A Study on the Complementary Use of EC and CLD in Developing Win-Win Solution for Traditional Manufacturing Dilemma

Seonmin Kim[1)], Victoria J. Mabin[2)], and John Davies[2)]

[1)] Department of Business Administration, Seoul National University of Technology, Seoul, Korea (skim@snut.ac.kr)
[2)] Victoria Management School, Victoria University of Wellington, New Zealand (vicky.mabin@vuw.ac.nz), (john.davies@vuw.ac.nz)

Abstract

In decision making processes, it is important to fully understand the problematic situation as well as providing a solution. In order to address and fully understand problematic situations, this paper suggests a complementary method that demonstrates how the Evaporating Cloud (EC) Diagram in the Theory of Constraint method can be used to complement the use of well known system dynamics approach.

Exploring the case of general problem situations embedded in the manufacturing process, the paper examines the collective use of two approaches as a means of understanding of the conflict situations faced by production managers, and as a means of providing a basic frame for developing a win-win solution. This paper highlights that a student in production management field could get the benefits in using the integrated approach to better analyze and understand the nature of the problematic situation, and to better understand how and why the taking one action can cause conflicts with an alternative action in order to dissolve problem situations.

1. Introduction

In an environment characterized by fierce competition and uncertainty, manufacturing companies want to respond quickly and flexibly to changing customer demands and satisfy customer orders at relatively low cost. However, it is difficult to maintain their desired performance in throughput and cycle time since a variety of sources of statistical fluctuations exist in manufacturing processes, such as machine failures, material shortage, employee absenteeism, and variances in processing times. The impact of such fluctuations, if ignored, is that it becomes difficult for a production line to achieve the required performance levels. Thus, it is important for a production manager to identify which methods/ sources of protection are most desirable for a manufacturing process to offset such variations.

When statistical fluctuations occur across dependent resources, fluctuations (delays) accumulate across the resources. This natural phenomenon was described in The Goal (Goldratt and Cox, 1986; reprinted in 1992, 2004) and The Race (Goldratt and Fox, 1986). It is the combination of these two characteristics that limit line throughput and cycle time to well below the expected values. Thus the line has below expected throughput. To approach expected throughput for a line, inventory must increase. Therefore, in order to protect the performance of a line from statistical fluctuations, manufacturing companies historically have operated with significant amounts of work-in-process (WIP) inventory (or protective inventory) between workstations. The purpose of using WIP inventory is to provide each workstation of a production system with some degree of independence from other workstations.

However, the increase in inventory causes cycle time to increase. Conway et al. (1987) suggests that the most important cost of WIP using as a protection purpose is the effect on manufacturing "lead time" or "cycle time." Cycle time (also called flow time) is the time required to move a unit of material through the manufacturing process, from entry at the first workstation to completion at the last workstation. Thus, cycle time is the sum of processing times at each workstation and the queue, move, setup, and other times. For example, if excess WIP exists in the line, units of WIP spend a large amount of time waiting in queues as work-in-process; hence, products have long manufacturing lead times (i.e., cycle times). Especially, the benefits of reduced cycle times were examined by Taylor and Davis (1977).

They explained that reduced cycle time means quicker delivery to customer requests, less need for finished goods inventory, reduced operating cost, and increased market share. As a result, it is imperative to seek lower WIP inventory in order to reduce cycle time while remembering that, as discussed earlier, reducing WIP too much will harm throughput. In addition, with the advent of the Just-in-time (JIT) philosophy, advocates explain that the use of WIP buffers (protective inventory) increases the cycle times and also results in poor due date performance (Hall, 1987). It is imperative to plan and control the use of WIP buffers if one is to reduce the cycle time and to have the flexibility in responding to customer demands. However, reduced cycle time has a negative impact on the throughput level, i.e., the throughput level is reduced.

Therefore, the general manufacturing situation may lead a production manager to the following questions.

- Is using WIP inventory the only and/or best way to protect the line's performance from the statistical fluctuation?
- What is the systemic impact of using WIP inventory on the performance of a line?
- Is there another way to raise throughput and reduce cycle times simultaneously?

Thus, this paper seeks to provide a way to address and fully understand the system-wide effects of the use of WIP inventory. To do this, this paper will outline and provide constructive illustration of the use of the individual representational tools, the causal loop diagram (CLD) in system dynamics approach and the Evaporating Cloud (EC) Diagram in the Theory of Constraint method. In other words, it first shows how this conflict situation can be framed using a CLD and an EC respectively and then seeks to build a multi-methodological approach that harnesses the use of two complementary systems representational tools. This paper investigates how the EC in the Theory of Constraint method can be used to complement the use of well known CLD in system dynamics approach for framing a conflict situation and developing a systematic solution in the case of the use of WIP inventory as a protection purpose. This paper highlights that a student in production management field could get the benefits in using the integrated approach to better analyze and understand the nature of the problematic situation, and to better understand how and why the taking one action can cause conflicts with an alternative action in order to dissolve problem situations.

2. Causal Loop Diagram for Framing Problematic Situation

System dynamics approach has been used over the past 40 years to understand a problematic situation and then to develop an action for increasing system performance. Originally started from Industrial dynamics developed by Forrester (1961), system dynamics approach focuses on feedback loops, represented as cause-effect relationships and time delayed responses in order to analyze the complicated dynamic system behaviour. Thus, the first step in system dynamics model includes identifying and documenting the factors that drive system behaviour as cause-effect relationships. To do this, Causal Loop Diagram (CLD) is used to illustrate the key drivers of system performance and how they are interlinked.

When production managers try to adopt the use of WIP inventory to protect a defined performance from statistical fluctuations, CLD could be implemented to show the relationships embedded in the manufacturing problem situation. The CLD in Fig. 1 displays how the use of WIP inventory may have the system-wide effect on the performance of a line. In Fig. 1, +S and –O annotation indicates relationships between the variables. The +S annotation indicates that the more we do the action at the tail of the arrow, the more the effect at the head of the arrow. Thus, the +S annotation shows the variables move in the same direction for a positive cause-effect relationship. On the other hand, the –O annotation indicates the more we do something, the less the effect. Thus, the –O annotation shows the variables move in the opposite direction for a negative relationship. The double bar // across an arrow denotes a delay – the effect will occur over time or after a time but not immediately. For example, we interpret the relationships for loop B1.

> *As the statistical fluctuations in a manufacturing line increases, production managers' difficulty in maintaining the defined performance of a line increases, driving up the PM's desire to increase the throughput, increasing the need for using WIP inventory as a protective purpose, leading to increased WIP inventory level, improving the level of throughput, and finally driving down the difficulty in maintaining the performance of a line.*

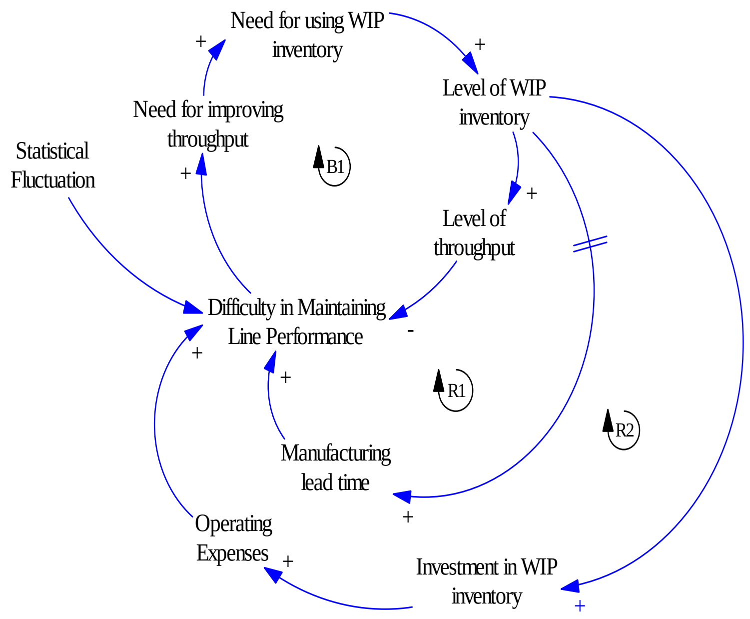

Fig. 1 Analysis of manufacturing problem using Causal Loop Diagram

When production managers use the WIP inventory as a protection means to offset the effect of statistical fluctuations, they could fully understand the relationships between key variables in the manufacturing line by using the CLD. Thus, production managers could get an insight for the problematic situation that shows whilst the use of WIP inventory may have its desired and intended impact in the short term (see loop B1), it may also have unintended and unwanted effects on the manufacturing lead time and production cost (see loop R1, R2). For example, in examining the loop R1, we find that….

> *As the statistical fluctuations in a manufacturing line increases, production managers' difficulty in maintaining the defined performance of a line increases, driving up the PM's desire to increase the throughput, increasing the need for using WIP inventory as a protective purpose, leading to increased WIP inventory level. As the WIP inventory level increases, the manufacturing lead time increases since any new released part have to wait for preceding parts to be processed before it can be processed, and then closing the loop, further increasing the PM's difficulty to maintain the performance. And also, as the WIP inventory level increases, driving up the willingness of PM to invest in inventory, leading to increased operating expenses, and finally further increasing the PM's difficulty to maintain the performance.*

As indicated in the loops R1, R2, the CLD shows that the use of WIP inventory may lead to worsening of already poor performance of a line. In other words, what this diagram is capturing is that WIP has both advantages and disadvantages: Too little and the line is starved sometimes, and too much and the parts are delayed on their way through the process. This leads to the thought that there must be an 'optimal' level of WIP. If we could have WIP such that the line is never starved and the parts are not delayed, then we would have an ideal. Many studies have searched for the 'optimal' level of WIP which balances the starving and delays in the process to maximize the performance of a line. However, selecting an 'optimal' WIP level does not provide a win-win solution such that desired throughput level and desired cycle times are maintained simultaneously

Therefore, the framing this conflict situation by the use of the CLD does not provide a win-win solution, but also does not capture what may be construed as the alternative actions or options for the use of WIP inventory. For the case of general manufacturing line, the use of waste removal, emphasized in Lean Manufacturing could be a candidate of the use of the WIP inventory. Thus, the CLD does not explain why plausible and seeming mutually exclusive actions or options for production managers will bring inherent conflict or dilemma. As such, the CLD approach does not reveal the nature of the dilemma faced by production managers. In order to shed light on such issues, this paper will show how the conflict resolution process of TOC, using the EC, can help identify and structure a dilemma, and how it can aid attempts to resolve a dilemma.

3. Evaporating Clouds of TOC for Framing Problematic Situation

The EC of TOC Thinking Process (TP) tools has been designed to explore, address and resolve a variety of conflict or dilemma situations as well as trade-off situations where compromise seems to be inevitable (Goldratt, 1990). The EC thus provides another way of conceptualizing tradeoffs, developing insightful ways of perceiving such tradeoffs and leading to alternative ways of dealing with them. We have found that, sometimes, the tradeoff can be avoided completely by reframing the problem through applying the EC. The advantage of the EC process is that it makes us explicitly consider and critique the assumptions we make implicitly when we frame the problem as a tradeoff. The process can also facilitate the surfacing of more options for dealing with tradeoffs, and ideally may be able to satisfy those on either side of the conflict without having to affect a tradeoff to meet our desired ends.

For the case of problem situations, embedded in general manufacturing process, the dilemma could be framed as whether or not to use WIP inventory, given the overall goal of improving the performance of a line. Since the EC explicitly focus the overall system goal, the choice dilemma and also the assumptions that underpin the dilemma, it emphasizes different features of the problem situation compared to the CLD in Fig. 1. The dilemma framed as the use of the EC is shown in Fig 2.

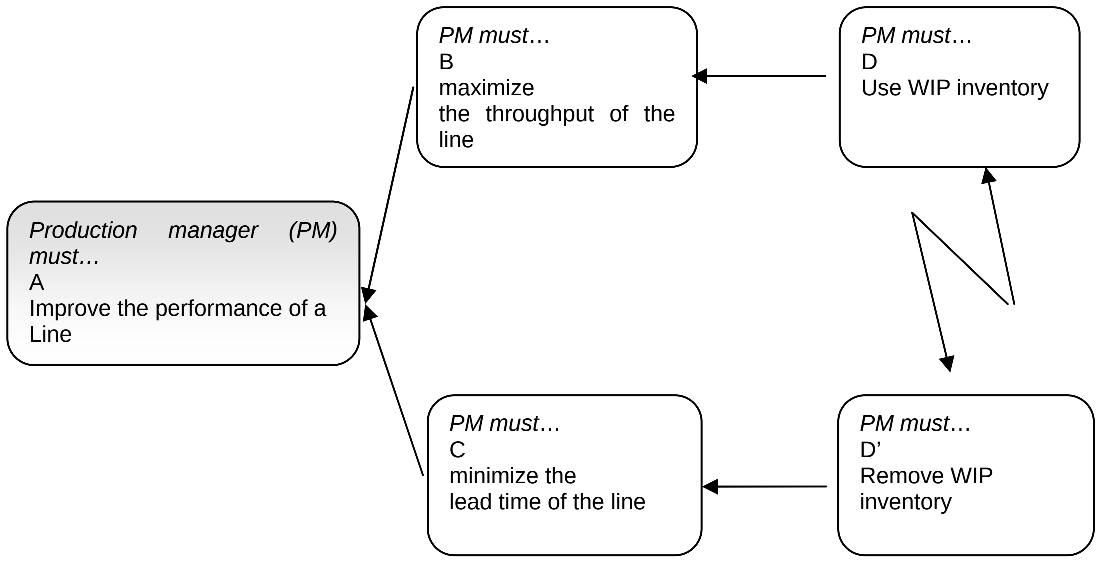

Fig. 2 The EC of TOC for the manufacturing problem

The dilemma in Fig. 2 can be interpreted as follows:

… that **in order to** ensure objective A *the improvement of the performance of a line*, **the production managers (PM) must** B *seek the way to maximize the throughput of a line…*

… and **in order to** B *seek the way to maximize the throughput of a line*, **the PM must** D use WIP inventory.

On the other hand, another view is:

… that **in order to** ensure objective A *the improvement of the performance of a line*, **the production managers (PM) must** C *seek the way to minimize the lead time of a line…*

… and **in order to** C seek the way to minimize the lead time of a line, **the PM must** D' remove WIP inventory.

Hence the conflict!

As soon as the dilemma has been framed in this way, the way of resolving the dilemma may quickly come up. However, whether or not we develop immediate insights, we may still need to elicit the assumptions that underpin each of the necessity-based logic relationships, represented as arrows in the diagram. Some of these assumptions relating to the logical relationships AB, BD, AC, and CD' are shown as annotations in thought bubbles on the EC in Fig. 3. These assumptions will provide a substantive rationale for the existence of the logical relationship; other wise, they will be found to be flawed or weak. Whenever the reasons or assumptions may be seen as false, the dilemma or conflict evaporates and win-win solution is developed.

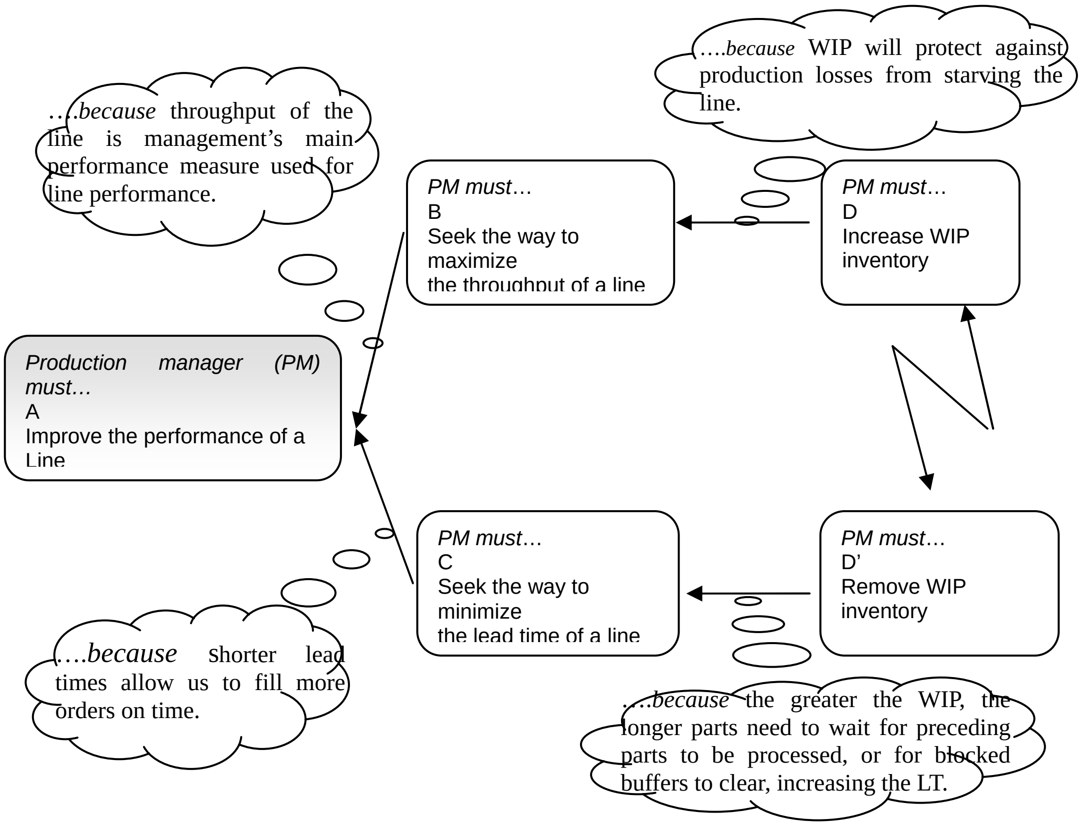

Fig. 3 The EC for the manufacturing problem with underpinning assumptions

4. A Complementary Use of CLD and EC

Production managers could seek a solution for the general manufacturing problem by using the EC or the CLD. However, neither the EC nor the CLD characterization of a problem situation can be expected to depict a fully comprehensive picture of the logic underpinning the various relationships between entities. Although the EC use the overall objective of dilemma resolution to be specified, the EC may represent only a subset of the necessity logic underpinning the relationships. On the other hand, although the CLD seeks to provide a holistic view of the problem situations, it can not hope to show all necessary and sufficient logic for all relationships. As such, it will be difficult to depict the full logic for the relationships embedded in the problematic situation. Therefore, it is important to fully demonstrate the nature of a problematic situation by integrating the relationships embedded between the EC and the CLD.

This paper suggests the combined and comprehensive CLD approach (Fig. 4) which includes the objectives, necessity and prerequisite conditions for the dilemma in the EC and the alternative to the use of WIP inventory infrastructure already surfaced in the EC. In addition, this paper argues that how the assumptions 'underpinning' a logical relationship between entities in the EC will often become intermediate links in the CLD logical chain. Therefore, this paper emphasizes that it is required to focus on system thinking in fully identifying the problematic situation by showing that one decision to solve the problem may incur the long term undesirable side-effects of alternative action.

The integrated CLD approach has the following characteristics. Firstly, as seen in Fig. 4, the overall objective variable A - improve the performance of the manufacturing line is located in the centre of the integrated CLD. The centrality of the overall objective variable A in the integrated CLD overcomes the weakness of the 'helicopter' view of the problem situation in the original CLD. For example, the integrated CLD describes how each of the balancing loops B1 and B2 show sequences of cause-effect relationships that 'start' with an the initial state of improving the manufacturing line performance …, and which drive PM needs and actions, and how each loop 'closes' with the efforts in improving line performance … decreasing. In illustration, we note for loop B2 of Fig. 4 that …

> *As the efforts in improving line performance increases, the production manager's requirement to reduce manufacturing lead time grows stronger, driving up the production manager's desire to reduce WIP inventory, decreasing manufacturing lead time, improving due date performance of the line, and finally driving down the*

effort in improving line performance .

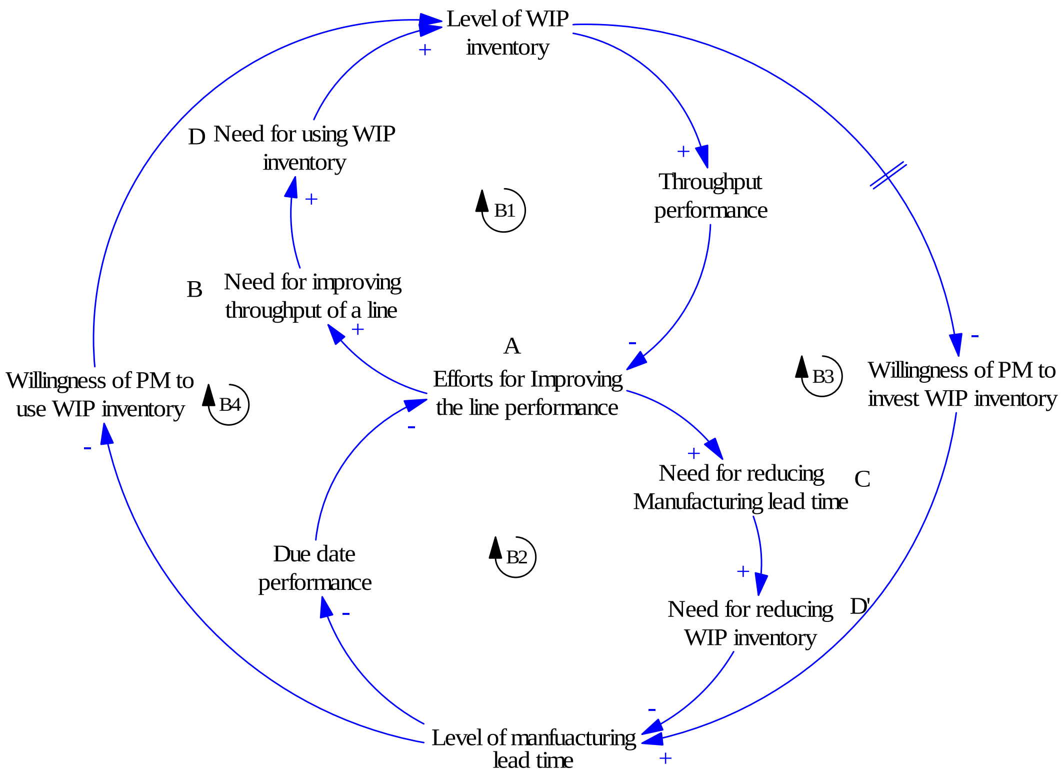

Fig. 4 Analysis of manufacturing problem with complementary use of EC and CLD

Secondly, the integrated CLD approach captures and displays the essence of the EC's necessity logic through a subset of individual cause-effect links and relationships. For example, the pair of balancing loops B1 and B2 act as a de facto reinforcing loop which can be interpreted as showing how the production manager actions D and D' are in conflict, such that taking the action D works against taking the action D'. The CLD also suggests how the taking of either action D or D' may lead to consequences and side-effects which have the impact of undermining the effectiveness of the other, and consequently the overall objective. Here, we can show how, for instance,

… action D (loop B1) may increase the level of WIP inventory, leading to reducing of willingness of PM to invest in WIP inventory to improving the line performance (via loop B3), adversely affecting the manufacturing lead time, (loop B2), thus jeopardizing the prior requirement C to provide the requirement of reducing manufacturing lead time, and undermining objective A.

That is, in terms of the EC, our dilemma is that although A necessitates C necessitates D', the alternative action D jeopardizes C which undermines objective A.
Similarly,

… action D' (loop B2) may lead to lowered the manufacturing lead time, reducing the willingness of PM to use WIP inventory (loop B4), lessening the extent of WIP inventory, lowing the level of throughput of a line, and once again jeopardizing objective A (loop B1).

Thus, again, in terms of the EC, whilst A necessitates B necessitates D, the action D' jeopardizes B and thus undermines objective A.

Thirdly, the integrated CLD approach reminds the characteristics of Senge's Shifting the Burden (STB) archetype, where a solution for a problematic situation can limit PM's ability to execute an alternative. Indeed, the integrated CLD can be viewed as an example of a modified version of Senge's STB archetype, where each alternative fix has the capability to undermine the effectiveness of the other in chronic conflict unless the dilemma is recognized and addressed. Therefore, there is promise of being able to enhance understanding of the inherent dilemma facing the production manager through mutually informing use of CLD and the EC.

5. Discussions and Conclusions

In decision making processes, it is important to fully understand the problematic situation as well as providing a solution. The CLD, shown in Fig. 1, captures and communicates the interconnectedness and interdependence implicit in the problematic situation. As such, construction of the CLD can be used usefully to deliver particular patterns of behaviour that arise from the interdependent and systemic structure of relationships to the stakeholders. The initial CLD (Fig. 1), however, does not capture any perceived choice for intervention, other than using WIP inventory - that is, it does not necessarily or explicitly present a choice dilemma of mutually exclusive options. On the other hand, The EC of TOC focuses on presenting a core choice dilemma by identifying the overall goal of the situation and devoting attention to other variable alternative actions. EC can show the nature of chronic conflict through analyzing how and why the taking of any one action can undermine production managers' ability to enact an alternative. However, the use of EC could be limited for its apparent simplicity and parsimony in presentation.

This paper tries to figure out how the different tools/approaches have been harnessed and applied to the general manufacturing line problematic situation; offering comment and insight on the nature of issues within the manufacturing sector; and how it may be addressed by the production manager. Especially, this paper argues that the integrated method suggests that iterative and mutually informed construction of EC and CLD diagrams is possible and desirable in teaching a traditional manufacturing dilemma in production management filed. Our experience in using the EC process to guide development of CLD representations, and using managerial insights from the EC to inform the development of insights from the CLD, has been, in the main, beneficial. Similarly, benefits have arisen from knowledge and recognition of systems archetypes, not only in the development of CLD, and understanding systemic structure, but in taking insights from the CLD to better understand the dilemma in general manufacturing line.

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