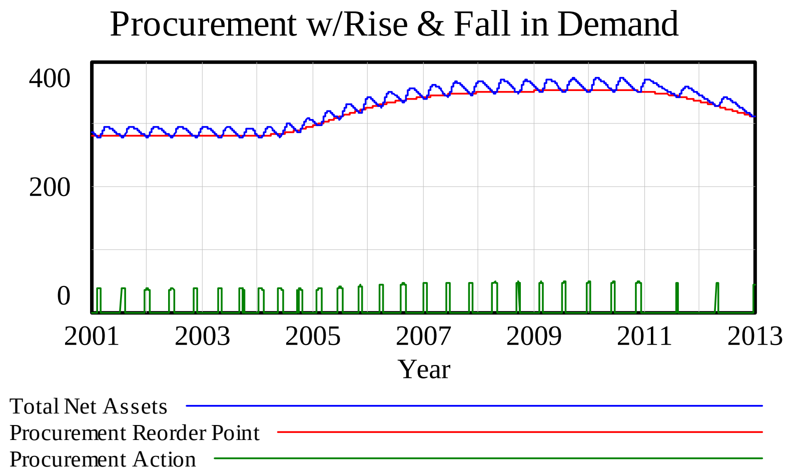


**Figure 35: Case 6, Ramp Up (2003) and Down (2009) in Demand with Overhaul and Production Constraints**

Another "real world" case with interesting implications combines several of the previous assumptions. In case 7, demand levels begin at 14 per month, ramp up to 18 per month in 2003, and decline back to the original levels starting in mid-2009. Production lead time begins at 22 months and ramps up to 32 months in 2004. The system continues to assume a PLT of 22 months until 2005, when it "learns" of the increase and ramps up to the equivalent of the actual value, 32 months. Case 7 also includes production and overhaul constraints, limiting depot overhaul to six items a month, commercial overhaul to ten items a month, and new procurement to eight items a month. Due to the limitations on the new production and overhaul processes, inventories immediately drop in 2003 and backorders ensue, picking up significant growth in 2004, upon the onset of the longer PLT (see Figure 36). The increase in PLT primarily affects the production completion rate, and with the capacity constraints, limits the recovery of the inventory levels until 2011.

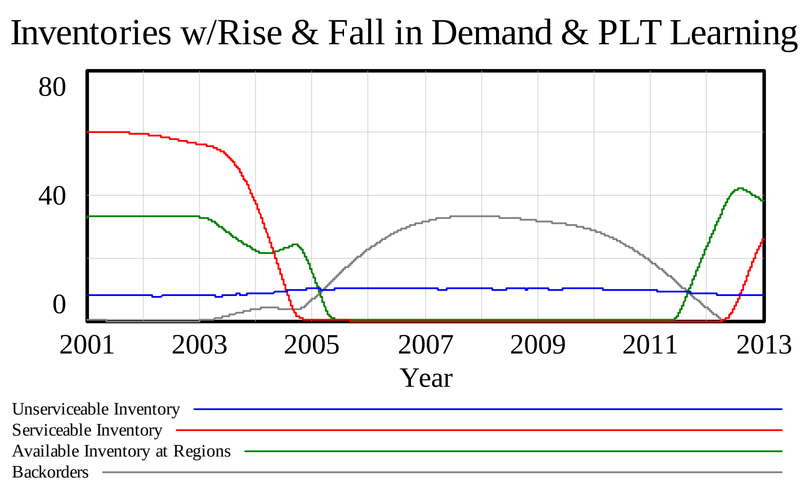


**Figure 36: Case 7, Ramp Up (2003) and Down (2009) in Demand with Overhaul and Production Constraints and an Error in Estimated Production Lead Time with Learning**

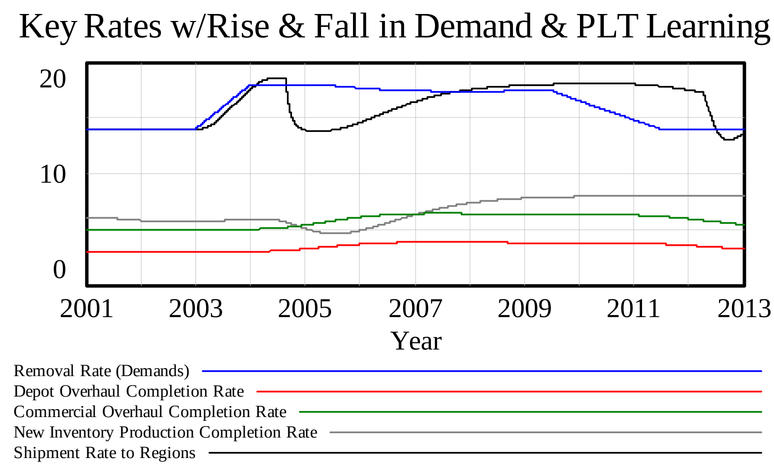


**Figure 37: Case 7, Ramp Up (2003) and Down 2009) in Demand with Overhaul and Production Constraints and an Error in Estimated Production Lead Time with Learning**

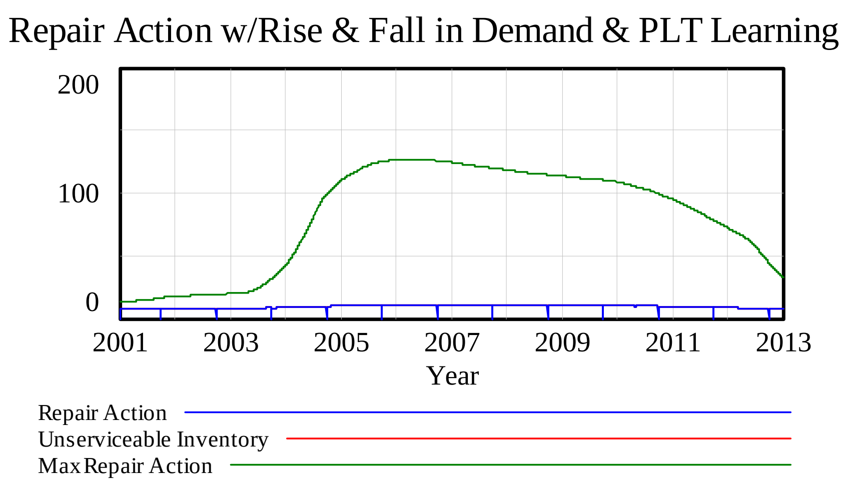


**Figure 38: Case 7, Ramp Up (2003) and Down (2009) in Demand with Overhaul and Production Constraints and an Error in Estimated Production Lead Time with Learning**

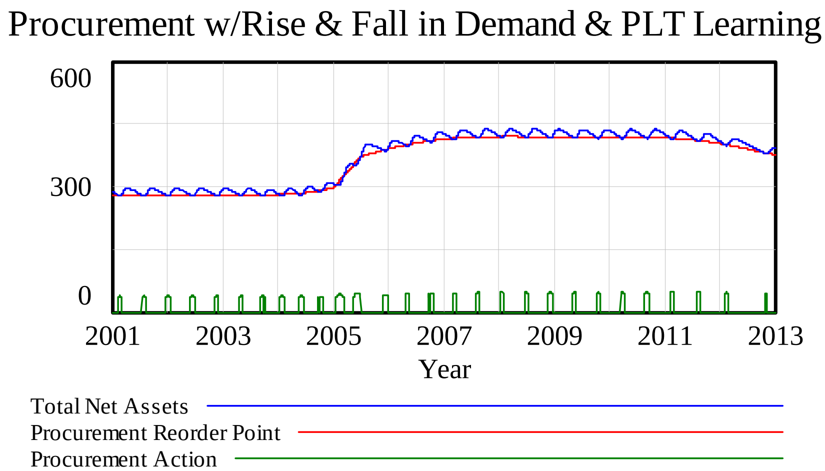


**Figure 39: Case 7, Ramp Up (2003) and Down (2009) in Demand with Overhaul and Production Constraints and an Error in Estimated Production Lead Time with Learning**

## Conclusions

Government procurement systems for high value spare parts have a long history of problems, often being plagued by both excess inventory and shortages. A process used in the calculation for recommended purchases of new spares and for overhauled parts is at the heart of many of these computerized processes. These algorithms have been embedded in a system dynamics model of the supply chain. This modeling effort has revealed that the requirements determination process or supply control study has several very troubling characteristics. First, recommended orders are calculated as the difference of two large numbers. This formulation requires extreme accuracy of data for the process to be stable and function appropriately. Second, data accuracy continues to plague these systems, and the system is shown to be highly sensitive to inaccurate data such as the production lead-time and the repair lead-time. Third, the process and the related supply chain are shown to exhibit substantial bullwhip effect in the face of varying demands. The tendency to bullwhip coupled with data inaccuracies can create, and has created in the past, considerable problems in inventory management with substantial swings in available inventory. On-going research is now using the model to develop alternative formulations for requirements determination and to develop supply chain strategies in the face of alternative demand scenarios.

**Appendix: Definitions**

**ALT Requirements**: Amount of stock necessary to meet expected demands during the Administrative Lead-time (the time from initiation of the contract until it is awarded)
**Assets Applicable to Repair Review**: The amount of inventory that is in a condition suitable for issuance through the time it takes to repair unserviceable inventory
**Below Depot Requirements**: Quantity of inventory stored at selected forward sites
**Due in from Procurement**: The amount of inventory purchased on contract, but not yet received in the inventory
**Due in from Repair**: The amount of inventory inducted into repair programs and not yet received in the inventory
**Due Out**: Backorders
**Max Repair Action**: The maximum amount of an item that may need to be repaired per month
**PLT Requirements**: Amount of stock necessary to meet expected demands during the Production Lead-time (the time beginning at the awarding of a contract until a product is delivered)
**Procurement Cycle Requirement**: The approximate time between scheduled purchases
**Procurement Reorder Point**: The minimum stock needed to meet demands until the next scheduled purchase
**Repair Action Point**: The total number of assets required for issue during the Repair Lead time period
**Repair Cycle Requirements**: Quantity of inventory held to fill orders while other assets are being repaired
**Repair Lead Time Requirements**: Amount of stock necessary to meet expected demands during the Repair Lead-time (the time required to repair unserviceable inventory)
**Serviceable Inventory**: Inventory that is in sufficient condition to be issued for use
**Total Net Assets**: The total amount of stock on hand and due in
**Unserviceable Inventory**: Inventory that is not in suitable condition to be issued for use, but which is in repairable condition

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