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Using a Game to Overcome Two Obstacles to Adopting a Pull System in a Make-to-Stock Production Plant

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Abstract

A low inventory with high availability is the primary objective for make-to-stock production plants. Thus, production plants must choose between two approaches, a push production system or a pull production system. Despite the simplicity of the pull system, and numerous reports of successful implementation, the push system remains prevalent. Interviews with local managers reveal two obstacles to implementing pull systems: (1) lack of a precise definition for pull systems, and a general ignorance among managers regarding the concept of pull systems. As a result, some managers may believe they are running a pull system when they are actually using a push system; (2) lack of confidence in the ability of a pull system to handle significant demand variability. This study designs a make-to-stock production plant game to enable managers to determine whether: (1) they are using a push or a pull system; and (2) a pull system is superior to a push system, even under significant demand variability. The results support our belief that most participating managers still use a push system, and demonstrate that a pull system is superior. We anticipate that the results of this study will increase the willingness of make-to-stock companies and make-to-order companies (especially fashion product manufacturers) to re-examine the potential benefits of implementing a pull system, and encourage them to assess whether such a move is suitable.

Keywords: Make-to-stock production plant, inventory management, push/pull system

1. Introduction

A low inventory with high availability is the primary objective for make-to-stock production plants,[1] such as those manufacturing consumer goods (Schragenheim *et al.*, 2009). Thus, production plants must choose between two approaches, a pull production system or a push production system.[2] According to the definition by Hopp and Spearman (2004), a pull production system explicitly limits the amount of work in process (WIP) that can be in the system. By default, this implies that a push production system has no explicit limit on the amount of work in process. Hopp and Spearman (2004) also concluded that though pull systems can adopt numerous forms for various circumstances, they all possess an internal system status that regulates releases to prevent inventories from exceeding a specified limit. Decisions on whether to use make-to-order or make-to-stock practices and how to rely on forecasting are important but orthogonal to the push versus pull decision. The advantage of a pull system is the maintenance of a WIP cap.

Maintaining the WIP cap, called the target level of inventory in this paper, in a make-to-stock production plant involves three major decisions (Goldratt, 2006, 2008a). The first is determining the target level of inventory, which is a strategic decision. The target level of inventory equals the average consumption expected during the replenishment time factoring in demand and production variability, such as the plus Three Sigma of standard deviation (Schragenheim *et al.*, 2009). For example, when the replenishment time is six weeks, and the average consumption expected for six weeks is 4,800 units, the standard deviation is 800 units, and the target inventory level is 7,200 units (4,800 + 800×3). The replenishment time equals the order pool lead time (the waiting time before a work order is released to the production plant) plus the production lead time. In a production plant, the order pool lead time denotes every part every interval (EPEI). EPEI is the lot size expressed in time; it depends on the range and changeover time of the produced assortments. A wide range of assortments and a lengthy changeover time negatively affect the EPEI parameter, and subsequently, the replenishment time. Therefore, the target level of inventory comprises the finished goods inventory in the plant warehouse and the production WIP on the plant shop floor. The second decision, which is tactical, is to release work orders to the plant shop floor based on what customers actually pull from the finished goods inventory. The third decision, also strategic, involves adjusting the target level of inventory according to changes in demand or production plant capacity. Although Goldratt (2006, 2008a) and Schragenheim *et al*. (2009) developed a buffer management system to adjust the target level of inventory, forecasting remains essential for adjusting the target. Goldratt (2006, 2008a) also indicated that adjusting the target level of inventory without waiting for a replenishment time can cause a bullwhip effect.

When the target level of inventory is established (decision two), how work orders are released to the plant shop floor determines whether the production plant uses a push or pull production system, according to the definition by Hopp and Spearman (2004). If the number of orders released to the plant shop floor is based on what customers pull from the finished goods inventory, the make-to-stock production plant is essentially a pull production system because it

[1] Make-to-stock means that production is begun without a specific customer order, including producing intermediate parts or components to be used once customer orders are received, producing to a forecasted demand, or producing according to a min-max algorithm.

[2] Material control schemes can be classified as push, pull, and hybrid (Krishnamurthy *et al.*, 2004). In this paper, we restrict our focus to only push and pull.

maintains the target level of inventory. By contrast, if the number of orders released to the plant shop floor is not based on what customers pull from the finished goods inventory but on other factors, such as demand forecasting, managerial experience (behavior), or order batching (Lee *et al*., 1997a, 1997b; Lee *et al*., 2010), the make-to-stock production plant is a push production system. Thus, the target level of inventory will be oscillated not limited.

The effectiveness of a pull system under demand variability is supported by two management giants, Deming (Latzko and Saunders, 1995) and Taiichi Ohno (Goldratt, 2008b). Deming's variation theory indicates that when the process is stable or under control, all the data points are within the two limits. These points result from a process that comprises only common variation causes (or noise). Without this basic knowledge, any management action is merely tampering. Deming's variation theory also applies to supply chain management. Providing demand fluctuation exists within the target inventory level, though the manager devotes significant effort, the situation will deteriorate. The simple and effective method is to base supply on actual demand (pull system). Goldratt (2008b) also suggested that the success of the Toyota Production System (TPS) was due to four supply chain features: (1) improving the flow (or equivalent lead time) is a primary operation objective; (2) this objective is translated into a practical mechanism that determines when to halt production (to prevent overproduction or limit the WIP cap); (3) local efficiencies must be abolished; and (4) a focusing process to balance flow (not capacity) must be implemented. According to these four features, the pull system extends TPS to customers or suppliers, and the practical mechanism that determines when to halt production (to prevent overproduction and shortages) is to place replenishment orders based on actual demand.

A number of studies demonstrated through simulations that in certain environments pull systems can be significantly insufficient (Masuchun *et al*., 2004; Krishnamurthy *et al*., 2004). For example, Masuchun *et al.* (2004) suggested that push outperforms pull with respect to customer service and throughput; whereas pull outperforms push with respect to the total inventory of a make-to-stock supply network under different environmental conditions (forecast errors and initial levels of inventory). Nevertheless, Masuchun *et al.* (2004) expected that increasing in the inventory buffer level and reducing the transfer batch sizes between each stage, would cause the throughput and customer service of a pull system to approach that of a push system. They suggested studying other aspects of the pull strategy, such as how managers can establish policies to determine the appropriate target levels of fixed stock at each stage, the frequency of adjusting target levels, and the use of forecast information. Studies conducted by Goldratt (2004, 2006, 2008a, 2008b, 2009a), Schragenheim (2006, 2007), and Ptak and Smith (2008) concurred that a pull strategy is critical to the effectiveness of implementing pull systems.

Although these parameters are critical for establishing an effective pull system, Goldratt (2006) highlighted another key issue. When establishing any new system, a number of assumptions (sometimes hidden assumptions) must be accepted. However, a new system cannot be expected to succeed if the assumptions are invalid. One assumption regarding pull systems is that the product lifespan is significantly greater than the replenishment time between each stage. Lai (2009) found that if the ratio of the product lifespan and the replenishment time was greater than seven times, a pull system would outperform a push system with respect to shortages, remaining stock after a product phase-out, and average inventory levels.

Researchers including Goldratt (2004, 2006, 2008a, 2008b, 2009a), Schragenheim (2006, 2007), and Ptak and Smith (2008) advocated a pull production system when the ratio of the product lifespan and the replenishment time between each stage was high. Previous reports (Aben, 2006; Camp, 2006, Krishan and Kothekar, 2007; Ploss, 2008; Grant, 2008) endorsed numerous accounts of successful pull production systems. This approach reduces inventory shortages, and eliminated urgent orders, leading to more than a 20% increase in sales. In addition, the pull production system almost eliminates surplus inventory. With respect to the manufacturer, reduced shortages and fewer urgent customer orders lead to fewer expedites and less overtime in the plant. This in turn leads to increased predictability, shorter lead times, and lower costs. Significantly reducing demand variability in the production process and simultaneously supporting higher sales volume is the greatest benefit to production plants.

Despite the simplicity of pull production systems, numerous reports of their successful implementation, and support from two management giants, Deming and Taiichi Ohno, the push system remains prevalent. Our interviews with local managers reveal two obstacles to pull systems.[3] The first is a lack of understanding and no precise definition of a pull system. Consequently, some managers may believe they are running a pull system, but are actually using a push system. The second obstacle is a lack of confidence in the ability of a pull system to handle high demand variability, even when an environment would suit the implementation of a pull system (the ratio of product lifespan and replenishment time between each stage is greater than seven times). Instead, numerous managers attempt to improve their production systems by adopting more sophisticated forecasting algorithms and software, implementing Collaborative Planning Forecasting and Replenishment (CPFR) (Chen *et al.*, 2000; Chang *et al.*, 2007; Pfeifer *et al.*, 2008; Du *et al.*, 2009) or adopting radio-frequency identification (RFID) technology (Wang *et al.*, 2008). Unfortunately, an excess of wrong inventory and insufficient right inventory remain major issues for the supply chain system. Both obstacles can impede improvements in performance (a low inventory with high availability) if their environment suits the implementation of a pull system.

The objective of this research is to overcome these two obstacles in a simulation setting. Since previous studies focused only on the second obstacle (Huang and Kusiak, 1998; Bonner *et al*., 1999; Duri *et al*., 2000; Li, 2003; Masuchun *et al.*, 2004; Krishnamurthy *et al.*, 2004), we were unable to establish a precedent for overcoming the first obstacle. Previous studies encountered one major pitfall in overcoming the second obstacle; a lack of direct involvement by managers in their study. Unless we can harness the experience of managers, we are unlikely to succeed in overcoming both obstacles. The push system would remain the prevailing paradigm, and poor results would continue. Continually seeking and trialing sophisticated forecasting algorithms and new information technology to improve the performance of the supply chain system or non-innovative mentality eventually becomes the norm.

Because of the difficulty in overcoming these two obstacles through the collection and analysis of data obtained directly from the field, we invited managers experienced in material planning, purchasing, warehousing, supply chains, and production planning to participate in a simulated make-to-stock production plant experiment (well-suited to the implementation of a pull system). The experiment comprised three games. The first make-to-stock production plant game was designed to reveal how teams manage make-to-stock production plants (push or pull). Results were collected to identify whether a push or a pull system was used in the game, according to the definition provided by Hopp and Spearman (2004). The results from the game served as a baseline to form comparisons with the other two games (Games 2 and 3), which were designed to be run

[3] During the year of 2009, four workshops (January, 17th, March 14th, May 9th and June 13th) were conducted on the campus of National Chiao-Tung University, Hsinchu, Taiwan. The workshop title is: “Distribution the TOC way.”

under a pull system.

Game 2 was designed for use with the yearly average target inventory of Game 1 (a result of Game 1) as the initial target inventory level with which to evaluate whether replenishment based on actual consumption would improve Game 1 results when run by experienced managers. Game 3 was designed to (1) prove to the teams that with the proper initial target inventory level, pull systems outperform push systems on shortages, inventory levels, and return on investments (ROIs), even with a high degree of demand variability; and (2) demonstrate to the teams how to transfer from a push system to a pull system.

2. A make-to-stock production plant experimental design

The designed make-to-stock production plant experiment demonstrates a simple production plant and customer relationship.[4] This section focuses on a production plant that produces a customized component for its customer (another production plant using components for its products). The game is applicable to production plants that produce products for both distributors and retailers. The customer is a big brand that requests the production plant to provide Vendor Management Inventory (VMI) services.[5] The customer provides space for the production plant at his or her site to store the component with no fee. Money is transferred to the production plant immediately after the component is consumed. The production plant’s responsibility is to track the customer’s consumption of the stock, and replace the stock as required, ensuring that the customer rarely runs out of stock. The customer provides rolling forecasts to the production plant for weekly references.

The component served is new; the customer production plant uses the component for production, starting the first week of Year 1. Weekly demand is normally distributed with a mean 800 units, a standard deviation of 560 units (high demand variability), and annual demand is 42,000 units. The lowest is zero, and the highest is 1,800 units. The order pool lead time is two weeks, and the supply lead time (production lead time plus transportation lead time to customer) is four weeks. This means that replenishment time is six weeks. The component lifespan is assumed to be greater than one year, which means that the ratio of product lifespan and replenishment time is high (more than seven times). The production plant is assumed to be highly reliable and can be trusted (the supply unreliability factor is excluded).

Table 1 shows the tracking table used for the experiment, which was designed using Excel. The ERP information is also provided in the tracking table for reference, including the last year’s historical data (column D), rolling six weeks actual demand (column E), difference between rolling six weeks actual demand and forecast demand (column F), and rolling six weeks forecast demand from the customer (column G). Column H denotes the actual inventory (demand) used by the customer. If the inventory (on site) is higher than the actual demand, column H is equal to the actual demand. However, if the inventory is less than the actual demand, shortage (sales loss,

[4] The point of this game was not to examine the complexity of production plants or customer relationships. In a typical supply chain network, the demand from a supply point is the aggregate consumption of all the points it feeds (manufacturers must supply a number of distributors or retailers). Under such structures, fluctuations in demand are averaged, thereby simplifying the supply chain and making the implementation of a pull system more suitable. After explaining the game to participating managers, they all agree that though the game was simple, it was realistic.

[5] One of the local companies that supplies components to a big-brand customer stated that VMI is not the abbreviation for “Vendor Management Inventory,” but the abbreviation for “Very Much Inventory.” This is the casual term used by those who operate VMI under the push system.

customer uses a competitor's parts) occurs (column L), and column H is equal to the inventory. The team is the manager leading the VMI operation for this component, and a low inventory with high availability is the team's primary objective.

Game 1: Make-to-stock production plant game

The game is designed to observe how the teams manage the supply chain system, and to collect their results, which are to serve as the baseline for further analysis and comparison to support the claim of this study. Each team was requested to play the game with their current mode of managing operations, to decide the initial target inventory level, and place a replenishment order on each even week (based on factors such as demand forecasting, managerial experience (behavior), or order batching). Because the first replenishment order is placed on the second week and arrives four weeks after, the size of the initial target inventory level should cover demand for the first 6 weeks; otherwise, a shortage immediately occurs.

Playing the game is relatively easy. Before starting the game, each team (three people) must discuss and decide the initial target inventory level. The decided inventory quantity is entered into the box of the initial target inventory level of the Excel tracking table. During the game, the instructor generates two figures for teams each week; one is the rolling six weeks forecasting demand, and the other is the actual weekly demand (Table 2). The forecasting error for the rolling six weeks was approximately 25 %. Each team then enters the rolling six weeks forecasting demand into column G and the actual weekly demand into column C, where Excel computes and updates relative columns automatically. Every even week, each team must decide whether to place the replenishment order for the production plant. If they decide to place the order, they discuss the quantity to place (no order size constraint) and enter the quantity they decide into column I (zero means no order placed). Excel schedules the order for delivery four weeks later. The process is repeated for 52 weeks. The game collects seven performance indices, including yearly initial target inventory level, average yearly target inventory level, sales volume, average on site inventory, inventory turn, quantity of shortage (degraded service and sales losses), and percentage of shortage.

Game 2: Pull system game, using the average target inventory of Game 1 as the initial target inventory

Poor results (either a shortage or excessive inventory) in Game 1 are because of two reasons; one is the method for setting the initial target inventory level, and the other is the method for placing the replenishment order on each even week. Game 2 is designed to evaluate whether to replenish based on actual consumption, which improves the results of Game 1 (managing by the experienced managers). To achieve this evaluation, all the teams use their average target inventory level of Game 1 as the initial target inventory level. Excel automatically runs the simulation and places the replenishment order on each even week based on actual demand (the demand pattern is the same as that of Game 1) pull from the finished goods inventory. Because the average target inventory level and demand are the same as in Game 1, if the shortage improves significantly when the average inventory on site does not increase notably, Game 2 shows that placing the replenishment order based on actual demand improves Game 1 results.

To equally maintain the average target inventory level for both Games 1 and 2, if shortage occurs, the quantity of actual demand in Game 2 is equal to the actual volume pulled from the inventory.

For example, if the actual demand of two weeks is 2,000 units, but the inventory on site only has 1,800 units, it is 200 units short. Therefore, the actual order placed is 1,800 units, and not 2,000 units.

Game 3: Pull system game, using the proper target inventory of Game 1 as the initial target inventory

The pull system advocators (Goldratt, 2004, 2006, 2008a, 2008b, 2009a; Schragenheim, 2006, 2007; Ptak and Smith, 2008) claim that, with a maximum demand during replenishment time (six weeks into the game) being within the initial target inventory level, despite the demand fluctuation, no shortage occurs when placing an order based on actual consumption demand. Therefore, in Game 2, we expect no shortage for teams with an initial target inventory level greater than or equal to 7,116 units (the maximum demand within six weeks replenishment time). Consequently, a shortage for the teams is obviously caused by the method used to set the initial target inventory level (insufficient initial target inventory level) and by the method placing the order (placing an order based on actual consumed demand, without adjusting the initial target inventory level to render the target inventory level insufficient). The lower the initial target inventory level, the higher the shortage is. Conversely, for teams without a shortage, the higher the initial target inventory level, the higher the average inventory on site is.

Therefore, the purposes of Game 3 are as follows: (1) to prove to the teams that using the pull system (determining the proper initial target inventory level and placing orders based on actual demand) enables teams with no shortage to reduce the inventory on site without shortages. For teams with shortages, with an increase of the initial target inventory level, no shortage occurs; and (2) to demonstrate to the teams how to transfer from the push system to the pull system. The approach for determining the initial target inventory level is first explained, which is set equal to the average amount expected for consumption within the replenishment time factored for demand and supply variability (for example, plus Three Sigma). In the proposed game, the mean demand for the six weeks replenishment time is approximately 4,800 units, and the standard deviation is 800 units; therefore, the initial target inventory level is set to approximately 7,200 units (4,800 plus three standard deviations). In reality, the optimized target inventory level depends on the desired service level, expedites option, and its costs.

The teams are then requested to continue running the game for a second year. The yearend data of Game 2 becomes the input data of the second year. The ending on-site inventory of Week 52 of the first year becomes the beginning inventory of the first week of Year 2, and on-route orders placed in Weeks 48, 50, and 52 are scheduled to arrive on Weeks 1, 3, and 5 on times. Their total is the target yearend inventory level of Game 2, which becomes the initial target inventory of Game 3. This game uses new demand (a different demand pattern with the same maximum rolling six weeks actual demand, 7,116 units) (Table 2). The replenishing order is placed based on actual demand.

Because the desired initial target inventory level is set to 7,200 units for this game, teams with an initial target inventory level lower than 7,200 units must increase their target inventory to 7,200 units. However, teams with an initial target inventory level higher than 7,200 units must lower their target inventory to 7,200 units. The target inventory level is adjusted on the second week. For example, a team with an initial target inventory level of 6,000 units on Week 2 must place the actual demand of Weeks 1 and 2 plus 1,200 units (the difference of 7,200 units from 6,000 units) to raise the target inventory from 6,000 units to 7,200 units on Week 7. A team with an initial target inventory level of 8,000 units on Week 2, for example, must place the actual demand of Weeks 1 and 2 minus 800 units (the difference of 8,000 units from 7,200 units) to reduce the target inventory from 8,000 units to 7,200 units on Week 7. However, a team with a high initial target inventory level may be required to lower the target inventory level to 7,200 units more than once. For example, for the 9,000 units team, if actual demand in the first two weeks is 1,500 units, no order should be placed on Week 2 (1500- (9000 - 7200) = -300). The fourth week also requires another reduction of 300 units from the actual demand. Teams with an initial target inventory level lower than 7,200 units that raise the target inventory level on Week 2 may still experience a shortage if the actual demand of the first six weeks is greater than the initial target inventory level, unless an expedite is undertaken.

The same applies for Game 1, during which the instructor generates two figures for teams every week; one is a rolling six weeks forecasting demand, and the other is the actual weekly demand. Each team then enters the rolling six weeks forecasting demand into column G and actual weekly demand into column C, and Excel computes and updates relative columns automatically. Every even week, each team enters the last two weeks' actual demand (except for the second week or fourth week. An adjustment may be necessary) into column I. Excel schedules the order to be delivered four weeks after on time. The process is repeated for 52 weeks.

The experiment represents a valuable educational opportunity; therefore, this study distributed invitation letters (explaining the purpose of the experiment, the time required, who should be team member candidates, and the value they can gain) to local manufacturing companies (make-to-stock companies), and invited them to organize one or more teams to participate in the experiment. We asked team members to be material planning managers, purchasing managers, warehouse managers, supply chain managers, and production planning managers. The response was excellent, and 30 teams from 25 companies were selected. The number of years of work experience of the participants ranged from 3 to 25, with an average of 7.

The experimental process was as follows: (1) Explain the purpose of the experiment; (2) explain Game 1 and perform a ten-week (game week) trial run for process familiarization; (3) a 30-minute discussion among the game players of how to play Game 1 to achieve better results; (4) play Game 1; (5) analyze and discuss the results of Game 1; (6) explain and auto-run Game 2; (7) analyze and discuss the results of Game 2; (8) explain and play Game 3; and (9) analyze and compare the results of the three games. The experiment requires approximately six hours to complete.

3. Analysis of the results

To collect valid data to support and prove our claims, we required at least 30 teams to participate in the experiment (Kerlinger and Lee, 2000). Each team comprised three people from the same company. The purpose of three people in a team is for group discussion. Table 3 lists the experimental results based on the considerations of the three games for each team. Column 1 lists the initial yearly target inventory level. Game 1 is determined by the team based on their experiences, Game 2 is the average target inventory level of Game 1, and Game 3 is the year-end target inventory level of Game 2. Column 2 is the average target inventory level, and the sum of the on-site inventory and on-route inventory of each week divided by 52 weeks. Game 2 is the same as Game 1 because this experiment uses the average target inventory level of Game 1 as the initial target inventory of Game 2 and auto-runs with orders placed on each even week based on actual demand. The target inventory level of Game 3 is approximately 7,200 for each team, slightly deviating from 7,200 because of the adjusting target inventory on Week 2. Because the total yearly demand is 42,000 units, actual sales volume (column 3) for each team is the total demand minus the total shortage. Column 4 is the average inventory on site, which is the sum of the average inventory on site each week divided by 52 weeks. Column 5 is the inventory turn, which is column 3 divided by column 5. Column 6 is the number of shortages. Games 1 and 2 include three shortage figures. For Game 1, the first figure (column A) is the shortage quantity caused by the method of setting the initial target inventory level (or insufficient initial target inventory level). The second figure (column B) is caused by the method of placing orders, and the third figure (column A plus column B) is the total shortage quantity. For Game 2, the first figure (column A) is also caused by the method of setting the initial target inventory level; however, the second figure (column B) is caused without adjusting the target inventory level (because the order is placed based on the actual consumed demand), and the third figure (column A plus column B) is the total shortage quantity. The shortage of Game 3 is caused by setting the initial target inventory level only. Column 7 is the percentage of shortages divided by 42,000 units.

Figure 1 illustrates the target level of inventory for 30 teams of Game 1. Except for teams 12 and 26, whose target level of inventory remained unchanged, the target level of inventory of the rest of the teams fluctuated. This result supports the hypothesis that most of the participating managers were still running their make-to-stock production plants using push systems. We believe that the lack of a precise definition and a failure to comprehend the nature of pull systems is the main reason.

Table 3 shows that the mean shortage of Game 1 is 3,016 units (2,094 units caused by the method of placing the order, and 922 units caused by the decision of setting the initial target inventory level), and the average shortage rate is 7.18 %. The mean inventory on site is 2,746 units, and the average target inventory level is 6,896 units. Based on their initial target inventory and the average target inventory, the teams can be classified into three groups (Table 4):

(1) Group A: teams with an initial target inventory larger than 6,993 units (Table 2, rolling six weeks actual demand of Week 6). Shortage (1,274 units on average) in this group is caused by placing orders on even weeks. In this group, only two teams (12 and 26) have no shortages, and both teams placed orders based on actual demand.

(2) Group B: teams with an initial target inventory smaller than 6,993 units, but the average target inventory level is greater than 7,116 units (the maximum demand within six weeks replenishment time, Table 2, Week 30, rolling six weeks actual demand). In this group, the main shortage (1,576 units) is caused by the decision of setting the initial target inventory level (less than 6,993 units), and shortage is seldom caused by the decision of placing orders. However, the average target inventory level (8,622 units) and average inventory on site (4,187 units) is significantly higher when compared with the other groups. This is why shortage caused by the decision of placing orders is almost zero. This result confirms the common practice that if a high target inventory level policy is established, the decision of placing orders is not as important a matter.

(3) Group C: teams with initial target inventories lower than 6,993 units and average target inventory levels also smaller than 7,116 units. Compared with the other two groups, the average shortage of this group (5,121 units) is significantly high. Shortage in this group is

caused by the decision of setting the initial target inventory level and the decision of placing orders. Based on the data, the major reason for shortages is the decision of placing orders, which indicates the push system.

This study sets the average target inventory level of 30 teams, 6,896 units, as the borderline of high inventory teams and low inventory teams. In total, 11 teams have a target inventory level above 6,896 units, whereas 19 teams are below the target level. The average shortage of the low inventory teams is 4,140 units, and the hypothesis test rejects the null hypothesis that their shortage is significantly higher than the shortage rate (1,283 units) of high inventory teams. However, a high inventory level does not automatically guarantee low shortage if setting the initial target inventory level and placing orders is not accomplished properly (for example, Teams 7, 11, 14, and 18).

Analysis of Game 2 results

This study first performed a hypothesis test to determine whether the same target inventory and placing orders based on actual demand significantly improves the total shortage of Game 2. The mean total shortage of Game 1 is 3,016 units (7.18 % shortage rate) (Game 2 is 1,943 units (4.26 %)), and thus, the null hypothesis is rejected. A hypothesis test is also performed to determine whether the average inventory on site of Game 2 is equal to the average inventory on site of Game 1. The average inventory on site of Game 2 is 2,774 units (that of Game 1 is 2,746 units), and thus, the null hypothesis is accepted. Both tests support that, with the same average inventory on site (and the same average inventory target), placing orders based on actual demand (consumption driven mode of operation or pull system) improved shortage significantly.

Further analysis of the findings reveals that only teams with initial target inventories greater than or equal to 7,116 units show no shortages. This supports the hypothesis that, with a maximum demand during replenishment time (in our game, in Week 6) being within the initial target inventory level, despite demand fluctuation, no shortages occur when placing orders based on actual consumption demand. This result agrees with Deming’s variation theory (Latzko and Saunders, 1995). However, the higher the initial target inventory level, the higher the inventory on site is. Consequently, setting the initial target inventory level (insufficient initial target inventory level) and placing orders (placing the order based on actual consumed demand without adjusting the initial target inventory level to render the target inventory level insufficient) causes shortages for the teams. The lower the initial target inventory, the higher the shortage is (both columns A and B).

Checking the teams with initial target inventories less than 7,116 units’ shows that the mean shortage of Game 1 is 2,938 units (7 %) and that of Game 2 is 2,098 units (5 %). Thus, the null hypothesis is rejected, namely that the shortage in Game 2 is significantly lower than that in Game 1. This result means that, for teams with shortages, placing an order based on actual consumed demand without adjusting the initial target inventory level (maintaining the same target inventory level for 52 weeks, signifying a pull production system) improves the shortage more significantly, instead of placing an order based on forecast plus experience (initial target inventory is adjusted based on forecast and game player experience, indicating a push system).

Although Game 2 results supports the hypothesis that placing the replenishment order based on actual demand significantly improved shortages in Game 1, five teams (6, 10, 16, 17, and 27) showed that shortages did not improve, but deteriorated the situation. Careful examination of the five teams reveals that their initial target inventory level is relatively low compared with the average initial target level (6,896 units). Because no initial target inventory is adjusted in Game 2, a high shortage occurs for teams with relatively low initial target inventories. However, in Game 1, the target inventory level is adjusted frequently to enable inventory teams with relatively low initial targets to have the chance of lowering shortages, instead of simply placing the order based on actual consumed demand without adjusting the initial target inventory level.

Analysis of Game 3 results

Only seven teams (10, 16, 21, 22, 25, 27, and 28) have shortages in Game 3. Because their initial target inventory is lower than the demand in the first six weeks, if their ordered quantity to raise their target inventory arrives on Week 7, no shortage occurs. The average shortage is 130 units (0.31 %), compared to that of Game 1 with 3,016 units (7.18 %), in which the shortage rate improved significantly. The results provide evidence that, with a maximum demand of replenishment time (in our game, six weeks) being within the initial target inventory level (even the right initial target inventory level is difficult to determine), despite demand fluctuation, the performance of the pull system is superior to that of the push system.

Return on investment analysis

The conclusions were based only on inventory levels and shortages, with no consideration for costs or prices. Therefore, in this study, we used ROIs, a single metric, to connect the performance of the games to price and cost. The ROI formula is defined as profit divided by average inventory (in the game, we assumed that inventory is the major investment). We considered two types of inventory to compute ROI: average target inventory (on site, in addition to on route) and average on-site inventory.

For simplicity, we assumed that the selling price was one dollar per unit (therefore, if the plants were managed well, the maximum revenue could be as much as $42,000). The only major variable cost was assumed material cost, which was the percentage of the selling price. In this plant, we assumed that it was 60 % of the selling price (it could be any percentage, depending on the type of industry). In addition to material cost, we established operating expenses to run the plant, including fixed costs such as labor, depreciation, utility, R&D, and sales and administration. We assumed that it would be approximately $12,600. The Throughout Accounting (TA) method (Corbelt, 1998) was adopted to compute the net profit.

Table 5 lists the revenue (from Table 3) and the cost of raw materials, throughput, operating expenses, net profit, average target inventory (from Table 3), ROI1, average inventory on site (from Table 3), and the ROI2 of the three games for each team. To explain the computation, Team 1 is used as an example. In Game 1, Team 1 earned revenue of $41,410, with the cost of raw material equal to 60 % of the revenue ($24,846). Revenue minus the cost of raw material was referred to as throughput, totaling $16,564. Operating expenses were fixed at $12,600, which were the same for each game and each team. The throughput minus the operation expense equals the net profit, which is $3,964. Inventory investment considers raw material costs only; therefore, ROI1 was 0.892 ($3,964 net profit divided by the average target inventory investment, totaling $4441.8 (7,403 units times 0.6 (60 % of selling price)), and ROI2 was 2.151 ($3,964 net profit divided by the average on-site inventory investment, totaling $1842.6 (3,071 units times 0.6 (60 % of selling price)).

The average ROI1 of Games 1, 2, and 3 were 0.736 (or 73.6 %), 0.834, and 0.961, respectively, and the average ROI2 of Games 1, 2, and 3 were 1.966, 2.190, and 2.644, respectively. The hypothesis tests for Game 1 with Game 2, Game 1 with Game 3, and Game 2 with Game 3 all rejected the null hypothesis. This means that the pull system improved both ROI1 and ROI2 significantly.

4. Conclusion

In this study, we designed a make-to-stock production plant experiment to help managers overcome two obstacles that prevented them from adopting the pull system. The first game, a make-to-stock production plant game, was designed to reveal how teams manage a make-to-stock production plant (push or pull). We then collected the results to identify whether the managers were using a push system or a pull system, according to the definition provided by Hopp and Spearman (2004). The results of the game then served as a baseline for comparison with the two other games (Games 2 and 3), which were designed to be run under a pull system. Game 2 was designed to use the yearly average target inventory of Game 1 (one of the results of Game 1) as the initial target inventory level, to evaluate whether replenishment based on actual consumption would improve the results of Game 1, as managed by experienced managers. Game 3 was designed (1) to prove to the teams that, with the appropriate initial target inventory level, a pull system outperforms a push system on shortages, inventory levels, and ROI, even with a high demand variability; and (2) to demonstrate to the teams how to transfer from a push system to a pull system.

Thirty teams comprising 90 people from make-to-stock companies participated in the experiment. The results of Game 1 indicated that 28 of the 30 teams were still running make-to-stock production plants with push systems, instead of pull systems. We believe that a lack of a precise definition and a failure to comprehend the nature of pull systems was the chief reason for this situation. The results of Game 2 indicate that hypothesis testing supported our contention that pull systems could improve shortages significantly, with the same average inventory level on site, as well as the same average target inventory. This supports our contention that if the environment suits the implementation of a pull system, a pull system would outperform a push system on service, profits, and ROI, even with high demand variability. This also supports our notion that, with the existence of demand fluctuation (or what we usually refer to as demand variability) within the target inventory level, the manager works hard, yet exacerbating the situation. Therefore, the root cause (must be improved first) of poor performance is not demand variability, but instead it is the method of management (determining the right target inventory level and placing order based on actual consumption and continually monitoring and modifying the target inventory level when necessary). With limited target levels for inventory, pull system managers can achieve their objectives of low inventory with high availability. Game 3 in this study also demonstrated the importance of determining accurately the initial target inventory levels. Teams without shortages in Game 2 were able to reduce on-site inventory without shortages, and teams with shortages were able to increase initial target inventory levels without incurring shortages. The results of Game 2 and Game 3 also support the expectations of Masuchun et al. (2004) that setting an inventory buffer level in a pull system increase the throughput and improve customer service.

Although we only used one forecasting error, this does not mean that the forecasting error is unimportant for adopting the pull system. For the pull system to be successful, suppliers must have a degree of reliable forecasting information with which to determine and adjust the target inventory level. Forecasting should still be used, not to produce the replenishment order, but to provide suppliers with an accurate estimate of potential gains, to help them prepare in advance for adjusting the target inventory level.

Implementing the pull system can lead to success or failure, depending on is the mode of implementation. The paradigm shift associated with shifting from a traditional push system to a pull system impacts all stakeholders significantly (participants in the supply chain such as parts suppliers, product manufacturers, distributors, and retailers). Whether this impact is positive or negative depends on its level of understanding by stakeholders, partnership robustness, the mechanics for information exchange, and most important, the financial implications for all parties involved (Goldratt 2009a, 2009b; Fox and Schleier Jr., 2010). Goldratt developed a make-to-stock Strategy and Tactics (S&T) tree (Goldratt, 2008a) to provide step-by-step guidance for inputting change. Although the S&T tree logic developed by Goldratt is relatively robust, TOC practitioners and academics have neither researched it extensively nor validated its effectiveness empirically. This would be a sound research topic for future studies.

Finally, the contributions of this study are as follows: (1) to raise the willingness of make-to-stock companies, to reexamine whether obstacles for the implementation of pull systems exist in their companies. Companies could play the game among their staff, or use their own historical data to examine whether their current modes are push or pull, according to the definition. If a company is currently running a push system, it could repeat the game in pull mode with the same historical demand data (using Excel) and compare the results; and (2) to provide make-to-order companies (especially fashion product manufacturers) to evaluate the possibility to change from make-to-order to make-to-actual consumption (pull system). These findings have provided several participating managers with the confidence to switch from push mode to pull mode immediately. These same companies showed significant improvements in their performance within a short period (Huang, 2010).

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Table 1: The tracking table of the game

1	Supply Lead Time	4	Initial Target Inventory Level		Order Lead Time	2							
				ERP Information				Shipping			Reset		
Week	A Beginning Inventory	B Order Arrived	C Actual Demand	D Historical Data	E Rolling Six Weeks Actual Demand	F The Different (Column E- Column G)	G Rolling Six Weeks Forecast Demand	H Actual Inventory (Demand by Customer)	I Order Quantity	J Inventory On The Way	K Endding Inventory	L Shortage	M Target Inventory
1													
2									0				
3													
4									0				
5													
6									0				
7													
8									0				
9													
10									0				
11													
12									0				
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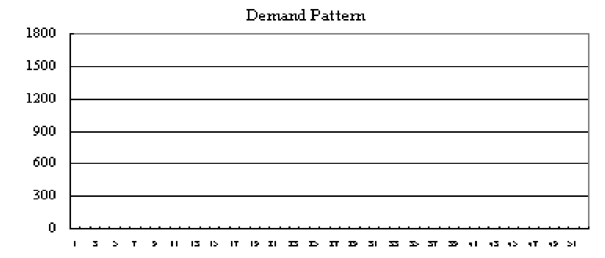
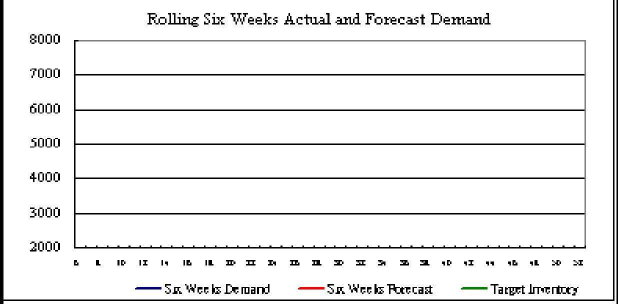
48									0				
49													
50									0				
51													
52									0				





		A	B
Sales Volume			
Average Inventory On Site			
Inventory Turn			
Frequency of Shortage			
Quantity of Shortage			
Shortage Rate			
Average Target Inventory			

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Table 2: The actual and forecast demand

	Game 1 & Game 2			Game 3				Game 1 & Game 2			Game 3		
	Actual Demand	Rolling Six Weeks Actual Demand	Rolling Six Weeks Forecast Demand	Actual Demand	Rolling Six Weeks Actual Demand	Rolling Six Weeks Forecast Demand		Actual Demand	Rolling Six Weeks Actual Demand	Rolling Six Weeks Forecast Demand	Actual Demand	Rolling Six Weeks Actual Demand	Rolling Six Weeks Forecast Demand
Week1	1344		4800	660	3523	4844	Week27	1369	4165	4822	572	5192	3761
Week2	1016		4256	1223	4458	5467	Week28	1688	5831	3543	1778	6690	4345
Week3	904		4040	1388	5036	4517	Week29	692	5740	3343	831	6516	4050
Week4	1098		4480	1210	6037	3789	Week30	1789	7116	4020	795	6615	3791
Week5	1087		4398	626	5841	3802	Week31	22	7048	3919	1022	6481	4774
Week6	1544	6993	4215	975	6082	4564	Week32	468	6028	4589	855	5853	4583
Week7	932	6581	3769	1285	6707	4799	Week33	0	4659	5910	1626	6907	4523
Week8	474	6039	3924	940	6424	4140	Week34	456	3427	5932	471	5600	3919
Week9	54	5189	4994	1726	6762	4175	Week35	1653	4388	5944	44	4813	4303
Week10	69	4160	5872	1542	7094	3734	Week36	538	3137	4291	1370	5388	5885
Week11	0	3073	6277	3	6471	3132	Week37	1346	4461	4209	208	4574	4986
Week12	1546	3075	6331	374	5870	4855	Week38	1002	4995	4516	271	3990	4822
Week13	1738	3881	4854	385	4970	6023	Week39	1408	6403	4052	1120	3484	5921
Week14	1123	4530	3116	235	4265	5641	Week40	1091	7038	3990	1658	4671	5009
Week15	954	5430	3539	499	3038	5780	Week41	1050	6435	3901	1192	5819	3622
Week16	528	5889	4323	1291	2787	5666	Week42	895	6792	4259	1398	5847	3550
Week17	1156	7045	4918	696	3480	4610	Week43	732	6178	4455	1459	7098	3810
Week18	21	5520	4716	219	3325	4413	Week44	853	6029	4773	139	6966	3543
Week19	597	4379	5223	461	3401	5485	Week45	169	4790	4815	784	6630	4802
Week20	11	3267	5782	643	3809	5720	Week46	1235	4934	5378	190	5162	5477
Week21	1676	3989	5792	453	3763	5296	Week47	13	3897	4996	1736	5706	5426
Week22	22	3483	4713	280	2752	5304	Week48	288	3290	5152	0	4308	4474

Week23	783	3110	4702	1005	3061	5667	Week49	810	3368	6099	412	3261	4664
Week24	413	3502	5595	696	3538	5115	Week50	209	2724	5302	224	3346	5988
Week25	90	2995	5204	1156	4233	4699	Week51	1283	3838	5381	337	2899	5764
Week26	1488	4472	5897	1483	5073	4548	Week52	273	2876	4908	54	2763	5893

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Table 3: The experimental results

	Initial Target Inventory Level			Average Target Inventory			Actual Sales Volume			Average Inventory on site			Inventory Turnover Rate			Quantity of Shortage							Shortage Rate (%)						
Teams	G1	G2	G3	G1	G2	G3	G1	G2	G3	G1	G2	G3	G1	G2	G3	G1			G2			G3	G1			G2			G3
																A	B	A+B	A	B	A+B		A	B	A+B	A	B	A+B	
1	6,600	7,403	7,403	7,403	7,403	7,208	41,410	42,000	42,000	3,071	3,103	2,664	13	14	16	393	197	590	0	0	0	0	0.94	0.47	1.41	0.00	0.00	0.00	0.00
2	7,000	6,858	6,858	6,858	6,858	7,186	40,365	41,426	42,000	2,452	2,613	2,600	16	16	16	0	1,835	1,835	136	439	575	0	0.00	4.37	4.37	0.32	1.05	1.37	0.00
3	6,600	6,316	6,316	6,316	6,316	7,166	37,565	39,802	42,000	2,186	2,228	2,539	17	18	17	393	4,042	4,435	677	1,521	2,198	0	0.94	9.62	10.56	1.61	3.62	5.23	0.00
4	7,000	6,809	6,809	6,809	6,809	7,185	41,365	41,280	42,000	2,508	2,578	2,595	16	16	16	0	635	635	184	536	720	0	0.00	1.51	1.51	0.44	1.28	1.72	0.00
5	6,000	6,669	6,669	6,669	6,669	7,180	37,994	41,814	42,000	2,568	2,387	2,579	15	18	16	993	7,280	8,273	324	4,129	4,453	0	2.36	17.33	19.69	0.77	9.83	10.60	0.00
6	6,000	6,561	6,561	6,561	6,561	7,175	40,394	40,535	42,000	2,360	2,402	2,566	17	17	16	993	613	1,606	432	1,033	1,465	0	2.36	1.46	3.82	1.03	2.46	3.49	0.00
7	5,000	8,479	8,479	8,479	8,479	7,249	39,894	42,000	42,000	4,023	4,179	2,788	10	10	15	1,993	113	2,106	0	0	0	0	4.75	0.27	5.02	0.00	0.00	0.00	0.00
8	6,600	6,676	6,676	6,676	6,676	7,180	40,670	40,882	42,000	2,504	2,484	2,580	16	16	16	393	919	1,312	317	801	1,118	0	0.94	2.19	3.13	0.75	1.91	2.66	0.00
9	9,000	6,973	6,973	6,973	6,973	7,179	41,384	41,772	42,000	2,871	2,695	2,614	14	16	16	0	616	616	20	208	228	0	0.00	1.47	1.47	0.05	0.49	0.54	0.00
10	5,100	5,031	5,031	5,031	5,031	7,116	35,580	35,086	40,949	1,233	1,427	2,491	29	25	16	1,893	4,527	6,420	1,962	4,951	6,913	1,051	4.51	10.78	15.29	4.67	11.79	16.46	2.50
11	3,000	10,841	10,841	10,841	10,841	7,408	38,007	42,000	42,000	6,524	6,541	3,128	6	6	13	3,993	0	3,993	0	0	0	0	9.51	0.00	9.51	0.00	0.00	0.00	0.00
12	8,400	8,400	8,400	8,400	8,400	7,24	42,00	42,00	42,00	4,10	4,10	2,77	1	1	1	0	0	0	0	0	0	0	0.0	0.00	0.00	0.0	0.00	0.00	0.0

						6	0	0	0	0	0	9	0	0	5								0			0			0
13	7,200	7,756	7,756	7,756	7,756	7,221	40,424	41,730	42,000	3,349	3,481	2,704	12	12	16	0	1,306	1,306	0	0	0	0	0.00	3.11	3.11	0.00	0.00	0.00	0.00
14	10,800	7,709	7,709	7,709	7,709	7,219	39,694	42,000	42,000	3,523	3,409	2,698	11	12	16	0	2,306	2,306	0	0	0	0	0.00	5.49	5.49	0.00	0.00	0.00	0.00
15	6,000	8,160	8,160	8,160	8,160	7,237	40,894	42,000	42,000	3,699	3,860	2,751	11	11	15	993	113	1,106	0	0	0	0	2.36	0.27	2.63	0.00	0.00	0.00	0.00
16	8,400	5,727	5,727	5,727	5,727	7,143	39,975	37,872	41,645	1,749	1,828	2,504	23	21	17	0	2,025	2,025	1,266	2,862	4,128	355	0.00	4.82	4.82	3.01	6.81	9.82	0.85
17	8,400	6,106	6,106	6,106	6,106	7,158	40,623	39,156	42,000	2,242	2,075	2,514	18	19	17	0	1,377	1,377	830	1,829	2,659	0	0.00	3.28	3.28	1.98	4.35	6.33	0.00
18	5,300	8,510	8,510	8,510	8,510	7,251	40,307	42,000	42,000	3,900	4,210	2,792	10	10	15	1,693	0	1,693	0	0	0	0	4.03	0.00	4.03	0.00	0.00	0.00	0.00
19	7,600	6,654	6,654	6,654	6,654	7,179	40,665	40,816	42,000	2,228	2,468	2,578	18	17	16	0	1,335	1,335	339	845	1,184	0	0.00	3.18	3.18	0.81	2.01	2.82	0.00
20	6,600	8,339	8,339	8,339	8,339	7,244	41,607	42,000	42,000	3,903	4,039	2,771	11	10	15	393	0	393	0	0	0	0	0.94	0.00	0.94	0.00	0.00	0.00	0.00
21	6,000	5,220	5,220	5,220	5,220	7,124	35,074	35,844	41,138	1,498	1,533	2,495	23	23	16	993	5,933	6,926	1,773	4,383	6,156	862	2.36	14.13	16.49	4.22	10.43	14.65	2.05
22	6,000	6,012	6,012	6,012	6,012	7,154	37,481	38,889	41,930	2,161	2,011	2,509	17	19	17	993	3,526	4,519	981	2,131	3,112	70	2.36	8.40	10.76	2.34	5.07	7.41	0.17
23	6,000	6,567	6,567	6,567	6,567	7,176	39,576	40,554	42,000	2,416	2,406	2,567	16	17	16	993	1,431	2,424	426	1,020	1,446	0	2.36	3.41	5.77	1.01	2.43	3.44	0.00
24	7,200	6,143	6,143	6,143	6,143	7,160	39,420	39,282	42,000	2,195	2,104	2,519	18	19	17	0	2,580	2,580	850	1,867	2,717	0	0.00	6.14	6.14	2.02	4.45	6.47	0.00
25	5,000	5,677	5,677	5,677	5,677	7,142	36,665	37,672	41,595	1,784	1,798	2,504	21	21	17	1,993	3,342	5,335	1,316	3,011	4,327	405	4.75	7.96	12.71	3.13	7.17	10.30	0.96
26	7,800	7,800	7,800	7,800	7,800	7,223	42,000	42,000	42,000	3,500	3,500	2,709	12	12	16	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	5,400	5,220	5,220	5,220	5,220	7,124	36,965	35,844	41,138	1,363	1,533	2,495	27	23	16	1,593	3,437	5,030	1,773	4,378	6,151	862	3.79	8.18	11.97	4.22	10.42	14.64	2.05
28	5,400	5,789	5,789	5,789	5,789	7,14	34,17	38,08	41,70	1,91	1,86	2,50	1	2	1	1,59	6,19	7,79	1,20	2,67	3,87	293	3.7	14.7	18.5	2.8	6.37	9.24	0.7

						6	4	4	7	1	9	6	8	0	7	3	7	0	4	5	9		9	5	4	7			0
29	4,800	6,153	6,153	6,153	6,153	7,160	35,976	39,312	42,000	2,170	2,111	2,519	17	19	17	2,193	3,831	6,024	840	1,848	2,688	0	5.22	9.12	14.34	2.00	4.40	6.40	0.00
30	3,800	6,326	6,326	6,326	6,326	7,167	35,525	39,831	42,000	2,384	2,235	2,540	15	18	17	3,193	3,282	6,475	667	1,502	2,169	0	7.60	7.81	15.41	1.59	3.58	5.17	0.00
Ave.	6,467	6,896	6,896	6,896	6,896	7,190	39,122	40,183	41,870	2,746	2,774	2,620	16	16	16	922	2094	3016	544	1399	1943	130	2.20	4.98	7.18	1.29	3.33	4.62	0.31

G1: Game one; G2: Game two; G3: Game three

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Table 4: The results of different groups

		Initial Target Inventory Level		Average Target Inventory		Average Inventory on site		Quantity of Shortage						Shortage Rate (%)					
Teams		G1	G2	G1	G2	G1	G2	G1			G2			G1			G2		
								A	B	A+B	A	B	A+B	A	B	A+B	A	B	A+B
Group A	2	7,000	6,858	6,858	6,858	2,452	2,613	0	1,835	1,835	136	439	575	0.00	4.37	4.37	0.32	1.05	1.37
	4	7,000	6,809	6,809	6,809	2,508	2,578	0	635	635	184	536	720	0.00	1.51	1.51	0.44	1.28	1.72
	9	9,000	6,973	6,973	6,973	2,871	2,695	0	616	616	20	208	228	0.00	1.47	1.47	0.05	0.49	0.54
	12	8,400	8,400	8,400	8,400	4,100	4,100	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
	13	7,200	7,756	7,756	7,756	3,349	3,481	0	1,306	1,306	0	0	0	0.00	3.11	3.11	0.00	0.00	0.00
	14	10,800	7,709	7,709	7,709	3,523	3,409	0	2,306	2,306	0	0	0	0.00	5.49	5.49	0.00	0.00	0.00
	16	8,400	5,727	5,727	5,727	1,749	1,828	0	2,025	2,025	1,266	2,862	4,128	0.00	4.82	4.82	3.01	6.81	9.82
	17	8,400	6,106	6,106	6,106	2,242	2,075	0	1,377	1,377	830	1,829	2,659	0.00	3.28	3.28	1.98	4.35	6.33
	19	7,600	6,654	6,654	6,654	2,228	2,468	0	1,335	1,335	339	845	1,184	0.00	3.18	3.18	0.81	2.01	2.82
	24	7,200	6,143	6,143	6,143	2,195	2,104	0	2,580	2,580	850	1,867	2,717	0.00	6.14	6.14	2.02	4.45	6.47
	26	7,800	7,800	7,800	7,800	3,500	3,500	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Ave.		8,073	6,994	6,994	6,994	2,792	2,805	0	1,274	1,274	330	781	1,110	0.00	3.03	3.03	0.78	1.86	2.64
Group B	1	6,600	7,403	7,403	7,403	3,071	3,103	393	197	590	0	0	0	0.94	0.47	1.41	0.00	0.00	0.00
	7	5,000	8,479	8,479	8,479	4,023	4,179	1,993	113	2,106	0	0	0	4.75	0.27	5.02	0.00	0.00	0.00
	11	3,000	10,841	10,841	10,841	6,524	6,541	3,993	0	3,993	0	0	0	9.51	0.00	9.51	0.00	0.00	0.00
	15	6,000	8,160	8,160	8,160	3,699	3,860	993	113	1,106	0	0	0	2.36	0.27	2.63	0.00	0.00	0.00
	18	5,300	8,510	8,510	8,510	3,900	4,210	1,693	0	1,693	0	0	0	4.03	0.00	4.03	0.00	0.00	0.00
	20	6,600	8,339	8,339	8,339	3,903	4,039	393	0	393	0	0	0	0.94	0.00	0.94	0.00	0.00	0.00
Ave.		5,417	8,622	8,622	8,622	4,187	4,322	1,576	71	1,647	0	0	0	3.76	0.17	3.92	0.00	0.00	0.00
Group C	3	6,600	6,316	6,316	6,316	2,186	2,228	393	4,042	4,435	677	1,521	2,198	0.94	9.62	10.56	1.61	3.62	5.23
	5	6,000	6,669	6,669	6,669	2,568	2,387	993	7,280	8,273	324	4,129	4,453	2.36	17.33	19.69	0.77	9.83	10.60
	6	6,000	6,561	6,561	6,561	2,360	2,402	993	613	1,606	432	1,033	1,465	2.36	1.46	3.82	1.03	2.46	3.49
	8	6,600	6,676	6,676	6,676	2,504	2,484	393	919	1,312	317	801	1,118	0.94	2.19	3.13	0.75	1.91	2.66
	10	5,100	5,031	5,031	5,031	1,233	1,427	1,893	4,527	6,420	1,962	4,951	6,913	4.51	10.78	15.29	4.67	11.79	16.46
	21	6,000	5,220	5,220	5,220	1,498	1,533	993	5,933	6,926	1,773	4,383	6,156	2.36	14.13	16.49	4.22	10.43	14.65
	22	6,000	6,012	6,012	6,012	2,161	2,011	993	3,526	4,519	981	2,131	3,112	2.36	8.40	10.76	2.34	5.07	7.41
	23	6,000	6,567	6,567	6,567	2,416	2,406	993	1,431	2,424	426	1,020	1,446	2.36	3.41	5.77	1.01	2.43	3.44
	25	5,000	5,677	5,677	5,677	1,784	1,798	1,993	3,342	5,335	1,316	3,011	4,327	4.75	7.96	12.71	3.13	7.17	10.30
	27	5,400	5,220	5,220	5,220	1,363	1,533	1,593	3,437	5,030	1,773	4,378	6,151	3.79	8.18	11.97	4.22	10.42	14.64
	28	5,400	5,789	5,789	5,789	1,911	1,869	1,593	6,197	7,790	1,204	2,675	3,879	3.79	14.75	18.54	2.87	6.37	9.24
	29	4,800	6,153	6,153	6,153	2,170	2,111	2,193	3,831	6,024	840	1,848	2,688	5.22	9.12	14.34	2.00	4.40	6.40
	30	3,800	6,326	6,326	6,326	2,384	2,235	3,193	3,282	6,475	667	1,502	2,169	7.60	7.81	15.41	1.59	3.58	5.17
Ave.		5,592	6,017	6,017	6,017	2,041	2,033	1,401	3,720	5,121	976	2,568	3,544	3.33	8.86	12.19	2.32	6.11	8.44

Table 5: Return on investment results

Teams	G1 Sale	VC	T	OE	NP	I1	ROI 1	I2	ROI 2
1 2	41,410	24,846	16,564	12,600	3,964.0	7,403.0	0.892	3,071.0	2.151
3 4	40,365	24,219	16,146	12,600	3,546.0	6,858.0	0.862	2,452.0	2.410
5 6	37,565	22,539	15,026	12,600	2,426.0	6,316.0	0.640	2,186.0	1.850
7 8	41,365	24,819	16,546	12,600	3,946.0	6,809.0	0.966	2,508.0	2.622
9 10	37,994	22,796	15,198	12,600	2,597.6	6,669.0	0.649	2,568.0	1.686
11 12	40,394	24,236	16,158	12,600	3,557.6	6,561.0	0.904	2,360.0	2.512
13 14	39,894	23,936	15,958	12,600	3,357.6	8,479.0	0.660	4,023.0	1.391
15 16	40,670	24,402	16,268	12,600	3,668.0	6,676.0	0.916	2,504.0	2.441
17 18	41,384	24,830	16,554	12,600	3,953.6	6,973.0	0.945	2,871.0	2.295
19 20	35,580	21,348	14,232	12,600	1,632.0	5,031.0	0.541	1,233.0	2.206
21 22	38,007	22,804	15,203	12,600	2,602.8	10,841.0	0.400	6,524.0	0.665
23 24	42,000	25,200	16,800	12,600	4,200.0	8,400.0	0.833	4,100.0	1.707
25 26	40,424	24,254	16,170	12,600	3,569.6	7,756.0	0.767	3,349.0	1.776

Teams	G2 Sale	VC	T	OE	NP	I1	ROI 1	I2	ROI 2
1 2	42,000	25,200	16,800	12,600	4,200.0	7,403.0	0.946	3,103.0	2.256
3 4	41,426	24,856	16,570	12,600	3,970.4	6,858.0	0.965	2,613.0	2.532
5 6	39,802	23,881	15,921	12,600	3,320.8	6,316.0	0.876	2,228.0	2.484
7 8	41,280	24,768	16,512	12,600	3,912.0	6,809.0	0.958	2,578.0	2.529
9 10	41,814	25,088	16,726	12,600	4,125.6	6,669.0	1.031	2,387.0	2.881
11 12	40,535	24,321	16,214	12,600	3,614.0	6,561.0	0.918	2,402.0	2.508
13 14	42,000	25,200	16,800	12,600	4,200.0	8,479.0	0.826	4,179.0	1.675
15 16	40,882	24,529	16,353	12,600	3,752.8	6,676.0	0.937	2,484.0	2.518
17 18	41,772	25,063	16,709	12,600	4,108.8	6,973.0	0.982	2,695.0	2.541
19 20	35,086	21,052	14,034	12,600	1,434.4	5,031.0	0.475	1,427.0	1.675
21 22	42,000	25,200	16,800	12,600	4,200.0	10,841.0	0.646	6,541.0	1.070
23 24	42,000	25,200	16,800	12,600	4,200.0	8,400.0	0.833	4,100.0	1.707
25 26	41,730	25,038	16,692	12,600	4,092.0	7,756.0	0.879	3,481.0	1.959

Teams	G3 Sale	VC	T	OE	NP	I1	ROI 1	I2	ROI 2
1 2	42,000	25,200	16,800	12,600	4,200.0	7,208.0	0.971	2,664.0	2.628
3 4	42,000	25,200	16,800	12,600	4,200.0	7,186.0	0.974	2,600.0	2.692
5 6	42,000	25,200	16,800	12,600	4,200.0	7,166.0	0.977	2,539.0	2.757
7 8	42,000	25,200	16,800	12,600	4,200.0	7,185.0	0.974	2,595.0	2.697
9 10	42,000	25,200	16,800	12,600	4,200.0	7,180.0	0.975	2,579.0	2.714
11 12	42,000	25,200	16,800	12,600	4,200.0	7,175.0	0.976	2,566.0	2.728
13 14	42,000	25,200	16,800	12,600	4,200.0	7,249.0	0.966	2,788.0	2.511
15 16	42,000	25,200	16,800	12,600	4,200.0	7,180.0	0.975	2,580.0	2.713
17 18	42,000	25,200	16,800	12,600	4,200.0	7,179.0	0.975	2,614.0	2.678
19 20	40,949	24,569	16,380	12,600	3,779.6	7,116.0	0.885	2,491.0	2.529
21 22	42,000	25,200	16,800	12,600	4,200.0	7,408.0	0.945	3,128.0	2.238
23 24	42,000	25,200	16,800	12,600	4,200.0	7,246.0	0.966	2,779.0	2.519
25 26	42,000	25,200	16,800	12,600	4,200.0	7,221.0	0.969	2,704.0	2.589

27 28	39,694	23,816	15,878	12,600	3,277.6	7,709.0	0.709	3,523.0	1.551	42,000	25,200	16,800	12,600	4,200.0	7,709.0	0.908	3,409.0	2.053	42,000	25,200	16,800	12,600	4,200.0	7,219.0	0.970	2,698.0	2.595
29 30	40,894	24,536	16,358	12,600	3,757.6	8,160.0	0.767	3,699.0	1.693	42,000	25,200	16,800	12,600	4,200.0	8,160.0	0.858	3,860.0	1.813	42,000	25,200	16,800	12,600	4,200.0	7,237.0	0.967	2,751.0	2.545
	39,975	23,985	15,990	12,600	3,390.0	5,727.0	0.987	1,749.0	3.230	37,872	22,723	15,149	12,600	2,548.8	5,727.0	0.742	1,828.0	2.324	41,645	24,987	16,658	12,600	4,058.0	7,143.0	0.947	2,504.0	2.701
	40,623	24,374	16,249	12,600	3,649.2	6,106.0	0.996	2,242.0	2.713	39,156	23,494	15,662	12,600	3,062.4	6,106.0	0.836	2,075.0	2.460	42,000	25,200	16,800	12,600	4,200.0	7,158.0	0.978	2,514.0	2.784
	40,307	24,184	16,123	12,600	3,522.8	8,510.0	0.690	3,900.0	1.505	42,000	25,200	16,800	12,600	4,200.0	8,510.0	0.823	4,210.0	1.663	42,000	25,200	16,800	12,600	4,200.0	7,251.0	0.965	2,792.0	2.507
	40,665	24,399	16,266	12,600	3,666.0	6,654.0	0.918	2,228.0	2.742	40,816	24,490	16,326	12,600	3,726.4	6,654.0	0.933	2,468.0	2.516	42,000	25,200	16,800	12,600	4,200.0	7,179.0	0.975	2,578.0	2.715
	41,607	24,964	16,643	12,600	4,042.8	8,339.0	0.808	3,903.0	1.726	42,000	25,200	16,800	12,600	4,200.0	8,339.0	0.839	4,039.0	1.733	42,000	25,200	16,800	12,600	4,200.0	7,244.0	0.966	2,771.0	2.526
	35,074	21,044	14,030	12,600	1,429.6	5,220.0	0.456	1,498.0	1.591	35,844	21,506	14,338	12,600	1,737.6	5,220.0	0.555	1,533.0	1.889	41,138	24,683	16,455	12,600	3,855.2	7,124.0	0.902	2,495.0	2.575
	37,481	22,489	14,992	12,600	2,392.4	6,012.0	0.663	2,161.0	1.845	38,889	23,333	15,556	12,600	2,955.6	6,012.0	0.819	2,011.0	2.450	41,930	25,158	16,772	12,600	4,172.0	7,154.0	0.972	2,509.0	2.771
	39,576	23,746	15,830	12,600	3,230.4	6,567.0	0.820	2,416.0	2.228	40,554	24,332	16,222	12,600	3,621.6	6,567.0	0.919	2,406.0	2.509	42,000	25,200	16,800	12,600	4,200.0	7,176.0	0.975	2,567.0	2.727
	39,420	23,652	15,768	12,600	3,168.0	6,143.0	0.860	2,195.0	2.405	39,282	23,569	15,713	12,600	3,112.8	6,143.0	0.845	2,104.0	2.466	42,000	25,200	16,800	12,600	4,200.0	7,160.0	0.978	2,519.0	2.779
	36,665	21,999	14,666	12,600	2,066.0	5,677.0	0.607	1,784.0	1.930	37,672	22,603	15,069	12,600	2,468.8	5,677.0	0.725	1,798.0	2.288	41,595	24,957	16,638	12,600	4,038.0	7,142.0	0.942	2,504.0	2.688
	42,000	25,200	16,800	12,600	4,200.0	7,800.0	0.897	3,500.0	2.000	42,000	25,200	16,800	12,600	4,200.0	7,800.0	0.897	3,500.0	2.000	42,000	25,200	16,800	12,600	4,200.0	7,223.0	0.969	2,709.0	2.584
	36,965	22,179	14,786	12,600	2,186.0	5,220.0	0.698	1,363.0	2.673	35,844	21,506	14,338	12,600	1,737.6	5,220.0	0.555	1,533.0	1.889	41,138	24,683	16,455	12,600	3,855.2	7,124.0	0.902	2,495.0	2.575
	34,174	20,504	13,670	12,600	1,069.6	5,789.0	0.308	1,911.0	0.933	38,084	22,850	15,234	12,600	2,633.6	5,789.0	0.758	1,869.0	2.348	41,707	25,024	16,683	12,600	4,082.8	7,146.0	0.952	2,506.0	2.715
	35,976	21,586	14,390	12,600	1,790.4	6,153.0	0.485	2,170.0	1.375	39,312	23,587	15,725	12,600	3,124.8	6,153.0	0.846	2,111.0	2.467	42,000	25,200	16,800	12,600	4,200.0	7,160.0	0.978	2,519.0	2.779

	35,525	21,315	14,210	12,600	1,610.0	6,326.0	0.424	2,384.0	1.126	39,831	23,899	15,932	12,600	3,332.4	6,326.0	0.878	2,235.0	2.485	42,000	25,200	16,800	12,600	4,200.0	7,167.0	0.977	2,540.0	2.756
Ave.	39,122	23,473	15,649	12,600	3,049.0	6,896.1	0.736	2,745.8	1.966	40,183	24,110	16,073	12,600	3,473.1	6,896.1	0.834	2,773.6	2.190	41,870	25,122	16,748	12,600	4,148.0	7,190.2	0.961	2,619.9	2.644

Sale: Actual Sales Volume; VC: Variable Cost; T: Throughput; OE: Operating Expenses; NP: Net Profit;
I1: Average Target Inventory (on site + on route); ROI1: ROI Based On Average Target Inventory; I2: Average On-site inventory; ROI2: ROI Based On Average Inventory On-site

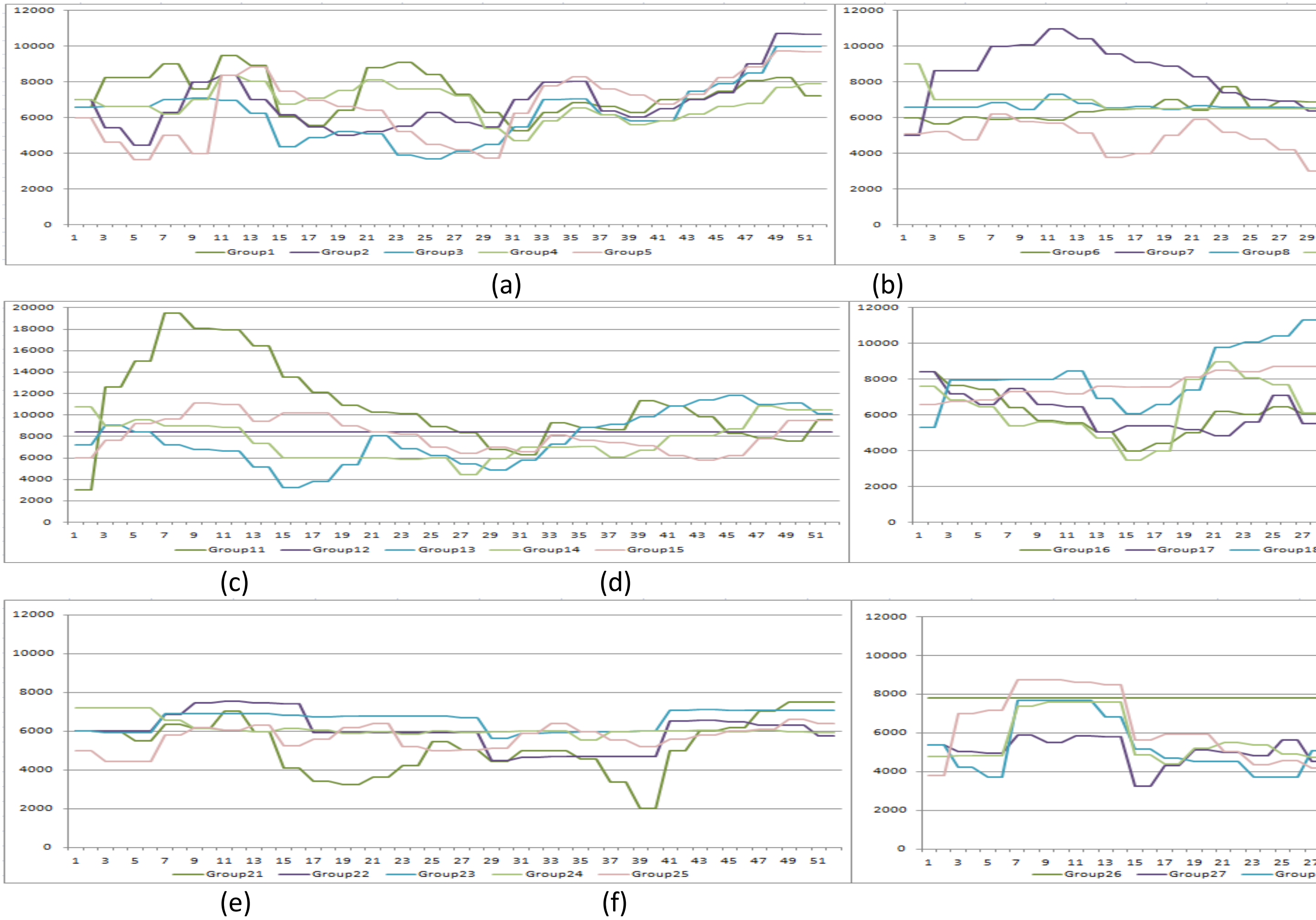

Figure 1: The pattern of the target level of inventory of thirty teams: (a) teams1-5, (b) teams 6-10, (c) teams 11-15, (d) teams 16-20, (e) teams 21-25, (f) teams 26-30