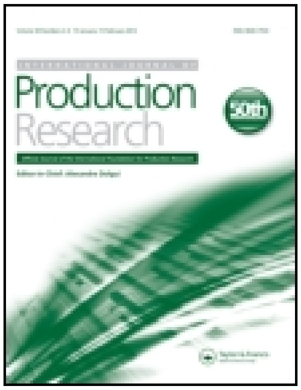

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Identifying inventory problems in the aerospace industry using the theory of constraints

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Identifying inventory problems in the aerospace industry using the theory of constraints

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In the aerospace industry, where each component is time-critical, many operation management tools are applied to improve material management efficiency. By using the theory of constraints (TOCs), this study diagnoses the undesirable effects (UDEs) of material management systems and identifies root problems or conflicting material management actions. In the second step, via UDEs, this study constructs a current reality tree (CRT) to identify a company's material management objectives and requirements, and the actions it takes to meet these objectives. In addition, the UDEs and CRT are applied to redesign the future reality tree (FRT) to develop strategies and eliminate the problems in the case company. By eliminating the conflicting inventory management activities of different departments, inventory management performance for the entire system is improved.

Keywords: theory of constraints (TOC); inventory management; aerospace industry

1. Introduction

Many organisations recognise the need to improve their operations. However, many managers have trouble focusing efforts and converting objectives into reality (Chase *et al*. 2006, Slack *et al*. 2006, Krajewski *et al*. 2007, Stevenson 2007, Heiser and Render 2008, Schroeder 2008). Because the aerospace industry uses a wide range of speciality materials, procuring materials takes considerable time and companies must stock certain amounts of raw materials to deal with changes to client orders. Consequently, warehousing costs for components and their related materials remain high. Major aircraft manufacturers worldwide face intense cost competition (Watson and Vokurka 2006). Therefore, to satisfy client requirements and minimise cost simultaneously, decreasing the possibility of lacking materials and eliminating inventory problems are factors critical to firm success.

The theory of constraints (TOC) is a thinking process that can be applied to help organisations to identify the problems, find the strategies to solve them and eventually implement those strategies successfully (Mabin and Balderstone 2003). In addition, researchers indicated that TOC was also helpful in identifying an effective leverage point and strategic direction for transforming an undesirable state into a desirable future (Cox *et al*. 2003, Gupta 2003, Gupta *et al*. 2004). By reviewing previous literature, it is witnessed that manufacture systems applying TOC have better performance than those adopting manufacturing resource planning (MRP), lean manufacturing, agile manufacturing, and just-in-time (JIT) (Cook 1994, Holt 1999, Mabin and Balderstone 2000). Therefore, compared with other techniques, TOC has been applied extensively in different academic interests, such as project management (Umble and Umble 2000, Steyn 2001, Cohen *et al*. 2004), supply chain management (Rahman 2002, Watson and Polito 2003, Simatupang *et al*. 2004), process improvement (Atwater and Chakravorty 1995, Gattiker and Boyd 1999), and inventory management (Rahman 2002, Mabin and Balderstone 2003).

The advantages of TOC techniques regarding decreasing the inventory and cycle time, and increasing the output has been proved in previous literature (Aggarwal 1985, Johnson 1986, Koziol 1988). Moreover, TOC has been applied primarily to managerial challenges in the private sector for production improvements, logistics, and inventory control (Umble *et al*. 2006, Tsai *et al*. 2010), especially in the aerospace industry, such as Boeing and Delta Airlines (Watson *et al*. 2007). Therefore, this study applies the theory of constraints to identify the problems of

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inventory management and found out the solutions in the aerospace industry in Taiwan. This study uses a case study to define inventory problems and discover their root causes.

2. Background and literature review

2.1 *Theory of Constraints (TOC)*

Materials requirements planning (MRP), supply chain management (SCM), just-in-time inventory management, and enterprise resource planning (ERP) are all common tools in operations management. TOC is relatively new and less known in operations management. As a fairly new managerial philosophy, TOC has evolved steadily since the early 1980s. This systems-based approach to management, primarily developed by Eliyahu M. Goldratt, uses fundamental logic to identify the principal relationships responsible for an organisation's performance. This theory has three major components: a set of fundamental system-oriented premises, a five-step focusing process and a set of robust logic tools that facilitate the focusing process.

TOC considers a company as a system, and a system as a chain of interrelated components or subsystems. A system-based management philosophy, TOC is based on the following three interrelated assertions (Schragenheim and Dettmer 2001, Boulding *et al.* 2005):

- Each system has a goal and a set of necessary conditions that must be satisfied to achieve its goal.
- Overall system performance is more than the sum of the performance of its components.
- Very few factors or constraints (often only one) limit a system's performance at any given time.

TOC has a five-step process to solve system constraint (Goldratt and Weiss 2005, Gupta and Snyder 2009). As a weak link limits the strength of a chain, resource or production factors with the smallest capacity limit system throughput. Goldratt (1990) developed a five-step focusing process to guide management of a system's leverage points or constraints. By focusing time and energy on managing system constraints, managers can concentrate efforts on aspects that will improve the overall system performance. Table 1 lists the five focusing steps and describes their managerial implications.

TOC typically focuses on a process and is used as a framework guiding the behaviour of a system-oriented improvement team as its members seek to improve organisational responses to customer demands in a competitive and dynamic marketplace. The five steps are as follows:

(1) Identify system constraints.
(2) Determine how to exploit these constraints.
(3) Subordinate all other factors to decisions made in step 2.
(4) Delete system constraints.

Table 1. The TOC five step focusing process and associated managerial implications.

TOC five step focusing process	Meanings in managerial practice
1. Identify the constraint: Determine the system activity whose capacity is less than the demand placed on it.	System's constraint may be internal (because of organisation's resource, capability, or policy) or external (business cycle, customers' preference). Make sure where the constraint comes from and answer the question: What resource, if the system had more of it, would enable the system to increase its rate of goal attainment?
2. Exploit the constraint: Maximise the efficiency of the constraint activity in its existing system configuration.	Eliminate all waste or non-productive time or activities at the constraint.
3. Subordinate all else: Synchronise the operation of all other system components with the constraint activity.	Use a new process to manage the resource which is not being used efficiently.
4. Elevate the constraint: Increase the capacity of the constraint activity to eliminate it as the constraint.	Acquire additional resources to increase constraint capacity.
5. Return to step 1 but prevent inertia. Revisit all changes to ensure that they still support the current system configuration.	Preventing inertia means examining the new system configuration to ensure that the changes implemented in managing the prior constraint remain appropriate.

(5) Return to step 1 while preventing inertia from becoming the next constraint.

By applying TOC, Rahman (2002) identified the problems in inventory management and understand the underlying relationship between the problems in high inventory management cost. Umble, Umble and Murakamis's (2006) study also apply TOC in Japanese tool manufacturing company to identify and resolve problems. Through TOC can improve the work-in-process inventory, production lead time, on-time delivery, inventory turnover, product quality, and profitability. Therefore, TOC systems produce greater levels of output and reducing inventory, manufacturing lead time, and the standard deviation of cycle time (e.g. Cook 1994, Holt 1999, Mabin and Balderstone 2000).

By conducting a case survey on published case studies, Mabin and Balderstone (2003) provide the understandings of the results of applying TOC. Results of the survey showed that over half of the cases (42/81) reduced their inventory, for instance, Procter and Gamble and Ford Motor Co. Electronics Division reduced their inventory by US$600 million and US$100 million, respectively (Gardiner *et al.* 1994). In addition, three-quarters of the organisations experienced improvements of over 40%. Therefore, case study and case survey have both found that TOC is an improvement tool in inventory management.

2.2 *TOC is a thinking process*

In 1994, Goldratt introduced and demonstrated how use of a set of powerful logic tools helped managers understand and improve organisational performance (Goldratt 1994). This thinking process tool set guides a manager's thought processes and facilitates changes in management. These tools also help managers identify the core problem or root cause of system dysfunction, create an effective breakthrough solution and plan change implementation to eliminate this core problem. These tools are most effective in situations that represent true opportunities for managerial improvement, such as a longstanding issue or conflict that remains unresolved despite significant efforts to rectify this issue. The TOC thinking process, a structured approach to developing simple solutions to seemingly complex problems, uses a framework to help managers understand key relationships associated with improving organisational performance. In short, these logic tools help direct management of organisational change.

The TOC approach to change management requires that the following three questions are answered (Goldratt 1990): What must be changed? What is the change goal? How does one implement this change? Thinking process logic diagrams use these three questions to guide managers as they work to implement a change sequence. The TOC thinking process relies on logic diagrams to understand, analyse, and improve an existing system and one ancillary tool to proactively determine and eliminate unfavourable change consequences. These tools use either sufficiency or necessity logic to help managers understand why undesirable outcomes that characterise a current situation occur, ascertain the effects of interventions designed to eliminate undesirable conditions, and offer guidance on how to manage the change required for improved performance. To identify what to change, this study constructs conflict clouds from UDEs and a current reality tree (CRT) to identify the core problem. In terms of what to change to, this study constructs a future reality tree (FRT) that describes the future goals and how to achieve the desired results. Finally, this study identifies possible problems and specific actions to solve these problems effectively. The ancillary tool, negative branch reservation, is utilised to logically document the potential adverse effects of change in the FRT. Table 2 shows the relationship between each stage in the change sequence, and the steps that must be taken by an improvement team to manage change.

3. Current status of the case company

The case company uses software SAP, which provides an electronic operational process for sales, ranging from preliminary information processing to quoting, pricing, order management, shipment, collection, invoicing, and posting to markedly shorten the order management process that would otherwise be prolonged; SAP also shows cost in real time. According to the internal materials procurement process of the case company, the Material Division first submits its requirements to the Procurement Division, which in turn determines the amount to be procured, delivery date, and price based on the suppliers' previous performance. Because the procuring duration is protracted, and the discrepancy between the original contract and annually altered demand is increasing, if the modified demand in a client's order must be satisfied, suppliers may fail to deliver the materials in the allotted timeframe.

In terms of delivery of the case company's procurements, delayed payment interest from other deliveries is used to offset increased ordering cost per unit resulting from small purchases. The case company has no so-called best

Table 2. Relationships between change sequence and thinking-process analysis steps.

Stages in the change sequence	Thinking process steps	
1. What to change?	1.1	Identify undesirable effects.
	1.2	Create selective basic conflicts and synthesise the core conflict
	1.3	Provide entity linkages between the core conflict and undesirable effects.
2. What to change to?	2.1	Create and validate injections that will logically change undesirable to desirable effects.
	2.2	Identify and correct any negative side effects resulting from injections.
3. How to cause the change?	3.1	Identify all obstacles preventing implementation of injections.
	3.2	Provide a step-by-step tactical action plan for implementing injections.
	3.3	Communicate action rationales to others.

procuring mode. Additionally, the case company has attempted to establish materials-procuring norms for reference based on client order estimations, the information provided by a professional database, and prediction results acquired internally by case company. Errors arising from predictions lead to unnecessary material stockpiles. To increase the inventory turnover rate, extra materials must be sold at low prices. All of these factors led to unsatisfactory performance of the case company's overall inventory managerial system. After organising data collected from regular interviews conducted during a six-month period, this study identified the following problems encountered by the case company.

3.1 *Material division*

(1) When a project is complete, extra procured materials should be disposed because they cannot be sold; this increases cost.
(2) To address demands for military aircraft parts, material preparation activities are needed. However, as the procurement process is prolonged, inventory backlog likely occurs once orders change at the demand end.
(3) A false forecast of economic trends always leads to overstocked goods when excessive materials/parts are procured.

3.2 *Procurement section*

(1) The top priority is to purchase materials at the lowest price; the delivery period is the second priority. Thus, to obtain materials as scheduled, the firm must order in advance, which extends inventory storage time.
(2) As Company A is relatively small in the aerospace industry, it is weak when negotiating prices with vendors. Thus, problems associated with inventory occur often when the minimum order quantity (MOQ) set by a supplier exceeds the volume required by Company A.
(3) Suspending procurement due to order changes is impossible. Because Company A does not provide vendors with a high supply priority and the preliminary period for procurement is long, Company A should tackle the procurement in order materials in advance; however, this will inevitably cause overstock and excessively long inventory storage times. Furthermore, when an order changes, Company A, because of its long procurement time, should again purchase new parts/products from vendors for the required materials listed on the new order; this results in delayed production, thereby adversely affecting delivery date.

3.3 *Production division*

(1) Inaccurate forecasts of market demand result in failure to initiate [works TRY production] as scheduled and delayed production.
(2) When the configuration of an aircraft's parts changes, the firm can claim compensation in the case of an original equipment manufacturer (OEM) order. Conversely for an original design manufacturer (ODM) order, all semi-finished products and materials will be wasted when the product configuration changes.

(3) The production division has not established a precise material input estimation model. Thus, the division can only estimate consumption of open were based on experience, resulting in excessive procurement.

This study uses TOC to develop a thinking process that leads individuals and divisions of the case company to improve performance significantly via a logical relationship. The following section presents some simple examples, which match the case company's status, to demonstrate the application and implementation of the TOC.

4. Diagnosis

Thinking process logic tools are applied to describe and analyse the major issues associated with the organisation's current situation. The analytical approach undertaken involves identifying the core conflict, defining the root problem, proposing and validating changes to eliminate this problem, and managing the implementation of desired changes. To analysis involve three steps: Step 1 provides a situational background and uses analysis to define the problem. It introduces the study system and documents various UDEs associated with the firm's situation. Selected problems are characterised by conflicts that are used to identify the core problem responsible for the vast majority of UDEs and, thus, the relatively poor system performance. A major logic diagram is then created to generate a comprehensive understanding of the fundamental cause of the existing situation. Step 2 combines the UDEs and core conflict to construct the current reality tree (CRT), which can confirm the real problem. In addition, this step also understands the UDEs resulting from implementation and improvement guidelines. In order to break through the existed conflict, Step 3 constructs future reality tree (FRT) to found out and implement the solutions. It can change the status quo and achieve the future goal. Following the three steps of TOC applied in inventory management.

Step 1: After several interviews (including two system management engineers, three purchases managers, six materials management engineers, one materials management manager and two production management engineers) this study identified a number of UDEs for the case company.

UDE 1: No effective management of inventory turnover.
Interpretation: To enhance inventory turnover, the management and administration division establishes goals for inventory turnover for each division when conducting an appraisal to accelerate internal inventory flow and thereby reduce inventory storage time. Unfortunately, the firm ignores the fact that a division/section may decrease the quantity of materials for each production process to increase inventory turnover and reach the goals set by the management and administration division. These goals may increase total production time and procurement frequency, leading to increased risk for the company subject to supply chain delays, thereby hindering production progress and delaying delivery, for which the case company must compensate clients according to contractual agreements.

Based on this description, this study builds a conflict resolution diagram for UDE 1 as shown in Figure 1.

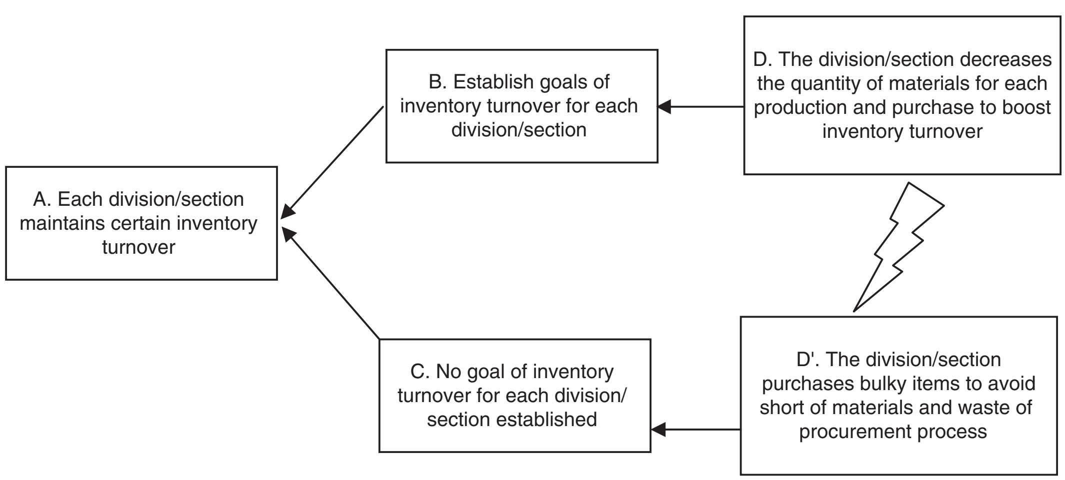

Figure 1. Conflict resolution diagram resulted from UDE 1.

UDE 2: Delayed delivery due to material shortages.

Interpretation: UDE1 is supported when the case company has stronger negotiation power than vendors. To avoid internal inventory backlog, the Logistics Management Division alleviates overstock problems using vendor consignment stock. As inventory pressure is transferred to the vendor, the vendor may also maintain the minimum inventory level instead of the optimal or safest inventory level to reduce its inventory cost. When a customer demands delayed delivery, no extension problem results; however, once the delivery configuration changes or when a rush order is placed, the case company will delay delivery as a result of insufficient inventory. Notably, each purchase order requires a certain procedure and delivery time. Furthermore, a vendor may dispatch its personnel to the case company, even though they do not observe or measure how to materials are fed into production in a timely manner.

Based on this description, this study constructs a conflict resolution diagram for UDE 2 as shown in Figure 2.

UDE 3: Reduce losses resulting from configuration changes.

Interpretation: To reduce loss from recognised idle materials due to configuration changes the case company uses procurement mechanisms such as flexible ordering and procuring in batches. Because the case company is smaller than other international players and its purchases are much smaller, supplying the case company is not a top priority for vendors. Therefore, when using flexible ordering or procuring in batches, the case company will not receive supplies until the vendor has supplied its top-priority clients.

From this description, this study constructs a conflict resolution diagram for UDE 3 as shown in Figure 3.

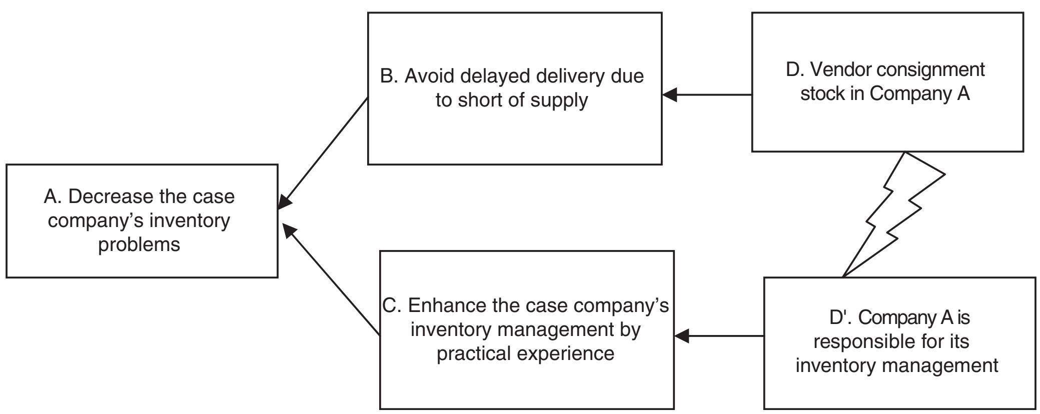

Figure 2. Conflict resolution diagram resulted from UDE 2.

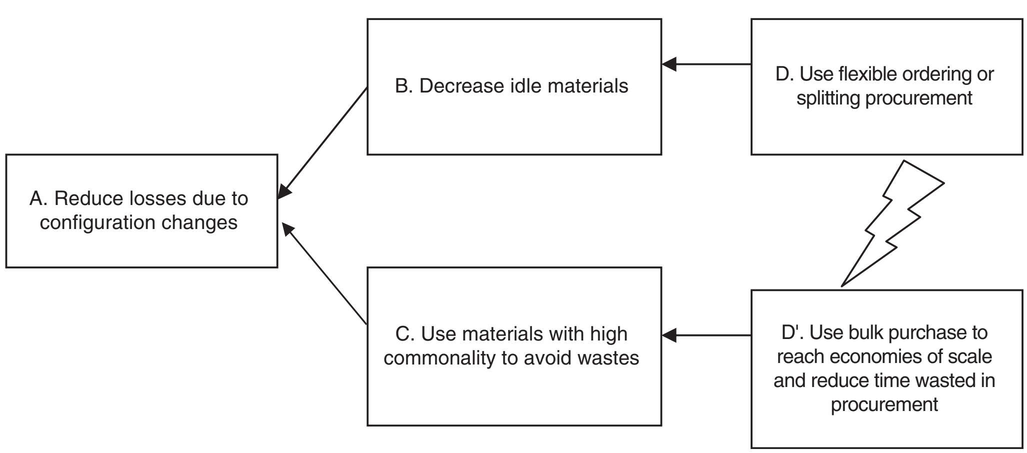

Figure 3. Conflict resolution diagram resulted from UDE 3.

Step 2: Based on the UDEs derived from Step 1 and discussions with managers, this study summarises the various UDEs and builds a CRT for the case company as shown in Figure 4.

We proposed that the procurement section of the material division achieve performance goals as well as the UDEs resulting from conflicts between performance improvement guidelines in divisions/sections.

1. *The UDEs resulting from implementation guidelines – Procurement Section, Material Division*

(1) *Interpretation*: To avoid procuring excessive amounts of materials, which may result in prolonged inventory storage, reduced inventory turnover, and increased inventory costs, the case company uses the economic order quantity (EOQ) to minimise the sum of ordering cost and storage cost. However, when a vendor has relatively stronger negotiation power and when the order quantity does not meet the shipment standard, Company A must negotiate with the vendor on the MOQ to narrow the gap between the EOQ and MOQ and thereby reduce inventory cost and increase inventory turnover. However, this causes the following UDEs resulting from two interference factors:

(a) Unstable delivery in the supply chain: As delivery in the supply chain is unstable (many materials ordered by Company A are also ordered by other companies who have higher priority than Company A), production materials are lacking, which delays product delivery. In this case, Company A must compensate clients.

(b) The MOQ is larger than that required for production: Because the materials ordered by Company A have unique specifications, and the vendor is only willing to initiate production when the order quantity covers its production costs, such as mould opening and transportation costs, the MOQ may exceed that required by Company A. For instance, when Company A's project requires 80 pieces, but the vendor's MOQ is 100 pieces and the cost of 100 pieces is the same as that for 80 pieces (as the vendor needs to dispose of the remaining 20 pieces), Company A will purchase 100 pieces. Excessive materials prolong inventory storage. Moreover, many pieces may be tailor-made for special aircraft, thus only idle materials and wasted materials can be recognised, which may result in inventory costs remaining high for Company A. The relationship among UDEs in connection with procurement section of material division as shown in Figure 5.

(2) *Interpretation*: To increase inventory and keep inventory costs minimal (avoiding the situation that, when a certain project ends, one can only recognise idle materials or wasted materials or dispose of materials at cheap prices for materials ordered each time for the project), Company A uses materials with universal specifications and high commonality. However, this causes a problem – projects sharing these materials are not conducted simultaneously or sequentially; furthermore, with configuration changes, many materials may not be applicable to a new configuration, leading to the recurrence of recognition of idle materials or wasted materials or disposition at cheap prices, which increases inventory costs. The causal relationship between UDEs in connection with procurement section of material division in Figure 6.

2. *The UDEs resulting from conflicts between performance improvement guidelines in divisions/sections–Procurement Section, Material Division*

(1) *Interpretation*: To eliminate losses due to configuration changes, the company uses flexible ordering and batch procurement to reduce order quantity and risk. To avoid procuring excessive amounts of materials, Company A negotiates with vendors on the MOQ. However, for special materials, the vendor may be required to proceed with mould opening before production; production cost is only allocated when production reaches a certain level. Under such circumstances, Company A cannot effectively lower its inventory costs, because it has weak negotiation power with upstream suppliers. The concrete action conflict resolution diagram as shown in Figure 7.

(2) *Interpretation*: To increase inventory commonality and avoid problems associated with idle materials and wasted materials, Company A uses materials with universal specifications and high commonality. Alternatively, to reduce inventory storage time, Company A eliminates inventory or idle materials as soon as possible and promptly recognises wasted materials. However, conflicts exist between these two approaches. When the configuration of a specific project changes materials with high commonality that were purchased previously should be stored in a warehouse until the next appropriate project. In this case, inventory cannot be eliminated as soon as possible; although a high likelihood exists that these materials with universal specifications and high commonality will be used in future projects, Company A must eliminate these materials to reduce inventory storage time.

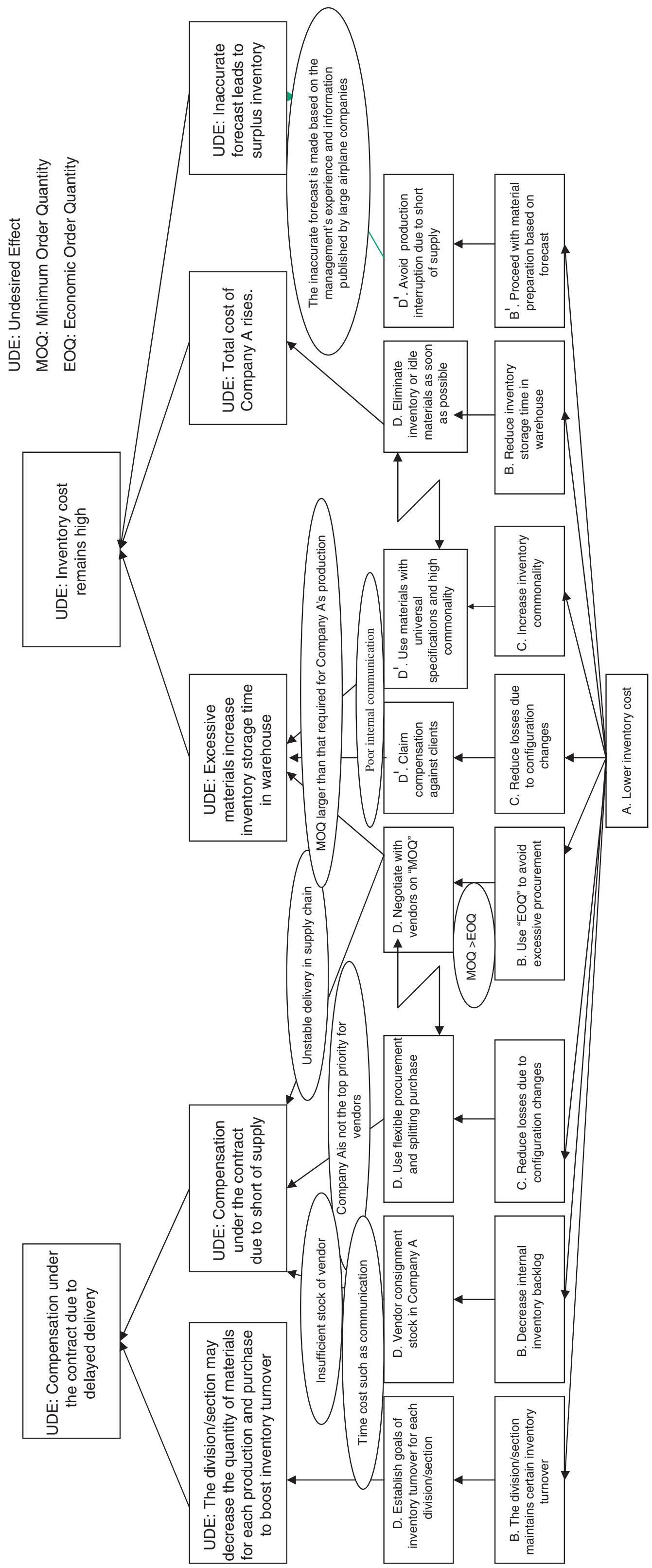

Figure 4. Conflict resolution diagram and current reality tree of the Company A.

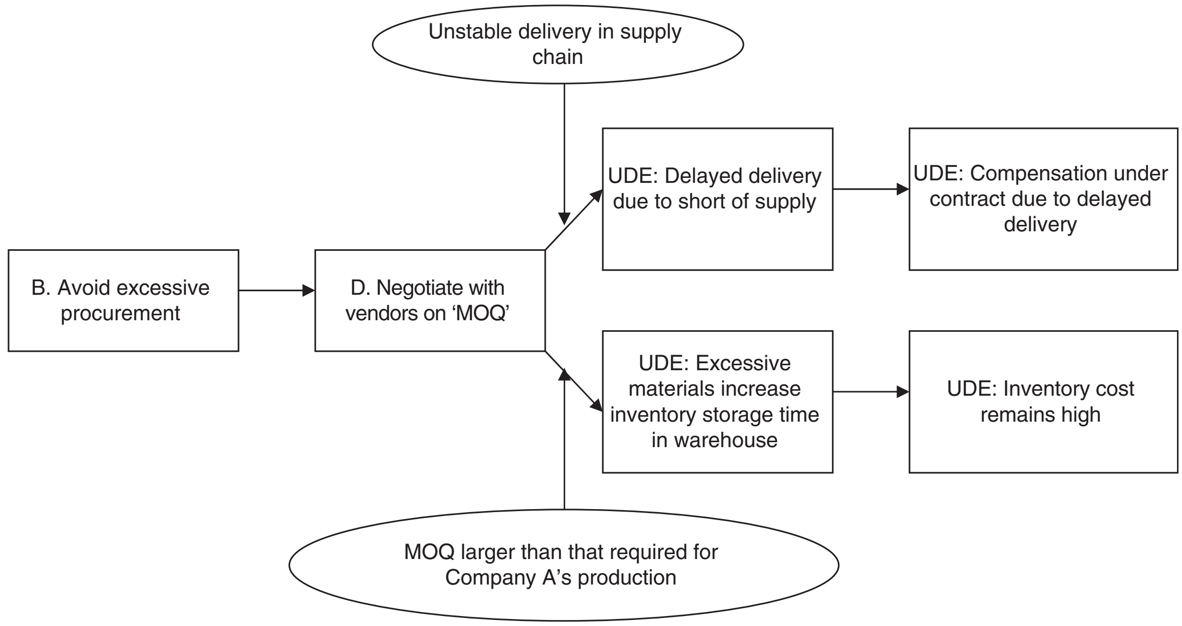

Figure 5. Relationship among UDEs in connection with procurement section of material division.

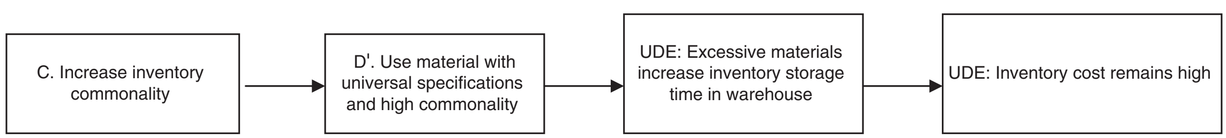

Figure 6. Causal relationship between UDEs in connection with procurement section of material division.

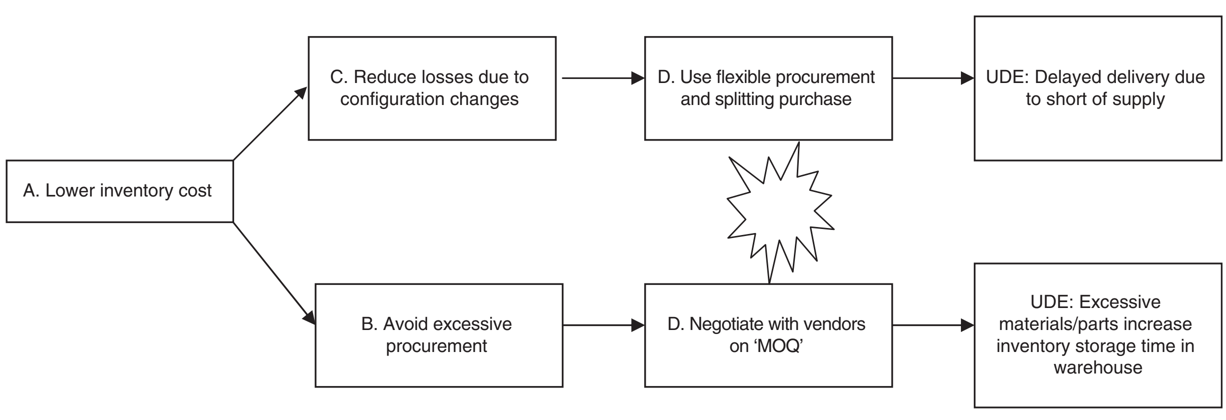

Figure 7. Concrete action conflict resolution diagram (1).

Therefore, project production cost increases, as does the cost for new projects, for which Company A must again purchase the same materials. The concrete action conflict resolution diagram as shown in Figure 8.

Step 3: After drawing a CRT to confirm the current situation faced by Company A, one must think about how to eliminate these UDEs. By drawing a FRT, some procedures for eliminating UDEs can be developed. Furthermore, an FRT can help determine whether these steps generate additional UDEs. After eliminating all UDEs, the initial desirable effect can be achieved. The future reality tree of Company A as shown in Figure 9.

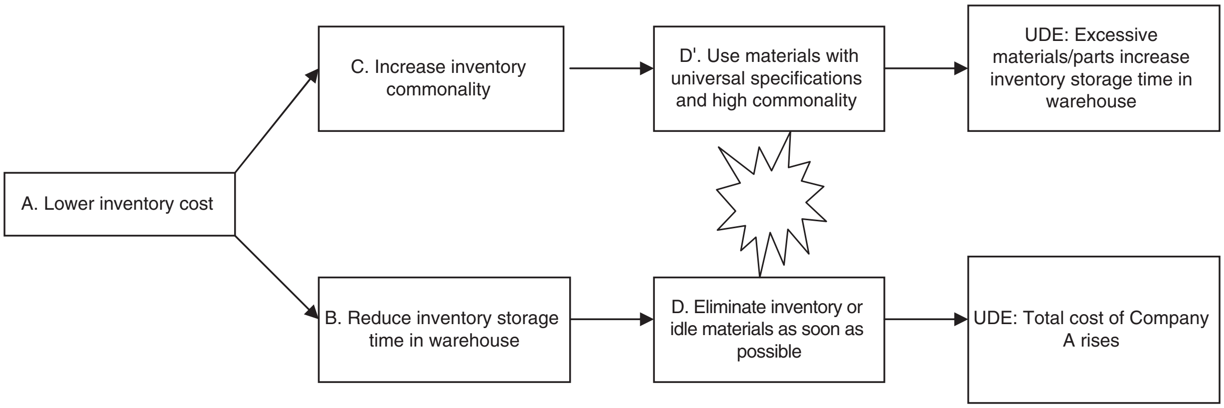

Figure 8. Concrete action conflict resolution diagram (2).

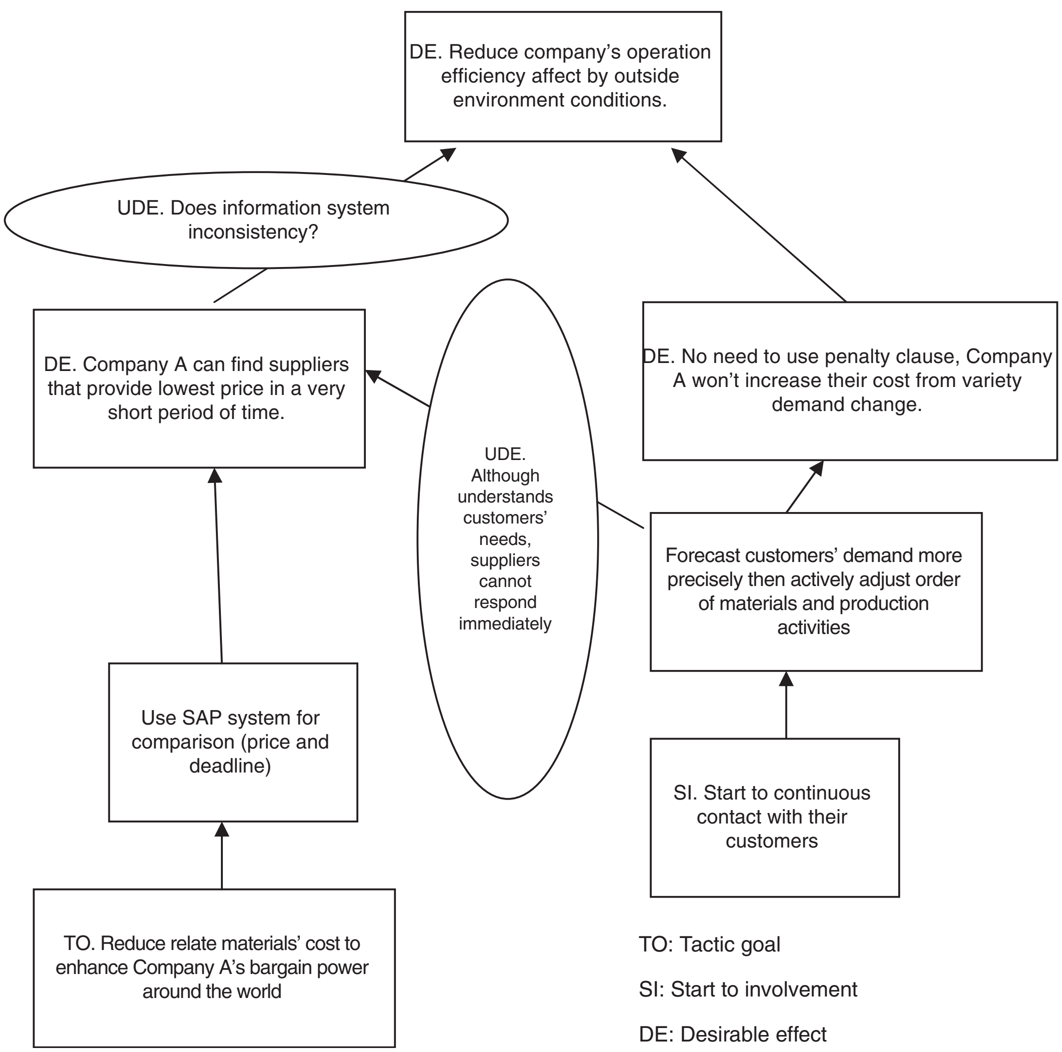

Figure 9. Future reality tree of Company A.

Interpretation: Before drawing the FRT for Company A, one must determine whether any unexpected problems have developed. For instance, inconsistency in the information system between Company A and its suppliers increases waiting cost. This is because a gap exists between customer need variation and supplier capability to provide materials. To overcome these problems, Company A should develop solutions that resolve unexpected problems.

5. Conclusion

First, each department in Company A has implemented concrete programmes to improve operational performance. However, some department goals are conflicting. For instance, an inconsistency exists between the departmental goal of 'using flexible ordering to reduce losses due to aircraft configuration changes' and 'the MOQ for vendors'; management ignores the gap between minimum shipment quantity for the vendor and company demand. In this case, the procurement department must dispose of surplus inventory at cheap prices to reduce inventory management costs. Second, conflicts may occur between inter-department performance improvement programmes. To avoid waste, the management and administration division favours procuring materials with wide applicability, such that these materials can be applied to the next project even when model design changes. However, for the material control section of the material division, excessively long inventory storage adversely affects its performance and, therefore, the section must dispose of materials at cheap prices to reduce inventory storage time. Thus, a conflict exists between the division and section, which, in turn, results in mutual resistance to their performance improvement programmes.

Based on the aforementioned analytical results, we suggest that the three divisions/sections of Company A use the following strategies. For the procurement section, analytical results suggest that the top priority is to use inventory by enhancing mechanisms, such as transfer/alternative/exchange, which help in eliminating unnecessary orders and reducing inventory. Additionally, continued consignment or procurement of long-term contracts can be based on the project schedule for allocating orders.

For the material division, an incoming material quality control strategy is needed. Any order requisition over a certain price should be reviewed by a specific committee. Further, materials can be classified according to their price and importance for further control. Methods such as batch ordering and avoiding purchasing materials too early should be considered. Finally, extra materials can be sold to reduce material wastage.

For production scheduling, the production division of Company A should require that its contractors follow its production schedule when providing materials. Moreover, the production division can integrate production engineering, scheduling, and site management to reduce work-order cycle time.

While a project must change because a customer has changed an order, problems arise such as when ordered materials are unsuitable for production or products cannot satisfy customer need. This may require negotiation for claims as the customer has changed the order. Therefore, one must track materials in transit. When customers cancel or delay orders, Company A should have response strategies. Accordingly, Company A should set goals for annual inventory turnover by each division and hold regular monthly inventory review meetings to monitor inventory.

5.1 *Implication*

This study applies TOC in the aerospace industry and provides valuable insights into the prerequisites for success of TOC implementations. This study shows how TOC can be applied in the aerospace industry for identifying the core problems and developing strategies when encountering critical obstacles or conflicts. Analytical results demonstrate that each department has different goals. The material management department utilises economic order quantity (EOQ) to reduce average material cost, while the inventory management department uses a flexible purchasing system to reduce inventory cost. Furthermore, the company should have the same goal to reduce the contradiction in inventory management. In addition, company can use TOC regularly to view the defect or fault before proceeding with high inventory management cost. Finally, TOC can be applied into other operation systems for improvement performance.

5.2 *Future research*

The majority of TOC research is limited to cross-sectional survey and neglects longitudinal research. Due to the fact that the company's situation may be influenced by the outside environment, the core problems may be different in operation and inventory management. However, longitudinal research can further analysis and explore the underlying critical issues by more confirmation. Therefore, further research is suggested to adopt longitudinal study to effectively confirm and eliminate core problems by TOC implementation.

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