Applying Theory of Constraint on Logistic Management in Large Scale Construction Sites ~ A Case Study of Steel Bar in TFT-LCD Factory Build-Up

Chih-Yao Huang[1], Ching-Piao Chen[2], Rong-Kwei Li[1] and Chih-Hung Tsai[2†]

[1]Department of Industrial Engineering and Management
National Chiao-Tung University, Hsinchu, Taiwan, ROC

[2]Department of Industrial Engineering and Management
Ta-Hwa Institute of Technology
1 Ta-Hwa Road, Chung-Lin
Hsin-Chu, Taiwan, ROC
Tel: +886-3-5927700~2953
E-mail: ietch@thit.edu.tw

Abstract

The steel bars account for a high percentage of material costs for the current construction projects. At the present time, most of the construction projects for the factories of thin-film transistor liquid crystal display (TFT-LCD) complete the transactions of steel bars when the suppliers ship the steel bars to the temporary storage/processing sites. This paper applies the buy-in concept in the Theory of Constraint (TOC) on the supply chain of steel bars. In this study, suppliers are required to establish warehouses at the construction sites and complete the transactions when the formed and processed steel bars are shipped into the factory sites. The aim is to find a win-win solution to meet with the expectations from constructors as they hope that there is no need to build up inventories but supply is ready at any time. Also, this paper compares and analyzes the traditional supply/inventory model of steel bars and the Demand-Pull (D-P) model under the TOC framework. It is proved that Vendor Management Inventory (VMI) in the D-P model is able to more effectively manage steel bars as a material.

Key Words: Theory of Constraint, Steel Bar, Thin-film Transistor Liquid Crystal Display (TFT-LCD)

1. Introduction

With the efforts from the government to boost the development of the economy over the recent years, the relevant industries have been booming with constant upgrades and progress.

† Corresponding Author

The government has been, in particular, supportive of the development of technology-intensive and capital-intensive high tech industries. The most well-known industry development policy is "The Two Trillion, Twin Stars Plan." In essence, this project aims to boost the production values of the semiconductor and image display industries to over NT$1 trillion, respectively, and to develop the digital contents and biotechnology industries as the rising stars. Therefore, since 2002, AU Optronics Corp. decided to riding on the wave and started to build its 5.5th generation factories in Aspire Park, Lung-Tan, Tao-Yuan, Taiwan. In 2003, it kicked off the project for the construction of 6th generation factory in Taichung. In 2004, it commenced the project for 7.5th generation. In 2007, AU Optronics Corp. started its plan to establish the first 8th generation factory. The scale of the factory build-ups went from approximately NT$5 billion for the 5.5th generation projects (based on the value of civil engineering contracts), NT$10 billion for the 6th generation projects, NT$15 billion for the 7.5th and 8th generation projects. The typical timeframe per project has been locked at 14 months, but the scale has been growing one generation after another. The pressure for AU Optronics Corp. to keep up with the schedules has also been mounting one factory after another, in particular in the face of the competition from Samsung and LG. Given the limited resources, the only way to achieve time-to-market for new products is to squeeze the factory construction process to make it quicker than that in Korea. Chi-Mei Optoelectronics in Taiwan is in the same boat. The large scale construction sites referred to by this paper are defined as the construction sits for TFT-LCD and 12-inch wafer factories on large sites. In particular, on the basis of the scale of AU Optronics Corp.'s projects for its new-generation TFT-LCD factory build-ups, it is no doubt the world No. 1 in terms of its relative scale in total quantity and schedule.

Theory of Constraint (TOC) has been widely applied in various domains (1~5) and the results have been impressive. Therefore, if the TOC thinking and methodology can be applied to the management of materials and supplies for the large-scale technology factory projects with the establishment of Vendor Management Inventory (VMI) solutions, the effects are expected to be different from the past. It is also expected to trigger another wave and rounds of discussions (6, 7, 9~15), and change the current prevalent model in the management of steel bars as a material. The current model is as follows: the shipment is based on the determined schedule and the inventory is built up based on the rule of the thumb at the steel bar processing sites established by constructors. However, the schedule is a combination of a series of uncertain factors. Even if the schedule is regularly updated, it is just a new estimate of the shipments based on the old data. This operational model generally results in the two possible phenomena. One is a lack of inventory or materials in transition. This affects the shipments, and as a result, the effective output. The other is an excessive inventory and the resultant increase in costs. Due to the inaccuracy of information, suppliers can only run about to meet with the changing demands. In particular, as the average prices of steel bars have been steadily rising, the impacts are also increasingly widespread. Given the growing competition in the market, the pressures from customers for price reductions have been mounting. The effective management of steel bars, which account for a high percentage of costs, will undoubtedly enhance the effectives of site management and bring about noticeable results.

The jumbo scale projects of factor build-ups are compressed for time and highly complex in engineering. Steel bars are a major building material. They do not only account for a high percentage of costs, but are also highly relevant to the project progress. The proper logistics of the materials requires a new thinking pattern and model in planning and management. The scale of factory constructions increases one generation after another, yet the timeframes can only be shortened (8). Therefore, to ensure the robust logistics of materials in order to reduce costs, assure project progress and properly manage the construction sites, this paper applies the VMI concepts and methods under the TOC framework. It uses the build-up of AU Optronics Corp.'s 7.5^{th} generation TFT-LCD factory as a case study so as to compare and validate the current supply management model and TOC Demand-Pull model for the supply of steel bars. The results show that both IDD and TDD methods report significantly fewer times of supply shortage than the current model.

In addition, this paper incorporates the buy-in concept under the TOC framework by convincing the suppliers of steel bars to establish inventories at the building sites, in order to stay close to the demands. It is expected that this approach in the steel bar management breaks away from the tradition by guaranteeing the effective outputs. It is hoped to create a win-win model in which the suppliers do not have to establish high levels of inventory and the constructors do not have to build up their own inventory so as to enhance the construction effectiveness. The TOC thinking is, "What can be improved? To what should it be improved? How can these improvements be executed effectively and gradually?" The approach to see one issue and solves one issue is discarded, because it ignores the essence of the problems. This paper applies the TOC concepts and uses the Demand-Pull supply model for the steel bars of the TFT-LCD factory construction projects. The purposes of the case study are to validate and analyze. Suppliers of steel bars are asked to establish inventories at the construction sites in order to create a win-win outcome.

Research Scope and Limitations: Up to the present, there is little literature addressing the VMI under the TOC framework in the material management of large scale construction projects. Therefore, despite its efforts to assure robustness and thoroughness, this paper experiences the following limitations:

1. Two commodity steel bars, i.e. #8 and #10, are selected to go through the validation process. This paper does not take into consideration the steel bars supplied in small quantities and of special specifications.
2. As large factory construction projects similar with AU Optronics Corp. or 12-inch wafer plants have only been active in progress in Korea and Taiwan over the past years,

there have limited relevant discussions. It is difficult to avoid any losses or misses in terms of data collation.

3. Most construction projects, such as large public works or small-and-medium construction projects, have already developed fixated management models. Their unit time/scale tends to be smaller too. Therefore, the conclusion drawn by this paper if applied to the usual projects may not report any immediate and noticeable improvements.
4. In the empirical analysis of the case study, this paper finds it hard to avoid the subjective judgment, despite its efforts to perform the analysis and empirical study in an objective manner to avoid any bias.
5. This paper performs its measurements from the perspectives of the customers, rather than the overall reviews of the complete supply chain. Therefore, the conclusion of this study may be different from the viewpoints of the suppliers in the upper stream.

2. Examinations of Current Management Method of Steel Bars

2.1 Background and Snapshot of Current Situations

The supply and demand in the steel bar market worldwide have been affected with the rise of emerging markets (China and India) and the drastic fluctuations of commodity and material prices. In Taiwan, 921 Earthquake has also altered the structural designs of domestic architectures. The domestic real estate market has experienced a boom after SARS. The awareness on the construction safety has been rising too. All these factors have been affecting the supply-demand structure among constructors, steel bar suppliers and formwork providers/assemblers. The fluctuations of steel prices have not only impacted on the steel plants in terms of access to raw materials, production planning and inventory changes, but also altered the contents of existing contracts between constructors and steel-bar assemblers. Constructors no longer purchase bulks in order to reduce attrition rates. Assemblers transfer the costs of cutting and forming onsite to steel bar manufacturers. However, up to the present the ordering procedures at most sites have not changes with the market. The logistics personnel at large construction sites should understand not only the work status of the sites, scheduled material consumptions and planned shipments of materials, but also the production flows, inventory levels, transportation adjustments of steel bars and the fluctuations of materials and commodities, in order to effective manage steel bars to reduce costs and enhance competitiveness. In particular, a large-scale construction project consumes 50,000~60,000 metric tons of steel bars. If the logistics is well managed to reduce the consumption by 1~2%, there can be a reduction of costs by approximately NT$10~20 million. Also, well-managed logistics can also achieve greater benefits with the reduction in interest expenses and transportation charges.

2.2 Current Policies in Management of Steel Bars as Material

In the construction site of the case study, this paper finds that usually the supervisors of individual sites will directly assign one or several people to manage the steel bars. The scope covers the traditional flows, i.e., the arrangement of material orders, ordering, receiving, storage, processing, and shipments to the sites. As the construction sites in the case study follow the traditional flows to manage the supply and inventory of steel bars, they are usually confronted with the problems that when in urgent need of supplies, the replenishment takes too long or is simply not reliable. Ordering is made pursuant to the original schedule; however, the progress is subject to the influence of all factors and changes are dynamic. Therefore, ordering in accordance with the schedule leads to either an absence of the wanted goods or the excessive inventory of unwanted goods and overcrowded warehouses. Therefore, managers are always bogged down in taking care of this "important mission." It is not difficult to image the results of this fire-fighter type of management. Below is a detailed explanation of the current situation:

2.2.1 Current Situations of Steel Bar Storage Sites

Large-scale construction projects establish temporary steel bar processing venues or storage premises close to the construction sites. However, the hardware facilities of such locations are usually insufficient and none of the construction companies have standardized these locations. Therefore, they are often neglected. Some of the flooring in these locations is not even polished. Although the ISO regulations stipulate that the floors have to be raised, some steel angles are used as make-shift padding. Due to a prior planning, the steel bars are placed messily and it is difficult to keep the traffic lines clear. As a result, some of the inventory is pushed to the back and damaged goods increase. It is not possible to access the steel bars that are needed. What is worst is that workers are asked to get whatever they can

Figure 1. Current Facilities at Steel Bar Sites

reach to meet the urgent demands, or new orders are placed with suppliers. All these are the main factors that cause overly high attrition rates. Because each building is responsible for its own steel bars, there are no consistent policies or regulations. The usual problem is that assemblers access steel bars at will by moving, processing or placing them around. As a result, the steel bar sites are messy and chaotic, as if there were seven buildings responsible for seven construction sites. This causes inefficiency and a waste of resources (Figure 1).

2.2.2 Current Flowchart of Steel-Bar Supply

Figure 2 illustrates the current supply/inventory management model of steel bars as follows:

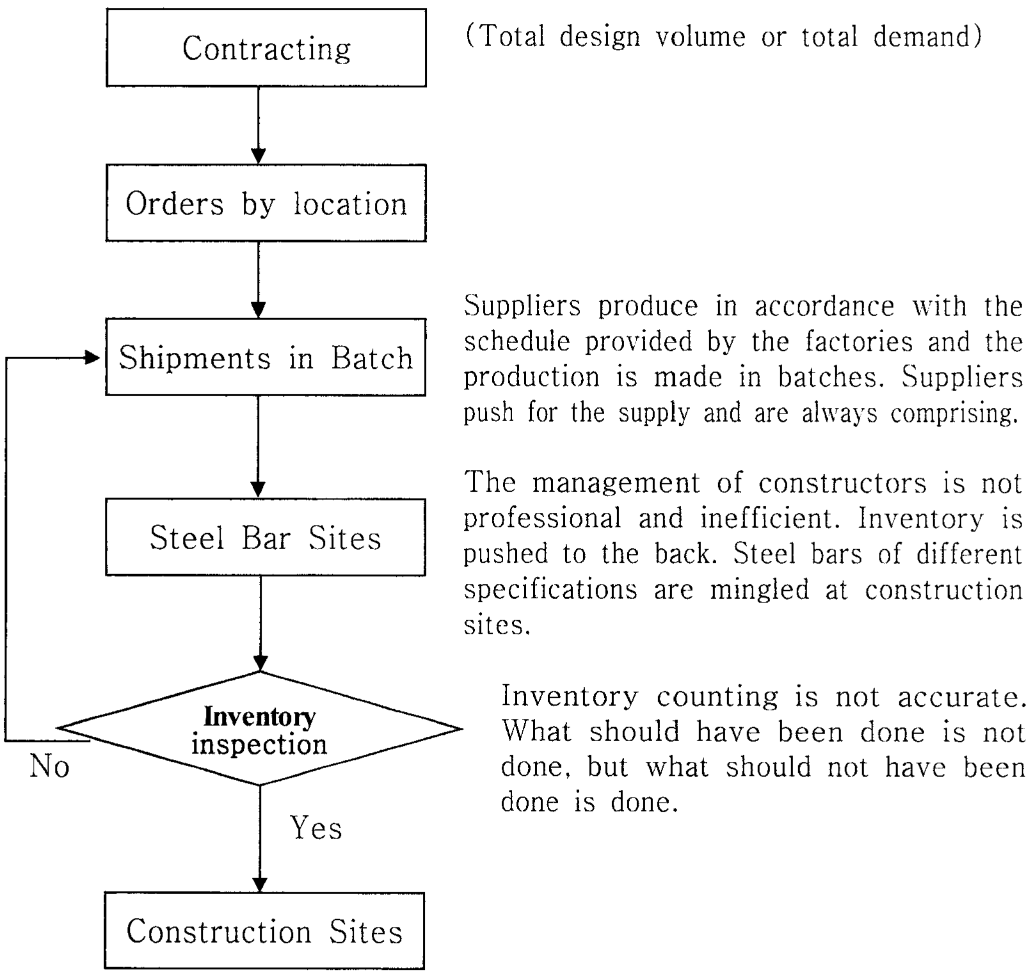

Figure 2. Flowchart: Current Steel Bar Supply/Inventory Management

According to this flowchart, the supply/inventory is projected in accordance with the schedules of individual buildings or locales and the total demands. Usually, it is jointly determined by the suppliers and engineer-in-chief and the professional subcontractors working for individual buildings. Below is a description of the process: (1) Planning is made in accordance with the schedule. Material lists for different locales are made in the preparatory stage. Orders for individual locales are also made; (2) Negotiations with suppliers are made to determine the schedule of batch shipments and quantities (pursuant to the contract and at least 25T); (3) Suppliers schedule their productions (1 cycle every 2 weeks) and inventory in order to deliver the orders; (4) Steel bars are shipped (1~2 days) to the storage/processing premises of the construction sites; (5) Subcontractors ship the steel bars to the construction sites for engineering work; (6) When there may be insufficient inventory or a shortage, efforts are made to speed up shipments/supplements from suppliers; (7) Back to Step (3).

2.2.3 Examinations on Supply/Inventory of Steel Bars

(1) Contract with Suppliers for Construction Projects: The main contents of the contract are the unit prices, quantities, total prices and final shipment dates. The detailed shipments, batches and scheduling are determined by the construction sites and the suppliers. However, the contract specifies the following: the deadline of the following shipment is A; SD420W for random-length bars is 7 days; B. For fixed-length bars (including large and small), it is 14 days; C. For large-sized bars, such as D22, D29, D36, it is 25 days. In case of a delay, there will be other procedures.

(2) Batch Orders: Currently, the personnel in charge of procurement often follow the original schedule in order placements, by directly referring to the batch orders from the subcontractors. Therefore, the production capacity of suppliers is not taken into consideration. Planning in batch ordering and measuring, transportation and temporary storage is not done in accordance with the actual progress of the construction sites. It is not difficult to imagine the resulting inefficiency.

(3) Collection/Storage: When it comes to the collection and storage of steel bars, nothing is systematic from arriving schedules, due to unprofessional management, a lack of regulations on standardization, weighing procedures and order placements for steel bar sites or construction sites. All is done by the personnel in charge for individual buildings by coordinating with subcontractors. Steel bars are stacked in a messy manner. There is no effective method to tell new shipments, order shipments or spare supplies, let along the effective differentiation of steel bars of various sizes and numbers.

(4) Shaping Process: Due to a lack of systematic approach in the inventory, the shaping process of steel bars is based on the one-sided decisions from the subcontractors. Suppliers continue to churn out the steel bars but not totally in line with the demands from the construction sites. The finished goods at the processing sites are also placed in a chaotic manner. Therefore, the total demand in quantities or the required processed outputs at each stage are not effectively controlled. In addition, there is more than one

subcontractor and they are not well disciplined. This makes the situation at the processing sites worse. The outcome is always that there is a lack of space, subcontractors do not follow instructions and not disciplined, or there is no way to inspect inventory.

2.2.4 Changed Expectations

Due to high uncertainties in the construction projects, in order to keep up with the schedule (to guarantee the effective outputs), construction sites have to establish inventory of materials. This is why the management of steel bars is a problem. In particular, large-scale tech factory projects that have extremely tight schedules need to shore up a sufficient inventory of materials to ensure the engineering progress. However, as the valuations of any projects are the combination of a series of uncertainties, the prior scheduling and planning of material suppliers mostly fail to function properly. Inventory is either insufficient or in excess. If the supply is insufficient, the replenishment cycle is approximately 14 days, which seriously hampers the engineering progress. If the supply is in excess, the management costs skyrocket. What is worst is that unsuitable inventory will even become wastes. This has been going on for years and little has changed. For a single construction site and a project that demands a total of over 60,000 tons of steel bars, a simple improvement will result in significant effects.

For most engineering managers, the management of steel bars and steel bar sites is undoubtedly a puzzle. Also, senior managers are usually unwilling to invest in the deployment or management in this regard. The mainstream idea is to save as much as they can. The engineers in charge of steel bars are often burdened with heavy responsibilities but their performances are easily seen; therefore, they do not have any enthusiasm on their jobs. Also, the management of steel bars is roughly based on experience, but experience is often insufficient. From the mangers' point of view, the more efficient inventory, the better. This does not only save considerable rents on land, but also a huge sum of interest expenses. The best status is "no need to build inventory but supply is always ready." If the VMI System for the supply of steel bars can be applied with the appropriate ideas and methods, it will surely be a blessing for the managers of steel bars.

3. TOC Management and System Design for Steel Bar Supply

This paper adopts the distribution model in the TOC framework proposed by Dr. Goldratt to analyze the feasibility of storage of steel bars at construction sites. TOC believes that the traditional approach to place inventory as much as possible at the warehouses close to clients to cope with the changes of market demands is likely to generate higher inventory and cost. Therefore, it is suggested that inventory should be kept at the source of the supply. Pull should be used to replace the traditional "push" distribution method. The inventory at the regional warehouse is recommended to maintain at a level equal to "average demand plus safe inventory" based on the distribution time from the central warehouse to regional warehouse. Also, the inventory at the central warehouse should also equal to the level of "demand plus safety inventory" on the basis of the time to produce the goods from materials. This approach makes it easier to cope with the fluctuations of market demands in a flexible manner. It does not only satisfy the demand from customer, but also reduces unnecessary inventory. This chapter applies the three important thinking steps proposed by Dr. Goldratt, i.e. what to change, what to change to and how to cause it to change.

3.1 What To Change?

3.3.1 Who should build the inventory?

Traditionally, steel bars are supplied by suppliers on the basis of orders from construction sites (from constructors). They ship the steel bars according to the specifications and deadlines stated in the contract to the steel bar sites so that the construction sites can use them. In other words, the construction sites build their own inventory. However, inventory increases many costs and is difficulty to manage. Therefore, it is hoped that suppliers should build inventory at the construction sites. With their professional expertise in the management of warehouses, they can establish "regional warehouses" at the construction sites by applying the concept of "buy-in" to alter the original supply model, as shown in Figure 3.

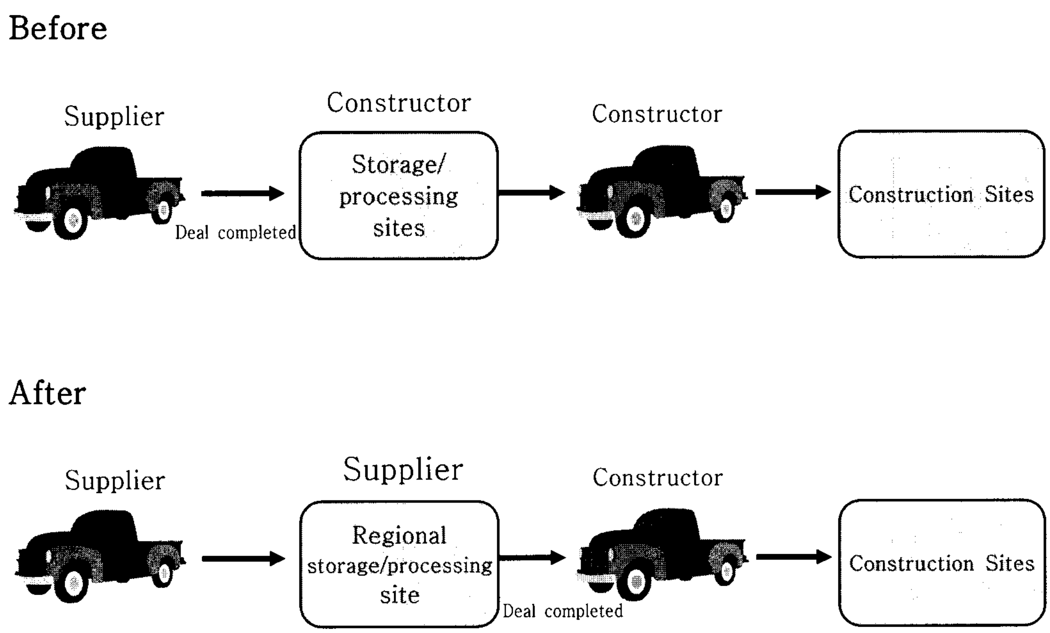

Figure 3. Supply Model after the Changes

This outcome brings the following benefits to constructors: (1) No need to build up inventory means a reduction in investment, a relief on capital flow and zero attrition rate; (2) Elimination of management cost associated with the steel bar sites (including software, hardware, manpower and security); (3) More reliable, convenient and efficient in accessing inventory; (4) Possible to constantly monitor the levels of inventory; (5) Introduction of more professional and efficient warehousing/processing model (e.g.: Tung-Ho Steel Enterprise Corp.'s Dali Regional Warehouse, Figure 4).

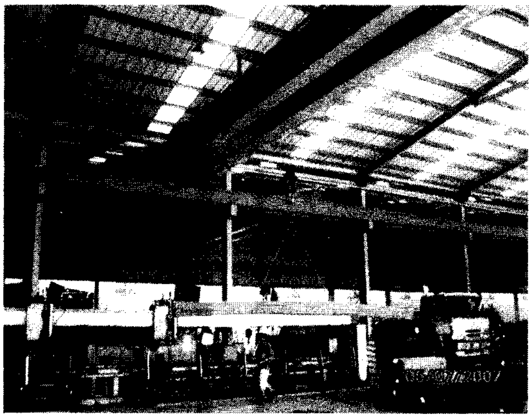

Figure 4. Tung-Ho Dali Regional Warehouse (Source: Tung-Ho Steel Enterprise Corp.)

3.1.2 How to Change Supply Model?

The orders and shipments under the current supply model are based on the existing schedule. As progress is a combination of a series of uncertainties and the changes of progress is dynamic, inventory is either unable to correctly meet with the demand from the construction sites or in excess due to changes of designs or progress scheduling. There is no ready supply of wanted goods, but there are piles of unwanted goods. This paper intends to break through from the traditional supply model by adopting the Demand-Pull supply model under the TOC framework with the actual usage as the indicator to supply. This approach will enable demand to better reflect the reality and maintain more flexibility for construction sites in order to enhance efficiency and reduce costs.

3.2 What To Change To?

The construction sites have to establish high levels of inventory to ensure the supply. However, they also believe that the costs need to be reduced by bringing down the levels of inventory. These two obviously contract each other, as shown in the Conflict Cloud in Figure 5 below.

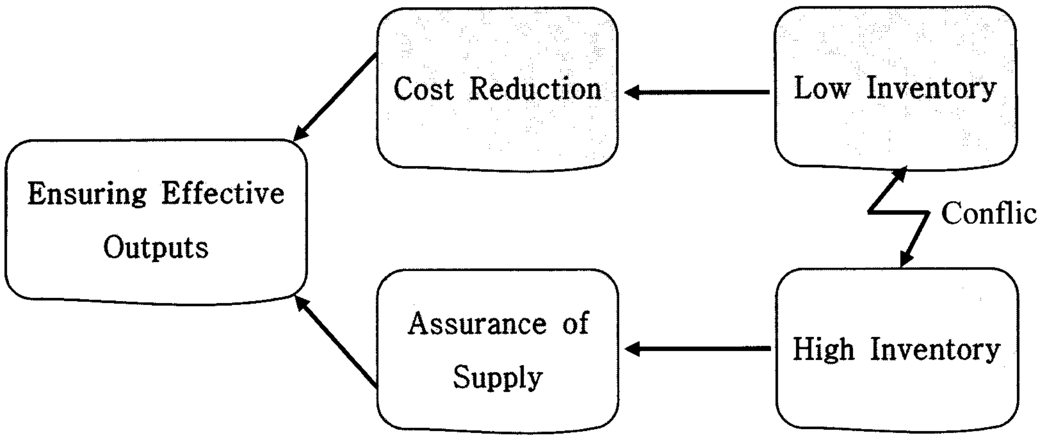

Figure 5. Conflict Cloud

In order to boost the profits for the construction sites, it is necessary to reduce costs. It is also required to avoid a waste of materials and to take the burden off the management costs. Therefore, the lower the inventory, the better it is. On the other hand, in order to guarantee effective outputs, it is necessary to assure punctual supplies. Therefore, there must be sufficient inventory to cope with potential uncertain factors. In the above conflict cloud, there are two premises that need to be resolved. Steel bar storage sites are hard to manage. The management cost is high but inefficient. The management functions are lacking in professional knowledge in management. Does it have to be constructors that deploy the steel bar sites to stack up inventory? What indicators should be used to determine the levels of inventory is closer to the reality, rather than just an experience value or the result of an inaccurate supply estimate? Is it possible to find a win-win strategy that reduces costs, guarantee supply and assure effective outputs? These are the targets this paper would like to achieve. Generally speaking, it is to achieve the target for constructors that there will be no need to build inventory but access to supply is secured.

According to Figure 6, the core issue and assumption are that in order to guarantee the effective outputs, constructors have to establish steel bar storage/processing sites near the construction sites and build up inventory in order to assure the progress of engineering work. However, the inefficient management of the steel bar sites increase inventory and results in a rise in management costs. However, why must constructors build up inventory? If the situation permits, can suppliers set up, with special licenses, regional warehouses to shore up inventory of steel bars at construction sites? In that case, constructors no longer have to establish inventory at construction sites, but have access to inventory to guarantee their effective outputs? What kind of responding measures are required to trigger such changes? Can a win-win strategy be found so that both constructors and suppliers benefit? If there are no professional managers at constructors to manage the steel bar storage sites, can

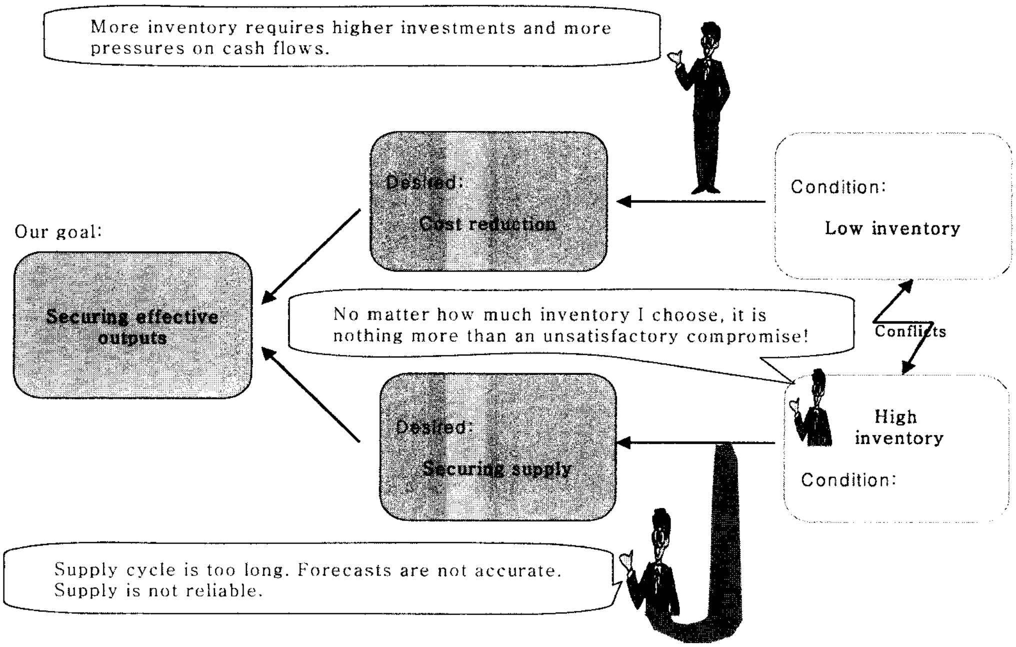

Figure 6. Details of Conflict Cloud

the model where professional suppliers manage the steel bars with their existing regional distribution/processing centers break the established false idea that the steel bar sites cannot be effectively managed? What are the tools or methods to measure the appropriate levels of inventory? Can the introduction of the TOC distribution model to establish the VMI model lead to the effective management of inventory?

In the case of large-scale TFT-LCD factory construction sites, in order to meet with the demand from customers, suppliers should deploy warehouses nearby and establish inventory to provide better supply services. This is to change from the original push to the pull model of supply and inventory so that constructors no longer need to establish inventory but their access to inventory is assured. Let us use the Five Focus Steps of TOC to analyze the supply/distribution of steel bars. The first step is to identify the system constraint, which dominates the effective output of the system. What is the factor that decides the system's effective output? The engineering progress is the system constrain. The faster the progress, the payment comes at a larger sum and a quicker pace. If it is not possible to meet with the engineering demands, it is running against the exploitation of the constraint. The second step is to exploit the constraint, i.e. to make the most out of it. Simply put, it is to store the level of steel bars at the right place and at the right time to meet with the engineering demand. The third step is to subordinate everything to the above decision. How can the supply of steel bars be managed so as to assure the right levels of inventory at the right place and at the right time? Obviously, the levels of inventory are in proportion with the consumption in engineering, but that is not the only factor. Replenishment time is an equally important factor. The longer it is, the more inventory required by the construction sites. Therefore, the conclusion is that construction sites should order on the basis of target levels of inventory, i.e. the consumption during a replenishment cycle.

Replenishment time = order lead time + production lead time + transportation lead time. Frequent ordering and frequent delivering can shorten order lead time. For example, we can make a monthly order by placing an order for 1/4 quantity per week. Nonetheless, we all understand that consumption and replenishment time are changeable. When demand exceeds the average consumption, the unreliability with replenishment time should also be taken into consideration in order to avoid a shortage of supply. In this way, the inventory at construction sites is equal to the target level of inventory. The explanation is as follows: The key parameters to determine the target levels of inventory are consumption, replenishment time, variables of consumption and variables of replenishment. Replenishment time is the key factor that determines the target levels of inventory! Both consumption and replenishment time directly affect the target levels of inventory, but replenishment time also has indirect influence as follows: (1) The longer the forecast horizon, the lower the forecast accuracy becomes. The longer the replenishment time, the greater the variables of consumptions become; (2) Under most circumstances, the longer the replenishment time, the greater the variables of replenishment time becomes. Therefore, if the replenishment time is doubled, the target levels of inventory will more than double!

Below is the list of parameters in the D-P model:

Target inventory = $(P+F) \times u + Z_{\alpha} \times \sqrt{(P+F)} \times \sigma$

P: Lead time (lead time required to manufacture and ship steel bars).

F: Replenishment frequency.

$(P + F)$: Replenishment lead time.

Z_a = Service standards.

μ = Average demands.

σ = Demand variance.

High levels of inventory imply high investments and more pressures on cash flows. More obsolete inventory also leads to high levels of inventory and a sharp rise in costs. In fact, the inventory of necessary supply turns out to be zero; while other supply may be able to last a year. In order to resolve the conflicts between effective outputs and inventory, we have to find a solution that is able to guarantee effective outputs but does not require the establishment of high levels of inventory.

3.3 How to Cause it to Change?

3.3.1 Supplier to Establish Inventory at Construction Sites

The inventory is no longer maintained by constructors. Rather, the supplier will take over. This brings about great advantages to constructors, but is it an attractive offer to the supplier? Firstly, let us examine that the supplier will be faced with what cost concerns or extra burdens during the flows:

(1) Increase of investment in a distribution/storage/processing site.
(2) There is no business case if the scale and operating lifespan do not reach any economies of scale.
(3) Are the contracts determined on unit prices eventually?
(4) How both parties share the benefits?
(5) Can the supplier supply to other clients?

If we are to follow the thinking process of TOC, only by creating a win-win solution can lead to full cooperation from both parties. This paper uses AU Optronics Corp.'s TFT-LCD G7.5 Construction Project and its supplier, Tung-Ho Steel Enterprise Co. as a case study to examine how both parties reach a win-win strategy with the supplier agreeing to establish inventory at construction sites. Below is the interview with the assistant manager in business development of Tung-Ho Steel Enterprise Corp. and the constructor who discuss the process and key issues in this project.

(1) Question: From our (Tung-Ho Steel Enterprise) point of view, we basically regard this as a buy-in and are willing to accommodate because you (our client) makes such a request.
Answer: AU Optronics Corp.'s TFT-LCD G7.5 Construction Project in Central Taiwan Science Park demands approximately 60,000 tons of steel bars (NT$1.2 billion) for each factory. There are three more factories under planning at Howli. We have sufficient bargaining power to make such a request.
(2) Question: The capital expenditure from Tung-Ho for one regional warehouse costs at least NT$15 million. Who should pay for the extra cost?
Answer: In the past, our construction sites had a budget for the capital investment of steel bar storage warehousing/processing site. In fact, our site is larger than any regional warehouse of Tung-Ho, because it is used inefficiently. The investment amount was also about NT$15 million. Therefore, this problem may be resolved with some flexibility. It is either the constructor may build up the regional warehouse or we allocate a budget to Tung-Ho and Tung-Ho can construct the warehouse.
(3) Question: Will the operating benefits or lifespan of the new regional warehouse reach economies of scale?

Answer: Although Futsu JV makes the request that Tung-Ho should establish the target levels of inventory to meet with the engineering demand from AU Optronics Corp.'s construction sites, we are not opposed if this regional warehouse wants to supply to other clients or construction sites in central Taiwan. According to the rule of the thumb, the development period for a science park is at least 15 years on average. Taiwan Hsinchu Science Park has been around for over 20 years. We believe that this open approach equates to building up a regional warehouse for Tung-Ho and Tung-Ho should be more than happy to cooperate.

(4) Question: Will your company eventually decide everything based on pricing?
Answer: Our company will handle this case with a long-term concession contract. The unit prices will be based on the market prices. What we are concerned about is whether this model brings about the benefits to Futsu JV more than the price gap of a few hundred NT dollars per ton.

(5) Question: After giving it a good thought, the benefit should be great. Is it possible to share the benefits?
Answer: In the past, on average the management of steel bars increased costs by 10~15% (approximately NT$120~180 million). This can be discussed.

(6) Question: If orders and shipments are going to be made on a frequent basis, how should we resolve the problems associated with economical batches and transportation expenses?
Answer: The establishment of a regional warehouse/processing site at Central Taiwan Science Park already saves some transportation expenses for Tung-Ho because the original flow is to ship goods from the factory to its central warehouse and then to construction sites. The new regional warehouse/processing site will make it possible for goods to arrive at Central Taiwan Science Park directly from Tung-Ho's factory. Therefore, some standard transportation expenses will be saved. As to the economical batches for orders and shipments, as the average consumption at the construction sites is over 25 tons per day, it equates to the shipment of one truck. It is also the economical batch quantity specified in the contract. Therefore, Tung-Ho is also a benefactor in this change.

(7) Question: What is the target level inventory determined?
Answer: The constructor aims to be freed from the burden of establishing inventory, but maintain access to ready supply. Therefore, they construct a VMI model (Futsu JV vs. Tung-Ho Steel Enterprise Corp.) based on the actual situation to manage the target level of inventory. The details can be further discussed by the responsible teams from both parties in due course.

After the previous discussion, Tung-Ho Steel Enterprise has been convinced to establish a regional warehouse/processing site at Howli, Central Taiwan Science Park.

3.3.2 Implementation Method (Introduction of D-P Supply Model under TOC Framework)

The next step is to figure out how to alter the existing inventory management policy. Under the original project model, as there are seven or more factories in construction at the same time, orders are placed by individual factory buildings because they are allocated steel bar storage/processing sites dedicated to their buildings. However, based on the TOC approach, a single window should collate all the demands for materials because it will come up with more accurate results. In other words, the originally distributed approach in which individual steel bar processing sites make their own orders is changed into the centralized collection for steel bars from Tung-Ho Steel Enterprise Corp.'s Dali Regional Warehouse/ Processing Site located in Central Taiwan Science Park. This concept is similar with "central inventory." It will drastically reduce the management efforts in steel bars from constructors and save them the investments. Also, the demand for materials at construction sites due to climates, labor availability and demand changes. After the integration of demand requests, the demand figures will become a lot more reliable. The problem remaining is how to establish the target inventory level at the regional warehouse/processing site. We follow the aforesaid TOC model to establish the target level inventory and ask Tung-Ho Steel Enterprise Corp. to build the inventory at their factory based on the demand nationwide. With frequent ordering and inventory replenishments, the inventory at the regional warehouse/processing site is lowered and as a result, it creates a win-win situation for both Tung-Ho Steel Enterprise Corp. and the construction sites. Figure 7 is the supply/distribution model under the TOC framework. The establishment of a plant warehouse to meet with the demands from individual area warehouses. This replaces the original model where the factory supplies steel bars directly to individual area warehouses. As replenishment time equals to order lead time + production lead time + transportation lead time, the new approach shorten the replenishment time by taking order lead time and production lead time out of the equation. Also, the factory's central warehouse will be confronted with a smaller variance.

The replacement of the push model with the pull model means that replenishment only occurs when the supply is actually consumed at the regional warehouse and the replenishment is made according to the actual consumption volume. Computer technologies make it possible that the regional warehouse reports the daily consumption (orders) and replenishments can be made from the factory's central warehouse in a frequent manner. This saves the factory the hassles of producing on the basis of inaccurate forecasts and frees it from the troubles of meeting with small but urgent orders. The desired levels of inventory of individual products are predetermined and three colors, i.e. red, yellow and green, are used to indicate the changes in the actual consumptions (not forecasts) so as to monitor whether the levels of inventory remain within the optimal range or already too high/low. Measures will be taken accordingly to adjust the inventory target with the following three solutions: (1) operations on the basis of more accurate forecasts; (2) drastic shortening of replenishment time; (3) enhancement of supply reliability.

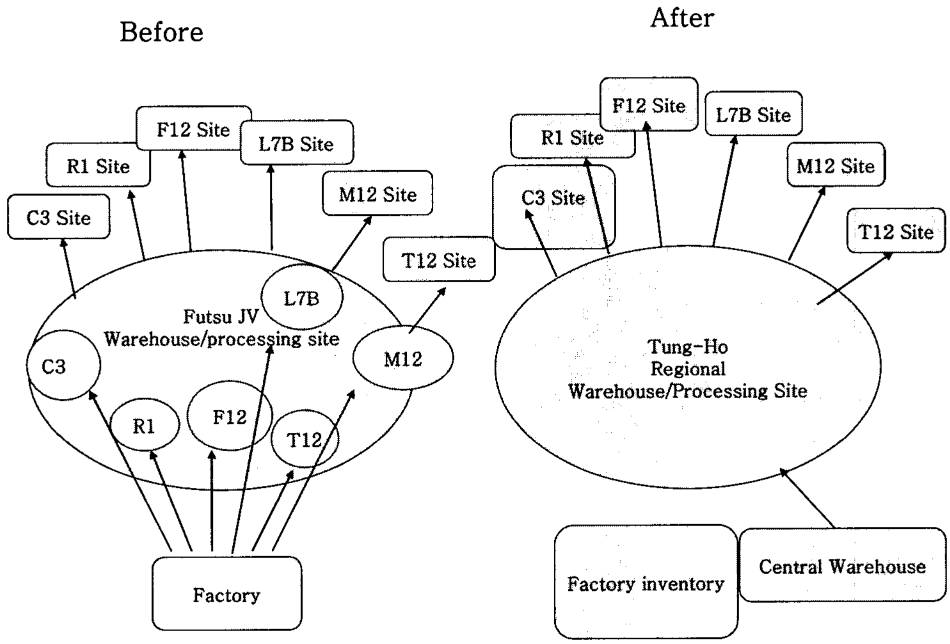

Figure 7. TOC Supply/Distribution Model between Futsu JV and Tung-Ho Steel Enterprise

3.3.3 Operational Flows

The operational flows are as follows: (1) Establishment of the central factory warehouse at the steel bar producer (Tung-Ho Steel Enterprise) and the regional warehouse/processing site; (2) Target levels of inventory for steel bars of all specifications determined in accordance with formulae and demands; (3) Frequent ordering and replenishments; (4) Three lights, i.e. red, yellow and green, are used to monitor the target levels of inventory; (5) Review of the policy of production-to-order and production-for-availability; (6) The instruction to individual subsystems is made so that they can make use of the daily measurement to execute T/I/OE as the performance indicators. In this way, each chain is able to respond accurately because they are given correct measurement indicators and as a result, the overall benefits are maximized. This also facilitates management for managers.

Let T (TDD, Throughput-Dollar-Day) = Value of Finished Goods × Engineering Delayed Days;
I (IDD, Inventory-Dollar-Day) = Value of Inventory × Inventory Days;
OE (Local Operating Expense) = Operational Expenses of Each Chain;

The target is to minimize IDD and OE, as well as to pursue zero TDD.

4. Case Study Validation

4.1 Analysis of Current Replenishment Model of Steel Bars

Currently, the replenishment model of steel bars is based on the forecasted supply/inventory desirable in accordance with the schedules and aggregated demands from individual factory buildings or areas at construction sites. Usually, the chief engineers of individual buildings make the calls by discussing with the subcontractors and supplier. Below is the explanation. This case study uses the #8 and #10 steel bars for the main FAB for the third-phase project of AU Optronics Corp. in Taichung, Taiwan. The replenishment, consumption and inventory figures are entered into the table, as Table 1 and Table 2 show.

Table 1. TDD and IDD of #8 Steel Bars

Week	Replenishment	Consumption	Inventory	TDD	IDD
1	165		165	0	20,790,000
2	29		194	0	24,444,000
3	8		202	0	25,452,000
4	636		838	0	105,588,000
5	357	502	693	0	87,318,000
6	506	537	662	0	83,412,000
7	0	498	164	0	20,664,000
8	554	585	133	0	16,758,000
9	249	699	-317	39,942,000	0
10	539	721	-499	62,874,000	0
11	970	650	-179	22,554,000	0
12	865	758	-72	9,072,000	0
13	772	100	600	0	75,600,000
14	193	102	691	0	87,066,000
15	193	130	754	0	95,004,000
16	0	154	600	0	75,600,000
17	0	165	435	0	54,810,000
18	127	179	383	0	48,258,000
19		186	197	0	24,822,000
20		197	0	0	0
Total	6,163	6,163	5,644	134,442,000	845,586,000
Average			282	960,300	6,039,900

Table 2. TDD and IDD of #10 Steel Bars

Week	Replenishment	Consumption	Inventory	TDD	IDD
1	988		988	0	124,488,000
2	304		1,292	0	162,792,000
3	314		1,606	0	202,356,000
4	333		1,939	0	244,314,000
5	920	430	2,429	0	306,054,000
6	694	447	2,676	0	337,176,000
7	283	479	2,480	0	312,480,000
8	185	515	2,150	0	270,900,000
9	633	589	2,194	0	276,444,000
10	243	597	1,840	0	231,840,000
11	230	608	1,462	0	184,212,000
12	274	700	1,036	0	130,536,000
13	34	98	972	0	122,472,000
14		79	893	0	112,518,000
15		122	771	0	97,146,000
16		130	641	0	80,766,000
17		130	511	0	64,386,000
18		149	362	0	45,612,000
19		169	193	0	24,318,000
20		193	0	0	0
Total	5,435	5,435	26,435	0	3,330,810,000
Average			1,322	0	23,791,500

4.2 Analysis of Supply/Inventory Model under TOC Framework

4.2.1 Demand-Pull Replenishment Model under TOC Framework

The key concept of the Demand-Pull replenishment model is to establish the main inventory at the back end (factory/central warehouse) and the regional warehouse is aimed to stay close to the clients. In this case study, the operational highlights are as follows:

(1) The steel bar supplier (Tung-Ho Steel Enterprise) is asked to establish inventory at its factory or build up a central warehouse.

(2) The supplier is asked to establish a regional warehouse/processing site at the location close to the construction sites.

(3) The maximum consumption during the replenishment time is used as the target level of inventory.

(4) The actual consumption of the previous period is referred to as the basis for orders/ replenishments.
(5) Orders and shipments are made frequently. This case uses one replenishment and two replenishments a week as examples.
(6) TDD and IDD serve as the indicators to measure performances.

4.2.2 Results of Implementing Demand-Pull Model

This section also applies the consumption quantities of two steel bars mentioned in Section 4.1 into the Demand-Pull Model and the results are summarized in Table 3 ~ Table 6 as follows:

Table 3. #8 Steel Bars under TOC Model (Replenishment frequency: once a week)

Week	Replenishment	Consumption	Inventory	TDD	IDD
1					
2					
3					
4					
5	758	502	256	0	32,256,000
6	502	537	221	0	27,846,000
7	537	498	260	0	32,760,000
8	498	585	173	0	21,798,000
9	585	699	59	0	7,434,000
10	699	721	37	0	4,662,000
11	721	650	108	0	13,608,000
12	650	758	0	0	0
13	758	100	658	0	82,908,000
14	100	102	656	0	82,656,000
15	102	130	628	0	79,128,000
16	130	154	604	0	76,104,000
17	123	165	562	0	70,812,000
18		179	383	0	48,258,000
19		186	197	0	24,822,000
20		197	0	0	0
Total	6,163	6,163	4,802	0	605,052,000
Average			300	0	5,402,250

Table 4. #10 Steel Bars under TOC Model (Replenishment frequency: once a week)

Week	Replenishment	Consumption	Inventory	TDD	IDD
1					
2					
3					
4					
5	700	430	270	0	34,020,000
6	430	447	253	0	31,878,000
7	447	479	221	0	27,846,000
8	479	515	185	0	23,310,000
9	515	589	111	0	13,986,000
10	589	597	103	0	12,978,000
11	597	608	92	0	11,592,000
12	608	700	0	0	0
13	700	98	602	0	75,852,000
14	98	79	621	0	78,246,000
15	79	122	578	0	72,828,000
16	122	130	570	0	71,820,000
17	71	130	511	0	64,386,000
18		149	362	0	45,612,000
19		169	193	0	24,318,000
20		193	0	0	0
Total	5,435	5,435	4,672	0	588,672,000
Average			292	0	5,256,000

Table 5. #8 Steel Bars under TOC Model (Replenishment frequency: twice a week)

Week	Replenishment	Consumption	Inventory	TDD	IDD
1					
2					
3					
4					
5	391	244	147	0	9,261,000
6	244	258	133	0	8,379,000

7	258	224	167	0	10,521,000
8	224	313	78	0	4,914,000
9	313	257	134	0	8,442,000
10	257	242	149	0	9,387,000
11	242	303	88	0	5,544,000
12	303	282	109	0	6,867,000
13	282	379	12	0	756,000
14	379	320	71	0	4,473,000
15	320	359	32	0	2,016,000
16	359	362	29	0	1,827,000
17	362	387	4	0	252,000
18	387	262	129	0	8,127,000
19	262	391	0	0	0
20	391	366	25	0	1,575,000
21	366	56	335	0	21,105,000
22	56	44	347	0	21,861,000
23	44	51	340	0	21,420,000
24	51	51	340	0	21,420,000
25	51	65	326	0	20,538,000
26	65	65	326	0	20,538,000
27	65	69	322	0	20,286,000
28	69	85	306	0	19,278,000
29	85	82	309	0	19,467,000
30	82	83	308	0	19,404,000
31	83	79	312	0	19,656,000
32	79	100	291	0	18,333,000
33	93	84	300	0	18,900,000
34		102	198	0	12,474,000
35		77	121	0	7,623,000
36		121	0	0	0
Total	6,163	6,163	5,788	0	364,644,000
Average			181	0	3,255,750

Table 6. #10 Steel Bars under TOC Model (Replenishment frequency: twice a week)

Week	Replenishment	Consumption	Inventory	TDD	IDD
1					
2					
3					
4					
5	391	223	168	0	10,584,000
6	223	208	183	0	11,529,000
7	208	216	175	0	11,025,000
8	216	231	160	0	10,080,000
9	231	257	134	0	8,442,000
10	257	222	169	0	10,647,000
11	222	249	142	0	8,946,000
12	249	265	126	0	7,938,000
13	265	289	102	0	6,426,000
14	289	300	91	0	5,733,000
15	300	302	89	0	5,607,000
16	302	294	97	0	6,111,000
17	294	289	102	0	6,426,000
18	289	319	72	0	4,536,000
19	319	330	61	0	3,843,000
20	330	369	22	0	1,386,000
21	369	49	342	0	21,546,000
22	49	52	339	0	21,357,000
23	52	41	350	0	22,050,000
24	41	37	354	0	22,302,000
25	37	62	329	0	20,727,000
26	62	61	330	0	20,790,000
27	61	66	325	0	20,475,000
28	66	63	328	0	20,664,000
29	63	69	322	0	20,286,000
30	69	62	329	0	20,727,000
31	62	75	316	0	19,908,000
32	75	74	317	0	19,971,000
33	44	89	272	0	17,136,000
34		80	192	0	12,096,000
35		98	94	0	5,922,000
36		94	0	0	0
Total	5,435	5,435	6,432	0	405,246,000
Average			201		3,618,000

4.3 Comparison and Analysis of Current Model and Demand-Pull Model

This section applies the actual consumption of steel bars into the Demand-Pull Model and compares the derived results with the current model. According to the current, conventional model, forecasts of demands for different types of steel bars are made on the basis of engineering progress and area warehouses make orders by referring to the forecasts. Then Steel bar factories manufacturer in batches. However, in the Demand-Pull Model, orders are placed with the manufacturers in accordance with the actual consumption and the manufacturers replenish the inventory on the basis of the ordered quantity. The details are as follows:

1. The supplier of steel bars in the case study, Tung-Ho Steel Enterprise, is the largest supplier of steel bars in Taiwan. Conservatively speaking, the replenishment cycle of steel bars of all specifications is two weeks. The largest single-batch production is 2,000 tons and the minimal order is 25 tons.
2. Replenishment frequency is one a week and twice a week.
3. Comparison and analysis of the traditional model and Demand-Pull Model.
4. Analysis of the results in shortening of the replenishment time and stepping up the frequency of replenishments.

Table 7. Traditional Model vs. Demand-Pull Model

Traditional Model vs. Demand-Pull Model						
Replenishment				**Once per week**		
Operational Model	**Traditional**			Demand-Pull (D-P)		
Item	Avg. inventory	TDD	IDD	Avg. inventory	TDD	IDD
#10 steel bars	1,322	$0.00	$23,791,500	292	$0.00	$5,256,000
#8 steel bars	282	$960,300	$6,039,900	300	$0.00	$5,402,250
Replenishment Time				**Twice per week**		
Operational Model	~~**Traditional**~~			Demand-Pull (D-P)		
Item	Avg. inventory	TDD	IDD	Avg. inventory	TDD	IDD
#10 steel bars				201	$0.00	$3,618,000
#8 steel bars				181	$0.00	$3,255,750

The following conclusions can be made on the basis of Table 7:

1. D25 experiences 4 shortages in the traditional model, but none in the Demand-Pull Model.
2. D32 experiences no shortage in either the traditional model or the Demand-Pull Model (TDD = 0); however, the Demand-Pull Model satisfies engineering progress, i.e. guarantees the effective outputs, with very low levels of average inventory.

3. Table 7 shows that the IDD values in the traditional model are higher than those in the Demand-Pull Model.
4. Shortening of the replenishment time and frequenting of replenishments reduce drastically both average inventory and IDD values.

5. Conclusions

This paper refers to the TOC distribution model to make unprecedented changes to the traditional supply model between suppliers and constructors. The client demands that a feasibility study should be performed because they do not want to establish inventory but wish to maintain access to ready supply. It is hoped that a win-win model between the steel bar supplier and the constructor should be created. The supply chain of steel bars is introduced to the VMI model under the TOC framework. A method is proposed in order to guarantee effective outputs and exempt the system from high levels of inventory. T/I/OE is established as the indicator to measure performances. Although this paper comes up with a new thinking and management method to change the supply model of steel bars so as to enhance efficiency and guarantee effective outputs. During the research process, there are still many issues yet to be discussed and to be further studied in the future.

1. If a study can be performed to cover the whole supply chain of the steel industry, from upstream material suppliers to downstream steel bar manufacturers, the conclusions will be more robust and comprehensive. It will also establish a complete picture.
2. A feasibility study may be conducted on the TOC factory build-up project scheduling based on critical chain method by combining information technology to examine the possibility of making accurate material forecasts.
3. In addition to steel bars, the supply model of the concrete industry is also worth exploring.
4. If the inventory management of steel bars can be introduced into the traditional inventory management model, a comparison and analysis of (s, S), (s, Q), (R, S), (R, s, S), (s, Q, R) vs. the D-P model can be made.

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