Applying TOC Replenishment method to Improve Production Performance for TFT-LCD Industry

S.-H. Chang¹, C. Chuang², R.-K. Li³
¹Institute of Engineering Management
Minghsin University of Science and Technology
Hsin-Feng, Hsin-Chu County, Taiwan 304, R.O.C.
²AU Optronics Corp., Taiwan 300, R.O.C.
³Dept. of Industrial Engineering & Management
National Chiao-Tung University, Taiwan 300, R.O.C.

Abstract
Traditionally, answer the questions of "when to replenish" and "how many to replenish" using various forecasting methods are commonly seen in the supply chain inventory management. However, the uncertainty with changeful demand often makes various kinds of prediction methods became less efficient. To solve the problem, the demand-pull and buffer management of TOC replenishment method developed by Dr. Goldratt have been applied as solution in this research. Using a leading company of TFT-LCD industry in Taiwan to be the case to evaluate the feasibility and validity of the solution, the result shows that TOC solution provides a better performance in TDD and IDD than traditional methods.

Keywords: Supply Chain, Theory of Constraints, Demand-pull, Buffer management, Inventory Management

1 INTRODUCTION
For a long time, the way that supply chain operates begins by placing the forecasting orders via retailers. The orders are then collected by the regional or distribution center and sent to the manufacturer for production. After manufacturing, the finished products are delivered back to the regional or distribution center and then re-distributed again to the retailers. This operation model is called “Push” method. Since forecasting is usually inaccurate and has other uncertainties, such as lot-size orders, cost fluctuation, and long production/replenishment time, the variation in demand becomes more significant as it moves towards the supply end. This is the so-called Bullwhip Effect, which leads to high inventory in regional warehouses and downstream stages of the chain.

Most of the traditional replenishment policies make use of replenishment to initiate the system, which maintains the inventory level to meet customer’s satisfaction. Basically, the system conducts appropriate replenishment at the right time, such as the development of EoQ at the early stage to (s, Q) replenishment policy, (s, S) replenishment policy, (R, S) replenishment policy, and (R, r, S) replenishment policy. The parameter settings for these replenishment policies are influenced by demands. In the past, many studies have reported ways to find the optimal parameter setting, such as mathematical method, heuristic or simulation method, etc. However, these methods only emphasize on “partial” inventory problem without taking the real-time information into consideration. Furthermore, these processes are too complicated; as the result, applying these models in inventory management is not appropriate under such dynamic environment.

The supplier adopting Continuous Replenishment Program (CRP) must consider first the retailer’s order. After taking into account other relevant factors, the order is adjusted and ready for distribution. In this case, the process only activates when the retailers have placed an order. On the other hand, the suppliers adopting Vendor Managed Inventory (VMI) judge retailer’s demand from their previous-established information and subsequently perform replenishment adjustment to improve the performance of inventory management. Both CRP and VMI must be built on top of adequate information and mutual trust between members of the supply chain. Moreover, the maintenance of the system is more complicated. Although implementing modern information technology will speed up information transfer and facilitate supply chain integration, the problems within the supply chain cannot be efficiently resolved.

Most people believe that the problems occurred in supply chain are caused mainly by inaccurate forecasting, unreliable vendors, and long replenishment time, which are difficult to overcome. Although solving these problems seemed to be difficult from the perspective of traditional thinking, they are indeed much simpler to deal with if they are considered from a different point of view. From the calculation of statistical variation, individual calculation variation is always far greater than overall calculation variation; therefore, as the forecasting step moves closer to the demand aggregation, the accuracy of forecasting will also increase comparing to those performed and collected for each individual retailer. Dr. Goldratt believed that the main inventory should be located at places where the forecasting is most accurate, that is at the aggregation source. He also believed that the ways of operation should be changed from the original “push” method to the “pull” method that takes customer demand as the top priority. The amount consumed in the downstream is pull back from the upstream. The inventory is moved from places near the customer to the source. This not only is advantageous for making distribution that satisfies downstream demands but also separate the supply systems for the independent demands that are unstable. As the result, the only time that remains is the delivery time, which significantly reduces the replenishment time and enhances the replenishment reliability.

In this study, empirical analyses were conducted for the Cell assembly of a leading Thin-Film Transistor Liquid Crystal Display (TFT-LCD) manufacturing company in Taiwan. Utilizing the concept of Demand-Pull (DP) and Buffer Management (BM) derived from TOC, Demand-Pull Replenishment Model (DPRM) was proposed to establish the inventory that is efficient and adequate to meet customer’s demands; consequently, reduces the cost of inventory and achieves the ultimate goal of maximizing the
overall benefits. The operation results were indicated by the performances of Average Inventory, Throughput-Dollar-Days (TDD), and Inventory-Dollar-Days (IDD) indexes.

2 DPRM DECISION MODEL

Dr. Goldratt believed that there exists a conflict of supply chain management as illustrated in Figure 1 [20]. The goal of every manager is to provide good supply chain management. A good supply chain management should include minimizing the overall inventory cost (block B), selling as many products as possible, or lowering the out-of-stock frequency (block C). In order to minimize the cost, it is necessary to reduce the inventory (block D). However, it is necessary to increase the inventory (block D’) in order to sell as many products as possible or lowering the out-of-stock frequency. Therefore, a conflict exists while preparing the inventory. Dr. Goldratt believed that when a conflict occurs, one should find the assumption behind it and try to resolve the conflict by eliminating that assumption. By examining the conflict, one has discovered that it is necessary to have a high inventory (D’) in order to sell as many products as possible or reduce the out-of-stock frequency (C). In this case, the assumptions are long replenishment time, unreliable vendor, and inaccurate forecasting. Typically, people often think these three assumptions are the main reason that forces one to have a high inventory. However, this is not true and the explanations can be illustrated in reference No. 20.

![Figure 1: Typical conflict of supply chain](image)

To solve the problems mentioned above, the old operation model must be changed. By utilizing the concept of Demand-pull and Buffer management developed from TOC, a new model, DPRM, was proposed to replace the old operation model. The operation mechanism is described as the followings.

1. Instead of placing the products close to the consumer, Demand-pull renovates the old idea by moving most of the products to their source, which is in the factory end. Consequently, regional warehouse only needs to maintain the quantity needed for replenish lead time. Once the customer has placed the order and sent to the regional warehouse, the order quantity will simultaneously be report to the factory by the regional warehouse. Subsequently, the factory will promptly deliver the final product to the regional warehouse once they are completed.

2. Buffer Management is a method used to monitor the inventory in factory or regional warehouse. In TOC, the biggest quantity required in replenish lead time is regarded as the target buffer stock. Once the target buffer stock has been determined, it is divided into three parts including neglected zone (green zone), warning zone (yellow zone), and rush zone (red zone). When the inventory level is at the neglected zone, it is necessary to lower the inventory. On the other hand, it is necessary to increase the inventory level if it is at the rush zone. By utilizing buffer management, the inventory can be maintained at the appropriate level without running out of stock.

3. In the aspect of performance evaluation, Dr. Goldratt has modified the commonly used performance evaluation indexes, such as inventory turn-over rate, stock-out rate to TDD and IDD. TDD index mainly considers reliability that is “how much work is uncompleted”. Therefore, when the company or department is unable to meet the deadline of an order promised to its customers, TDD index will be calculated to show the level of incompleteness. The calculation is to multiply the effective production value by the total number of days delayed. The bigger the TDD value is, the longer the order is delayed, which means more damages to the company. Therefore, the company or department should pursue the goal of zero TDD. IDD index, on the other hand, considers efficiency that is “how much work is done”. When a company produces more than enough products, it is considered inefficient. This not only wastes the raw materials used for production, but also increases the cost of inventory. The calculation is to multiply the inventory value by the total time spent in the warehouse. The bigger the IDD value is, the higher the degree of overstock, which increases the inventory cost and causes delivery delay for other products due to insufficient raw materials. Therefore, company or department must strive for lowering the IDD value.

3 CASE STUDY

The case in this study is a leading TFT-LCD manufacturing company in Taiwan. The manufacture of TFT-LCD is analogous to a small supply chain system. The upstream processes are similar to that in foundry plants, which start with TFT-array fabrication and color-filter (CF) fabrication. The next step is the LCD cell assembly, which injects the liquid crystal in-between TFT and CF to form a sandwich structure. These processes are referred to as LCD fabrication. The downstream LCD module assembly then combines the LCD with the printed circuit, backlight module, and case to form the final product. This process is called LCM fabrication. The TFT-LCD industry is vertically integrated system as summarized in Figure 2. The upstream and downstream processes are closely linked together; therefore, if upstream is running out of supply, the production downstream will be affected. Similarly, the downstream demand will also influence the upstream production plan.

The front-end processes in TFT-LCD industry are similar to those in most semiconductor industries. They need to go through many photolithographic processes, such as exposure, development, and etching. Today, there are many studies focusing on solving problems for these processes. Nevertheless, they might not be applicable for the cell processes in the TFT-LCD industry since both processes are quite different. Due to the fact that cell assembly requires combining TFT with CF, there exist various combination possibilities for different TFT, CF or even polarizer. Most product variation will appear after cell assembly. As the result, cell assembly will face the more complicated production problem of product mix.

On the other hand, cell product is not the final product. Therefore, it still retains quite a few flexibilities for product mix. In terms of the entire TFT-LCD industry, cell
assembly is situated at the end of the upstream production activity. Considering from TOC's view point, most of the inventory buffers should be set in the factory upstream (source), whereas the regional warehouse downstream only needs to maintain the quantity needed for replenish lead time. Consequently, the production management model of the upstream cell assembly will have a direct impact on the factory productivity performance for the end customer.

The cell assembly process in TFT-LCD can be further distinguished into front-end cell assembly and back-end cell assembly. The front-end cell assembly includes PI→Rubbing→Attach. The back-end cell assembly comprises Cut→Polarizer→Gap former→Cell test. Due to the variation of product characteristics, some products can be differentiated during the front-end cell assembly. These products are mostly made of the same TFT with different CF. However, some products can only be differentiated at the back-end cell assembly. These products usually have the same TFT and CF, but combined with different polarizer.

Owing to the characteristic difference between front-end and back-end cell assembly, numerous product varieties are created. Therefore, how to establish an efficient and adequate inventory that satisfies customer’s demand has become the immediate issue for the business in order to lower down its inventory cost and maximize the benefits for the company. Utilizing the concepts of Demand-Pull and Buffer Management from TOC, an efficient product inventory management model DPRM was established in this study. By comparing with the existing product inventory management model, the new model has demonstrated improvements in inventory performance.

The production management flow of the original model for the case company begins with the demand forecasting provided by the sales. Once the production management staff received the demand forecasting, a production schedule that conforms to the sale's demand is created. If the capacity has surplus, it is saved as inventory based on experience. If the capacity has deficit, then the sales must provide a priority list of each product to the production management staff for allotting the capacity. The detailed steps conducted by the production management staff are summarized as the following.

1. Confirm replenish lead time: Replenish lead time is defined as the production cycle of cell assembly. Replenish lead time will vary for different products; however, it is approximately 3~4 days.

2. Production management staff will receive the updated demand forecasting every Friday. A production schedule must be ready prior to the end of the following Monday in order to facilitate the subsequent scheduling.

3. The production begins on Tuesday according to the schedule; however, appropriate manual adjustment of the production schedule is sometime necessary depending on the situation.

4. A production/marketing coordination meeting will be held every Wednesday to discuss about whether or not the capacity can fulfill the target and demand of the sales.

5. A commit meeting will be held every Thursday with the factory to discuss about the production schedule for the next few months. The updated master production schedule (MPS) for the corresponding week will be issued during the meeting as well in order to prepare the required materials in advance.

The original model of the company was analyzed based on the above-mentioned conditions. The average inventory, TDD, and IDD values were calculated from the company’s historical data in 7 months.

### 3.2 DPRM decision model

The main parameter used for DPRM operation is the "target buffer stock" (that is the safety stock recognized by most production management staff). The way it works is to accumulate the biggest demand in replenish lead time and basically follow the rule of “use more, pay more”. Since buffer stock can significantly influence the inventory
quantity as well as out-of-stock probability, it is, therefore, divided into neglected zone (green zone), warning zone (yellow zone), and rush zone (red zone) (some studies recommended to divide it into 5 zones [20]). When the inventory level rises to the neglected zone or falls to the rush zone, the buffer stock is adjusted by 1/3 (or 1/5) each time. Studies have indicated that 1/3 adjustment is higher than 1/5 adjustment in terms of average inventory. Also in the case of large demand alteration that needs to lower down the inventory, 1/3 adjustment will have a higher risk in out-of-stock than 1/5 adjustment [20]. In this study, the replenish method employed divides the buffer stock into 5 equivalent portions.

In addition, there are two performance indexes for the buffer management of DPRM. One is Throughput-Dollar-Days (TDD) and the other one is Inventory-Dollar-Days (IDD). Yuan et al. [20] have pointed out that when the inventory is in the red zone, the effective throughput for the customer might be in danger. Therefore, it is necessary to increase the inventory. In order to reduce out-of-stock probability and increase customer satisfaction, it is, therefore, recommended to start accumulating the TDD value when the inventory is in the red zone. Although customer satisfaction can be fulfilled when the inventory level is in the green zone, it leads to higher inventory management cost. Therefore, it is recommended to start accumulating IDD value when the inventory is in the green zone. This could prevent jeopardizing TDD performance while paying too much attention on IDD. The calculations for the performance indexes are described below.

1. Calculation steps for TDD index:
   a. The unit sales volume of the product P
   b. Assuming the level of red control line is U, the inventory on the nth day is W, i = 1, 2, 3, ..., n.
   c. Calculate the daily TDD index: if the actual inventory level is higher than the red control line level U (not in the red zone), the target TDD index is zero.
   \[ TDD_i = \begin{cases} (U - W_i) \times P_i, & W_i < U \; \text{for} \; i = 1, 2, 3, \ldots, n \; \text{if} \; W_i > U \\ 0, & \text{otherwise} \end{cases} \]  \[ (1) \]
   d. Set an evaluation period and periodically calculate the total TDD index.
   \[ \text{Total_TDD} = \sum_{i=1}^{n} TDD_i, i = 1, 2, 3, \ldots, n. \]  \[ (2) \]

2. The calculation steps for IDD index:
   a. The unit sales volume of the product P
   b. Assuming the level of inventory target is G, the inventory on the nth day is W, i = 1, 2, 3, ..., n.
   c. Calculate the daily IDD index: if the actual inventory level is lower than the target inventory level G (not in the green zone), the target IDD index is zero.
   \[ IDD_i = \begin{cases} (W_i - G) \times P_i, & W_i \geq G \; \text{for} \; i = 1, 2, 3, \ldots, n \; \text{if} \; W_i < G \\ 0, & \text{otherwise} \end{cases} \]  \[ (3) \]
   d. Set an evaluation period and periodically calculate the total IDD index.
   \[ \text{Total_IDD} = \sum_{i=1}^{n} IDD_i, i = 1, 2, 3, \ldots, n. \]  \[ (4) \]

Yuan et al. have also mentioned in their study that using buffer management to adjust target inventory can prevent out-of-stock and reduce the emergency replenishment frequency that is needed to maintain a reasonable target inventory level. Comparing with the traditional method of re-ordering or maintaining a large inventory, buffer management is a better way to manage the inventory effectively since it reduces the time of simulation needed [20].

The difference between DPRM and the original model of the case company is the setting for target buffer stock. The original model does not have a clear target buffer stock. The inventory is determined for certain products based on production management staff’s experience. On the other hand, DPRM emphasizes the idea of “use more, pay more” and define target buffer stock as “all investments in procuring materials to meet customer demand, such as raw materials, work-in-process (WIP), finished goods, and scrap”. During the arrangement of production schedule, the production management staff needs to take into account the production materials as well as the oncoming demands in order to deal with the demand fluctuation in the future. The new flow chart is described as below (Figure 3).

1. Confirm replenish lead time (consistent with original model).
2. Once receiving the updated version of forecasting demand on Friday, set target buffer stock (G).
   \[ (G) = \text{MAX} \left( \sum_{i=1}^{n} d_{i-1}, \sum_{i=1}^{n} d_{i-2}, \ldots, \sum_{i=1}^{n} d_{i} \right) \times \alpha \]  \[ (5) \]
   Where, \( d_i \): the daily actual demand for the previous month; n: Cell production cycle time (order lead-time); j: the maximum number of days in each month; \( \alpha \): Adjusting parameter.
3. Set the dangerous level for demand (U) = 1/2 target buffer stock (G).
4. Define “on-hand inventory (W)” as the “the total inventory of raw materials, work-in-process, and finished goods at hand”. (W) is used to satisfy target buffer stock.
5. If on-hand inventory (W) is greater than target buffer stock (G), replenishment is not needed. If target buffer stock (G)>on-hand inventory (W), target buffer stock (G), replenishment is needed (The replenishment quantity would be G-W). If on-hand inventory is less than the dangerous level of demand (U), replenishment is needed (The replenishment quantity would be U).

\[ \text{Figure 3} \; : \; \text{DPRM decision process} \]
6. After the production schedule has been arranged, a production/marketing coordination meeting will be held on Wednesday and a commit meeting with the factory will be held on Thursday. The updated MPS of that corresponding week will be issue to the purchasing department for material preparation and replenishment.

7. The average inventory, TDD and IDD values are calculated based on the company’s historical data in 7 months (the first month is treated as historical data and the other six months are used for analyses).

4 CASE ANALYSIS AND VERIFICATION

In this study, a 19 inch product, M190EG0A, was taken as the example to compare the performance of DPRM to the original model (OM) of the company. The cycle time for this process is approximately 3 days. By referring to the historical data of demand in January (as illustrated in Table 2) and utilizing equation (5), the target buffer stock of DPRM in February was calculated to be 9000. The TDD and IDD values are calculated by equations (1)~(4). From these two performance indexes, a comparison between OM and DPRM can be made effectively.

From Table 3, few conclusions can be drawn to explain the difference between OM and DPRM. First of all, the TDD values for most products calculated by OM are zero. This means that OM, in fact, is very protective for customer’s production. However, in terms of maximum production in cell assembly, OM does not define a system for target inventory. It only considers lot production mode for that process. In order to fulfill the demand for module production, the inventory cost is also much higher comparing to DPRM, which is the biggest difference between these two models. Instead of following the demand forecasting like OM, the operation of DPRM is much easier which makes use of the target buffer stock. Furthermore, over-replenishment will not occur during large demand. To protect the production, it is only necessary to establish the buffer stock adequate for the selling season.

1. Average inventory difference between OM and DPRM: From Figure 4, it is noted that the average inventory of DPRM is lower than that of OM, which means that DPRM has the ability to lower the inventory.

2. TDD difference between OM and DPRM: From the results of TDD, out-of-stock did not happen for DPRM. Zero in TDD values means that DPRM can better protect the production in order to satisfy customer’s needs. As indicated in Figure 5, the inventory cost of DPRM is lower than that of OM due to the fact that DPRM has lower average inventory.

3. IDD difference between OM and DPRM: As shown in Figure 6, the IDD value of OM is higher than that of DPRM. This is because when demand forecasting is higher than the actual demand, inventory turnover decreases; consequently, IDD value increases.

Table 2 Demand forecasting in January

<table>
<thead>
<tr>
<th>Product</th>
<th>Unit price</th>
<th>Start inventory</th>
<th>Mon 1/9</th>
<th>Tues 1/10</th>
<th>Wed 1/11</th>
<th>Tues 1/12</th>
<th>Fri 1/13</th>
<th>Sat 1/14</th>
<th>Sun 1/15</th>
<th>Mon 1/16</th>
<th>Tues 1/17</th>
</tr>
</thead>
<tbody>
<tr>
<td>M190EG0A</td>
<td>6,000</td>
<td>Demand</td>
<td>0</td>
<td>0</td>
<td>1800</td>
<td>2000</td>
<td>2000</td>
<td>900</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Supply</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>125</td>
<td>2125</td>
<td>3675</td>
<td>2775</td>
<td></td>
</tr>
<tr>
<td>Balance</td>
<td>3551</td>
<td>11025</td>
<td>11025</td>
<td>9225</td>
<td>7225</td>
<td>5225</td>
<td>3350</td>
<td>4575</td>
<td>8250</td>
<td>11025</td>
<td></td>
</tr>
<tr>
<td>WIP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>125</td>
<td>2250</td>
<td>5925</td>
<td>8575</td>
<td>6450</td>
<td>2775</td>
<td>900</td>
<td></td>
</tr>
<tr>
<td>WIP+Stock</td>
<td>11025</td>
<td>11025</td>
<td>9225</td>
<td>7350</td>
<td>7475</td>
<td>9275</td>
<td>13150</td>
<td>14700</td>
<td>13800</td>
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</table>

Table 3 The results comparison between OM and DPRM

<table>
<thead>
<tr>
<th>Product #</th>
<th>No. of replenishment</th>
<th>Average Inventory (pieces)</th>
<th>AVG_TDD</th>
<th>AVG_IDD</th>
<th>No. of replenishment</th>
<th>Average Inventory (pieces)</th>
<th>AVG_TDD</th>
<th>AVG_IDD</th>
</tr>
</thead>
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<tr>
<td>M190EG0A</td>
<td>45</td>
<td>37900</td>
<td>$0</td>
<td>$179,526,975</td>
<td>30</td>
<td>10911</td>
<td>$0</td>
<td>$14,717,069</td>
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<tr>
<td>M190EFOB</td>
<td>111</td>
<td>169653</td>
<td>$0</td>
<td>$1,018,724,586</td>
<td>54</td>
<td>8620</td>
<td>$0</td>
<td>$30,574,487</td>
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<tr>
<td>M190ENOC</td>
<td>98</td>
<td>10675</td>
<td>$26,679,561</td>
<td>$37,755,964</td>
<td>10</td>
<td>17380</td>
<td>$0</td>
<td>$48,593,480</td>
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<tr>
<td>B154EW0A</td>
<td>101</td>
<td>39057</td>
<td>$3,161,917</td>
<td>$108,756,763</td>
<td>59</td>
<td>32184</td>
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<td>33119</td>
<td>$0</td>
<td>$138,377,362</td>
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<td>17315</td>
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<tr>
<td>B154EW0C</td>
<td>65</td>
<td>15401</td>
<td>$58,032,202</td>
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<td>B170PW0C</td>
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<td>18655</td>
<td>$0</td>
<td>$105,501,876</td>
<td>23</td>
<td>6237</td>
<td>$0</td>
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<td>67</td>
<td>13007</td>
<td>$0</td>
<td>$47,582,557</td>
<td>61</td>
<td>8025</td>
<td>$0</td>
<td>$14,912,523</td>
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<tr>
<td>Total</td>
<td>679</td>
<td>356330</td>
<td>$101,853,681</td>
<td>$1,730,450,050</td>
<td>401</td>
<td>153594</td>
<td>$0</td>
<td>$362,847,169</td>
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</table>

Difference between DPRM and OM (Gain) 278 $101,853,681 $1,368,072,655
5 CONCLUSION

The main purpose of this study is to verify the application of Demand-Pull Replenishment Model (DPRM), derived from TOC, in TFT-LCD industry. By taking a leading TFT-LCD manufacturing company in Taiwan as an example, the comparison between DPRM and Original Model (OM) of the company was conducted. The results of the case study have indicated that DPRM outperforms OM in terms of average inventory, TDD, and IDD. In other words, the replenishment method of TOC can reach the ultimate goal of lowering the overall inventory level as well as satisfying customer’s needs.

6 ACKNOWLEDGEMENT

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7 REFERENCES