Pergamon

Computers ind. Engng Vol. 34, No. 3, pp. 695–701, 1998

Printed in Great Britain
0360-8352/98 $19.00 + 0.00

PII: S0360-8352(96)00196-9

NOTE

THE COMPLETE KIT: MODELING THE MANAGERIAL APPROACH

ABRAHAM GROSFELD-NIR and BOAZ RONEN
Faculty of Management, Tel Aviv University, P.O. Box 39010, Tel Aviv 69978, Israel

(Received 1 October 1995)

Abstract—One of the fundamentals of good operations management practices is the "complete kit" concept, which suggests that work should not start until all the items required for completion of a job are available. These items (the kit) include components, tools, drawings and information. Starting a job with an incomplete kit means more labor time to finish the job, longer lead time, more work in process, reduction of throughput, poor quality and impairment of due date performance. This paper analyses the various facets of the complete kit approach by an analytical model that shows when it is preferable to use this concept. The tendency of practitioners to work with incomplete kits is explained using the prisoner's dilemma. © 1998 Published by Elsevier Science Ltd. All rights reserved.

1. INTRODUCTION

Particularly since the advent of mass production, the business and manufacturing sectors of the economy have been bent on developing and implementing effective managerial methods that are imperative to the success of an organization. These methods cover many facets of today's competitive business environment, starting with organizational structure, selection of managers and employees and dealing with that most important aspect of technology management, namely, effective and efficient processes within the organization. In recent years we have witnessed the development of several new managerial methods. Among these are Just in Time (JIT), Optimized Production Technology (OPT), the Theory of Constraints (TOC), and Total Quality Management (TQM). One thing most of these new managerial methods have in common is that they express a general, non-technical, simple and intuitive idea, that can be implemented in almost all organizational activities. According to JIT, for example, costly activities should be postponed to the last possible moment and overproduction, i.e., production to inventory, is not to be allowed (on this point, see, for example, Ref. [10]). JIT can also be interpreted as a method that allows production only as a response to demand (demand being redefined to include the demand resulting from activities and plans within the organization). OPT and TOC state that we cannot analyze a complex system, but we can achieve good results by focusing on "critical resources", that is "bottlenecks" or other constraints (see, for example, Refs [1, 9]). TQM states that the way to achieve quality is to focus on the processes and to allow the workers to be responsible for it, rather then letting it be the responsibility of the quality control department (see, for example, Ref. [3]).

An additional common feature of the newly developed managerial methods is that they apply equally well to manufacturing and to service organizations, and can usually be applied to all departments within the organization. Most of the recently developed managerial theories emerged "from practice to theory"; that is, practices that had been developed and tried with enormous success in industry, subsequently also became the object of academic interest. For example, when academicians started to analyse and form a systematic structure for the understanding of JIT, it was already being widely practiced [7, 8]. The development of these strategies [and others, such as material-requirement-planning (MRP) and re-engineering] make it clear that the success of an organization depends upon the implementation not of one particular method, but a reasonable blend of some methods [6].

This paper suggests that the "complete kit" (CK), which has been virtually ignored in the literature, is also an important managerial tool. The CK concept suggests that work should not start until all the items required for completion of the job are available. These items (the kit) include components, tools, drawings and information. Starting a job with an incomplete kit means more labor time to finish the job, longer lead time, more work in process, reduction of throughput, poor quality and impairment of due date performance. We already have evidence that the marginal contribution of the CK, when implemented in conjunction with other managerial methods, is surprisingly high [4]. It has also been observed to improve quality, throughput and response time, to orders of magnitude that significantly increase the organization's profitability. Also, while it is clear that regardless of the managerial methods which are being used, all components are required for a job to be successfully terminated. Different managerial concepts stress different facets of the production process. For example while MRP mostly concerns itself with the timely ordering of components (to the different stages of a complex, multistage system) as a result of "dependent demand", the CK concept concentrates on the right time to start a job, mainly at one particular stage.

What then is the CK? We envisage an environment where the completion of a job requires the completion of several tasks, each task requiring specific components (materials). For example a manufacturing kit may require 20 components, and a bank loan usually requires several forms and information items. If at a certain time only a few components are missing (and part of the work-force is idle, say), management has the option of starting the job, completing all possible actions and terminating it at some future date, when the missing components arrive. In such cases, our message is simple and clear (depending, of course, upon the system's parameters, as we shall explain later): do not start work until the kit is complete, i.e., all the components are present. It will soon become clear how difficult it is to stick to this simple rule, and how many people with clout there will always be trying to make exceptions and start the job even though the kit is not yet complete. This rarely turns out to be an advantage. In summary, the CK method prescribes "do it right the first time, without interruptions".

Before presenting an analytical model which illustrates the CK's contribution in mathematical terms and providing a possible measure of its benefits and its relationship with the process' parameters, we would like to give an intuitive description of the evils of an incomplete kit and explain the misconception that prevents large-scale implementation of the CK. After introducing the model and deriving optimal strategies, the behavioral phenomena that result from using an incomplete kit are explained through the prisoner's dilemma. Finally, in the Appendix, we illustrate the contribution of the CK in reducing work-in-process (WIP) and lead time.

2. THE EVILS OF AN INCOMPLETE KIT

Three hundred components are required to complete the assembly of a certain printed circuit board (PCB). The foreman of the operation has a very tight schedule, whereby he has to rush delivery of 50 PCB units to an internal customer, who is pressuring him to get the work done as soon as possible (that is, yesterday . . .). His 20 production people are fully loaded with all kinds of PCB assembly work. So far, the purchasing department has on hand 298 of the 300 components required. The foreman's boss suggests releasing the order to the floor, starting to assemble, and adding the other two components later. This seems reasonable, as the purchasing people have already assured the foreman that the missing components are on the way. The end of the story is only too familiar: the 50 units are already assembled, and waiting for the missing components that have not yet arrived. Other jobs that were put aside to make way for this hot order have not been delivered on time. Two weeks later, upon arrival of the missing components, the foreman shortcuts procedures and assembles the components manually on the waiting PCBs, which then fail the inspection because the missing components were incorrectly placed. Sounds familiar? Clearly working with a CK would have led to the fastest productivity gain.

In simple terms and in most environments, a complete kit is the full set of components, drawings, documents and information needed to complete a given assembly, subassembly or a process. It should, however, be perceived as state of readiness prior to release to the "shop floor". Working with an incomplete kit is costly and disruptive, as the following evils will show.

- *Increase in processing time and its variability*: perhaps this is the most pronounced evil of an incomplete kit. The increase in processing time is due to additional setups which are required as work resumes when missing parts arrive. Also, often more work is required as the original order of installation may no longer be feasible. The increase in variability is because processing time will depend upon the parts available when a decision to start the job is made. In the Appendix we use queuing theory to show how a slight increase in processing time and its variability may dramatically affect the number of jobs waiting to be processed (i.e. WIP). We wish to stress that the increase in WIP due to a partially assembled kit waiting in line, is often small relative to the accumulation of WIP due to increased processing time.
- *High variance of quoted lead times (also leading to impairment of due date performance)*: it is very difficult to quote lead time when a major item of information (the arrival date of the missing items) is unknown.
- *Poor quality and more rework*: incomplete kits tend to wait in inadequate storage facilities. When the missing items arrive, they are often incorporated in an improvisatory fashion that may give rise to quality problems.
- *Decline in workers' motivation*: using an incomplete kit amounts to the "hurry up and wait" way of manufacturing. First the "red hot" incomplete kit gets top priority, then it waits till the rest of the items arrive.
- *Increase in complexity of controls*: because of the need to keep records of the location and type of incomplete kits on hand.
- *Small expected gain*: presumably, starting a job with missing components saves time. However, it is well recognized (see, for example, Ref. [8]) that the process time is only a small part of the total lead time, perhaps less than one percent.

Why then is a complete kit not always used? We will explain this phenomenon, via the Prisoner's Dilemma, in Section 5. Additional obstacles that impede the use of a CK are (for more details see Ref. [4]):

- *The efficiency syndrome*: this is the urge to have resources utilized as fully as possible. Following the fallacious notion that a worker should be busy all the time causes managers to have their people working using incomplete kits just so that they should not be idle.
- *Improper division into levels of assembly*: the trend today is to reduce the number of levels of assembly. This, in turn, may cause the number of components per assembly level to grow to a level that is difficult to control and almost impossible to gather at a given time. We accentuate that an assembly level (e.g. an airplane wing) which is an engineering kit is not necessarily a "managerial kit" (i.e. a complete kit). Quite often an assembly level consists of many sub-assemblies which are the true "managerial kits".

3. THE TWO-TASK MODEL

Consider a job which requires the termination of two tasks. The second task, say, may be thought of as the work associated with all missing components (for simplicity, we assume that all missing components will arrive in one shipment). The tasks can be performed simultaneously, or in two stages. We say that the CK rule applies if simultaneous work, waiting for the missing components for work to be done in one stage, is preferred over work done in two stages. We denote by α and β the setup time and processing time, respectively, if the tasks are executed simultaneously, and by α_i and β_i, $i = 1, 2$, the setup time and processing time, respectively, associated with the ith task, if the work is done in two stages. Naturally, we assume that

$$\alpha \geqslant \max\{\alpha_1, \alpha_2\}, \text{ and that } \beta \geqslant \max\{\beta_1, \beta_2\}. \tag{1}$$

The next equation corresponds to work done in lots of size N. The left-hand-side describes the cost of work done in two stages, while the right-hand-side corresponds to simultaneous work (one stage). Thus, the CK rule applies if and only if the r.h.s exceeds the l.h.s, i.e.

$$(\alpha_1 + \alpha_2) + N(\beta_1 + \beta_2) > \alpha + N\beta, \tag{2}$$

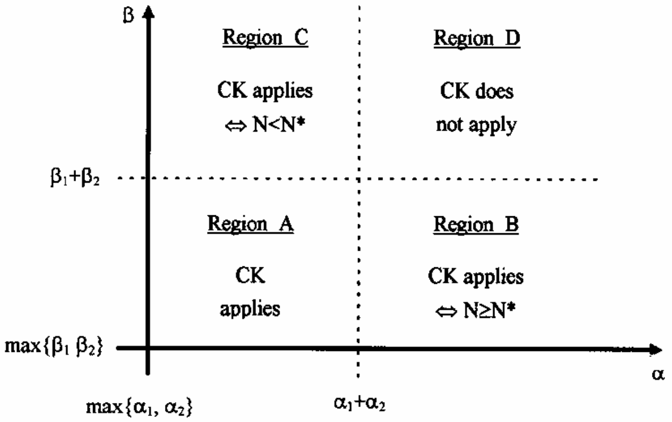

Fig. 1. Conditions for the CK rule to apply. For example, if (α, β) are in region A the CK rule always applies.

where N is the lot size. Let N^* be defined by

$$N^* = [\alpha - (\alpha_1 + \alpha_2)]/[(\beta_1 + \beta_2) - \beta]. \tag{3}$$

Then, the CK rule applies, if and only if, $N \geqslant N^*$. This means that N^* is a critical lot size, such that, one stage is preferable over two stages, only if the lot size is no smaller than N^*.

Figure 1 defines four regions. Region A, for example, is

$$A \equiv \{(\alpha, \beta): \quad \alpha < \alpha_1 + \alpha_2 \text{ and } \beta < \beta_1 + \beta_2\}.$$

Combine this with Equation (2) to conclude that in region A the CK rule always applies. Similarly, it is easy to verify that in region B the CK rule applies when $N \geqslant N^*$, in region C it applies when $N < N^*$, and that in region D the CK rule does not apply. Figure 1 also provides a simple rule for the determination of assembly levels: if the CK rule does not apply, the assembly level should be broken into sub-assemblies, each consisting of one complete kit.

4. THE KIT'S EFFICIENCY

We define the kit's efficiency by

$$e = [\alpha_1 + \alpha_2 + N(\beta_1 + \beta_2) - (\alpha + N\beta)]/(\alpha + N\beta) \tag{4}$$

The kit's efficiency represents the relative potential savings in using a CK rather than two tasks; it also provides a simple guide on when the CK rule applies, namely, when $e > 0$. [Note that $e > 0$ if and only if $\alpha_1 + \alpha_2 + N(\beta_1 + \beta_2) > (\alpha + N\beta)$, i.e. performing the two tasks separately will take longer than simultaneously; also see Equation (2)].

Remark. In Equation (4), $e \leqslant 1$. However, if a job consists of more then two tasks, the potential savings can amount to several hundred percent, as demonstrated in the following example.

Example. In an insurance company, the lot size for issuing a life insurance policy is one ($N = 1$). Four forms are needed to complete the job, and the working times are given as follows: $\alpha = \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 20$ min; $\beta = 60$ min; $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 25$ min.

Note that, if the job involves several tasks, the kit's efficiency is given by

$$e = [\Sigma\alpha_i + N\Sigma\beta_i - (\alpha + N\beta)]/(\alpha + N\beta) \tag{5}$$

Therefore, $e = [80 + 100 - (20 + 60)]/80 = 125\%$.

5. THE CK AND THE PRISONER'S DILEMMA

If it is so clear that both the producer and his clients will benefit if he works with a CK then why is it that only few companies work in this way? The reason is that we are dealing here with a variant of the prisoner's dilemma.

The prisoner's dilemma tells about two prisoners who have committed a crime, and are being interrogated in isolation from each other. If both confess, each gets 4 years in prison. If neither confesses, then, due to lack of evidence, each gets 1 year. If one confesses and the other does not, the one who confesses turns state witness and is allowed to go free, but the one who does not confess gets 5 years. Each prisoner figures out that no matter what the other does, it is best for him to confess (if the other confesses, he gets 4 instead of 5 years, and if the other does not confess he gets off free, instead of serving 1 year in prison). The only equilibrium in this "game" (choosing dominating best strategies) is that both do confess. The reason for this result is that this is a non-cooperative game (there is no binding agreement between the players—the prisoners).

Similarly, the client knows that whether or not the producer works in accordance to the CK rule, it is best for him that his job gets priority, and work starts right away (even if it is interrupted because of missing parts). The producer, for his part, is afraid that if he tells the client to wait for all the missing parts to arrive before work can start, the client may, in the meantime, look for another producer. Therefore, he chooses to start work right away and informs the client that his job is already in the line, even if he knows that he will have to stop at one stage or another for indeterminable periods of time, because of missing parts.

For example, consider a client who is negotiating with a house painter. The scenario is all too familiar. Within a few days the painter comes over and starts the job, without making any significant progress. He then disappears for a few days, comes back and continues for a couple of days, stops again, and so on. The whole job, without interruptions, should take 4–5 days; now it takes 7–8 days over a period of 2 or 3 weeks. The client is happy because after just 3 days he hears "I have started your job"; if he hears "we will start in 18 days", he may look for somebody else. The painter is happy too; by making a token gesture of starting the job, he knows that the client is his. Just as in the prisoner's dilemma, the only equilibrium is to work with an incomplete kit; both sides choose their best strategies and they both end up as losers.

Back now to our PCB assembly line. Some internal clients, say, project managers, compete on the same resource, the PCB assembly line. The time per part for a PCB assembly may be 6 h and lead time (caused by backlog and designed buffers) may reach 3 days. However, the project manager's eagerness to get to the front of the line as quickly as possible makes him put pressure on the PCB assembly foreman to start working using an incomplete kit. Thus, work in process, increases, lead time becomes as long as 2 weeks, and time per kit increases from 6 h to almost 10. The foreman is happy; he is not being pressured by the project manager. The project manager is happy too; the PCB assembly line is working for him instead of for some other project manager, who is competing in the same "game". And again, just as in the prisoner's dilemma, the only equilibrium is to work with an incomplete kit; both sides (the project manager and the foreman) choose their best strategies and they both end up as losers.

6. CONCLUSION

An important issue related to the complete kit is the distinction between an "engineering assembly level" ("engineering kit") and a "managerial assembly level" ("managerial kit" or simply "complete kit"). Often, an engineering kit is a visible large assembly level containing an enormous number of parts and it is neither possible nor efficient to wait for all the components before work starts. However, it should be realized that the engineering kit may contain many CKs. While in practice it is often easy to distinguish between the two, a formal definition is hard to form. We hope that Section 3 may serve as a guide whenever a clear cut is necessary, i.e. consider an assembly level as a CK whenever $e \geqslant 0$.

In our experience we found out that often both the foreman and the workers realize that working with incomplete kits is inefficient. However, because of the Prisoner's dilemma effect they give in to pressure from higher management and customers. We also found that once an organization becomes familiar with the CK concept it becomes easier for the foreman and workers to resist such pressure. Also, a word of caution, while in general working according to the CK is good practice there may be outstanding circumstances where because of strategic reasons or contractual considerations one may occasionally find it rewarding to start work with an incomplete kit. What we wish to stress is that such an exception should be very scarce and only as a result of careful overall considerations.

Some of the benefits of working according to the CK are reasonably easy to quantify. Others are hard to measure. For example, it is clear that working according to CK saves on repeated setups, thus reducing the total work on a job. Also, the total time devoted to a job becomes easy to estimate if it is done at one time, when all parts are present, and with a thorough setup. Thus the variability in processing time becomes small. On the other hand it is not easy to realize the magnitude of the benefits resulting from the quality gained and the decrease in WIP (which also leads to smaller lead time). Also, when a client is told that work on his job will not start until all items are available, extreme effort is made on his part to ensure prompt delivery of missing items.

Finally, if an organization does not follow the CK concept, and arrival of jobs is stochastic, and the work-force capacity is highly utilized, the effect of introducing the CK can be sensational. This is explained in the Appendix: "The CK In A Stochastic Environment". There an example is shown where slight reduction of average processing time dramatically reduces the number of jobs waiting to be processed.

APPENDIX

The CK in a stochastic environment

Consider a work center with one service facility, and suppose that jobs arrive randomly and that inter-arrival times are independent and identically distributed. It is reasonable to assume that inter-arrival times are exponentially distributed, since the exponential distribution is the only distribution with the property that the probability of a job will be arriving in the next time interval is independent of the time elapsed since the last arrival. Suppose that service times (setup time plus processing time) are also independent and identically distributed random variables, independent of the arrival process. The work center thus constitutes an $M/G/1$ queuing system. We use the following notations

λ—arrival rate (average number of jobs arriving, per time unit).
m—mean service time.
$\rho = \lambda m$—utilization factor (the proportion of time that the system is busy).
σ^2—variance of the service time.
$E(N)$—expected number of jobs in the system.
$E(Q)$—expected number of jobs in the queue (waiting for service).
LT—lead time (expected time a job stays in the system).
WT—waiting time (expected time a job stays in the queue).

Note that $LT = WT + m$, and that, by Little's formula

$$LT = E(N)/\lambda, \text{ and } WT = E(Q)/\lambda \tag{A1}$$

With this notation, the Pollaczek–Khinchine formula (see, for example, Gross and Harris, 1974, p. 226) becomes

$$E(N) = \rho + (\rho^2 + \lambda^2\sigma^2)/2(1 - \rho) \tag{A2}$$

Combining this with Equation (5), we obtain

$$LT = m + \lambda(m^2 + \sigma^2)/2(1 - \rho) \tag{A3}$$

Thus

$$WT = \lambda(m^2 + \sigma^2)/2(1 - \rho) \tag{A4}$$

and

$$E(Q) = \lambda^2(m^2 + \sigma^2)/2(1 - \rho) \tag{A5}$$

As we have explained, working in accordance with the CK rule reduces m (the average service time) and its variance σ^2; in view of Equations (A2)–(A5), this results in a reduction in LT, WT, $E(N)$ and $E(Q)$. Note that when the service time is deterministic, i.e., $\sigma^2 = 0$, the LT, WT and queue length are the smallest. This is consistent with Deming's theory, which calls for the elimination of uncertainties in production processes, and with the tendency of manufacturers to increase the use of robots in industry. If service time is exponential, then, for example, Equation (A5) becomes

$$E(Q) = \rho^2/(1 - \rho) \text{ and } E(N) = \rho/(1 - \rho). \tag{A6}$$

Since working according to the CK rule reduces the service time, and $\rho = \lambda m$, we see that by employing a CK ρ is reduced. As a numerical example, assume that Equation (A6) holds, that the number of jobs arriving per time unit is $\lambda = 99$, and the average service time per job is $m = 1/100$ (this also means that the work center has the capacity of servicing 100 jobs per time unit). Thus $\rho = 0.99$, and the expected number of jobs in the system is $E(N) = 99$. Now, if, by employing the CK rule, the average service time becomes $m = 1/120$ (an improvement of approx. 20%), then $\rho = 99/120$ and the expected number of jobs in the system becomes $E(N) = 4.7$!

REFERENCES

1. Goldratt, E. M. and Cox, J., *The Goal*. North River Press, Croton-on-Hudson, NY, 1986.
2. Gross, D. and Harris, C. M., *Fundamentals of Queuing Theory*. Wiley, NY.
3. Deming, W. E., *Out of the Crisis*. MIT, CIAS, 1986.
4. Ronen, B., The complete kit concept. *Int. J. Prod. Res.* **30,** 1992, 2457–2466.
5. Ronen, B. and Starr, M. K., Synchronized manufacturing as in OPT: from practice to theory. *Computers Ind. Engng*, **August,** 1990, 585–600.
6. Cameron, K., Effectiveness as paradox: consensus and conflict in conception of organizational effectiveness. *Mgmt Sci.* **32(5),** 1986, 539–553.
7. Schonberger, R. J., *Japanese Manufacturing Techniques*. Free Press, NY, 1982.
8. Schonberger, R. J., *World Class Manufacturing*. Free Press, NY (1986).
9. Schagenheim, E. M. and Ronen, B., The drum–buffer–rope shop floor control. *Prod. Inventory Mgmt*, Third Quarter, 1990.
10. Suzaki, K., *The New Manufacturing Challenge*. Free Press, NY, 1987.