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Full Length Research Paper

Mathematical models for component commonality under quality and resources breakdown in multistage production

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In the era of mass customization and supply chain rivalry, managing product diversity is essential for survival in business. The use of common part for different products is a vital method of achieving the goal. The advantages of insertion of duplicate component in a product family are stated in literatures. Simulation or conceptual beliefs is employed in the majority of the researches and mainly considered single stage manufacturing. However, the mathematical models in the premises of multistage production are not available. In this paper, the part commonality notion is integrated with venerable manufacturing resources planning models for a multiproduct, multi-period and multistage manufacturing under a deterministic demand and lead time. A random distribution of quality and resources breakdown events glued with the models. The models are validated with real data from a Malaysian company and arbitrarily numerical scheme. The material requirement schedule is generated using the proposed models. The outcomes are compared with the same from the basic MRP II and live archrival data collected from the floor. It is found that the two schedules converge. However, the proposed models are bearing additional information of the location where to be available the parts in a time frame. The effects of commonality on cost, capacity and requirement schedule under the quality and breakdown troubles are discussed. It is observed that the use of common parts in manufacturing is always better over the non-commonality scenario in terms of production cost and capacity requirements.

Key words: Component commonality, mathematical model, MRP II, quality, breakdown.

INTRODUCTION

The underlying ideas for commonality are not really new. As early as 1914, an automotive engineer demanded the standardization of automobile subassemblies, such as axles, wheels and fuel feeding mechanisms to facilitate a mix-and-matching of components and to reduce costs (Fixson, 2007). Commonality is the use of identical components in multiple or group of products in a product family. In manufacturing, component commonality refers to the use of the same components for two or more products in their final assemblies. The details about the commonality, its measurements and models are narrated in Wazed et al. (2010b). The commonality occurs in its own way in the system or can be planned for its preferred happening as well.

Nowadays, manufacturing companies need to satisfy a wide range of customer desires while maintaining manufacturing costs as low as possible. Many companies are faced with the challenge of providing as much variety as possible for the market with as a little variety as possible between the products' requirements. Hence, the component commonality has extensive span to penetrate in the manufacturing and thereby might allow cost-effective development of a sufficient variety of products to meet customers' diverse demands. However, too many

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commonalities within a product family can have major drawbacks. Consequently, there is a need of trade off between system performance and commonality within any product family. Again, none of the systems in the production premises are perfect. Many factors degrade the planned operation of the process. The factors and sources of various qualms interrupt the manufacturing observed in Wazed et al. (2009b). This article includes only the quality and machine breakdown in the models. These factors very often suspend the expected production schedules.

Machine breakdowns are a representation of machine failure. If machine breakdowns during production, the parts that required machining by this machine will be accumulated in the queue. These parts could be from a variety of products. Hence, the effect can be expanded across product range. In theory, machine failure can be measured with meantime between failures (MTBF) and meantime to repair (MTTR) (Koh and Saad, 2003). MTBF models how frequently these breakdowns occur and how reliable the machine is. MTTR models how long a breakdown will last, and how quickly repair can be made (Koh, 2004). The cost reduction delivery policy in an imperfect production system with repairable items is studied by Chen et al. (2010).

In manufacturing, the quality problem may come from the procured raw material or machines may produce defective products. Certain proportion of products became defective due to poor production quality and material defects, and subsequently defective products are scrapped if they are not re-workable, or it is not cost-effective to do so. In a multi-stage manufacturing, products move from one stage to the next stage, and every stage may yield a certain proportion of defective items. This proportion of defectives may vary from stage to stage and also from cycle to cycle. Furthermore, during changeover, meaning the effort required to switch from the production of one SKU to a different, some defective parts may be produce. The idea is that when one changes from one SKU to another, some material can be destroyed (that is, wasted).

In earlier studies (Baker, 1985; Baker et al., 1986; Berry et al., 1992; Collier, 1981, 1982; Desai et al., 2001; Eynan and Rosenblatt, 1996; Gerchak et al., 1988; Guerrero, 1985; Heese and Swaminathan, 2006; Hillier, 2000, 2002a, b; Kim and Chhajed, 2000; Labro, 2004; Ma et al., 2002; Maskell, 1991; McClain et al., 1984; Mirchandani and Mishra, 2002; Thonemann and Brandeau, 2000; Wazed et al., 2008; 2009a; 2010b; c; Zhou and Grubbstrom, 2004), the benefits of component commonality in the manufacturing systems are stated. The impact of both commonalities (part and process) is observed in Wazed et al. (2010a). However, the commonality issue is completely ignored in the existing manufacturing resource planning models. Furthermore, the analytical research on multistage manufacturing is very few in the present pool of knowledge. Hence, this *article will advance the existing MRP II models by integrating component commonality concept.*

COMPONENT COMMONALITY MODEL

The MRP and MRP II models have many limitations (Koh et al., 2000, 2006; Shenoy and Bhadury, 1998). Actually, they are nothing but a good scheduling tool for production. Additionally, the MRP II model assumed that any part/component/module can be processed at any machine, which is not realistic in many grounds. In any manufacturing system, facilities/machines/stations are anchored at a suitable point as per the planning guidelines. Parts are also planned to follow specific routings. They cannot move arbitrarily. So, planned and controlled route of components is needed to ensure. Secondly, the commonality dimensions (that is, component commonality) are not considered in any earlier such as a model. The models introduced in this article, incorporated commonality and able to trace routes the components in any epoch.

This paper begins with a venerable model called MRP II (Figure 1), rather than creating a model from scuff. The model is often referred to as MRP II to make clear the dissimilarity among MRP and MRP II. It is a useful starting point for further modeling. The first and the second constraint require that the sum of initial inventory and production up to each period has to be at least equal to respectively the total of external demand and demand for assemblies that uses the SKU. The summation is to $t - LT(i)$ for each period (there will be one constraint for each value of t) because of work that must be started LT periods before it can be used to satisfy demand. The product $R(i, j)x_{i\tau}$ anticipates the demand for SKU i that results when it is a component of SKU j. This product will turn out to be zero for a lot of i, j combinations, but that does not present any special difficulty for a computer. The objective function is to make things as late as possible but no later.

Using classic MRP II software, MRP II problem would not be solved directly. Instead, MRP problem would be solved and then the capacity constraint for the MRP II model would be checked. In other words, the result of solving MRP provides values for the decision variables. Once these values are known, they become data for subsequent processing. Direct solution of the optimization model is a much better idea. This article embeds similar constraints to capture costs and important limitations of production. Especially the dashing thought of component commonality is incorporated in proposed models under quality and breakdowns event.

Minimize:

$$\sum_{i}^{N}\sum_{t}^{T}(T-t)x_{it}$$

Subject to:

$$I_{it-1}+\sum_{\tau=1}^{t-LT(i)}x_{i\tau}-I_{it}\geq D(i,t)\quad i=1,..,ENDP;\quad t=1,..,T \quad \text{(Demand constraint)}$$

$$I_{it-1}+\sum_{\tau=1}^{t-LT(i)}x_{i\tau}-I_{it}\geq \sum_{j=1}^{N}R(i,j)x_{jt}\quad i=1,..,N\setminus ENDP;\quad t=1,..,T \quad \text{(Material requirement constraint)}$$

$$\sum_{i}^{N}U(i,k)x_{it}\leq 1\quad k=1,..,K;\quad t=1,..,T \quad \text{(Capacity constraint)}$$

$$x_{it}-\delta_{it}LS(i)\geq 0\quad i=1,..,N;\quad t=1,..,T$$

$$x_{it}\leq M\delta_{it}\quad i=1,..,N;\quad t=1,..,T$$

$$\delta_{it}\in\{0,1\}\quad i=1,..,N;\quad t=1,..,T$$

$$x_{it}\geq 0\quad i=1,..,N;\quad t=1,..,T$$

Figure 1. MRP II model.

Model environment

The model considers a planning and scheduling of $ENDP$ final products (independent items) and their sub-components (dependent items) over a discrete planning horizon of T periods (indexed by t) in a batch production environment. For each product at each time period, a proposed demand is specified based on the forecasted value or customers' orders. Associated sub-components are fed to assemble or manufacture their end products. Their demands are dependent on that of the parent products and obtained from considering the bill-of-material and are timed through offsetting by manufacturing lead time.

Certain resources are required to perform either serial or concurrent processes to produce/process product/item of either independent or dependent. These are pre-selected based on manufacturing criteria. It is supposed that each resource (machine) offer limited capacity. Unless otherwise mentioned, machines are dedicated to produce a specific product and/or its sub-components. Resource loading along the time horizon is accumulated in a time bucket such as hour, day, week and month by the manufacturing requirement of various products.

The model is formulated with the objective of minimizing the total production cost (production cost, holding and material) and capacity while considering resources constrained for demand of independent multi products. The characteristic of a typical real situation of multi-product manufacturing is that every product will have a multi-level structure with various components, different per unit quantities, which are required to be produce under multi resource capacity. Figure 2 is a schematic presentation of such a situation. The models are expected to provide an executable production schedule for a multi-level multi-items and multi-period manufacturing system under quality and breakdown problems. It is indeed a multi-resource capacitated problem. It is assumed that

1. The time horizon is uniform with equal length, such as hour, day, week or month;
2. The demands for each final product for each time period are known in advance and deterministic;
3. Lead time and processing times are integer multiple of epoch. They are known and settled for deterministic models;
4. The processing time is constant for a resource, but failure time may be added if the machine breakdowns;
5. Machine requires setup when system switches to another product/component and when it resumes from stoppage due to failure;
6. The resource capacity levels are uniform during the scheduling periods;
7. Shortages/backlogs are allowed at a penalty.

Compiling the demand data of an end product and carrying it to the component level will result in demands

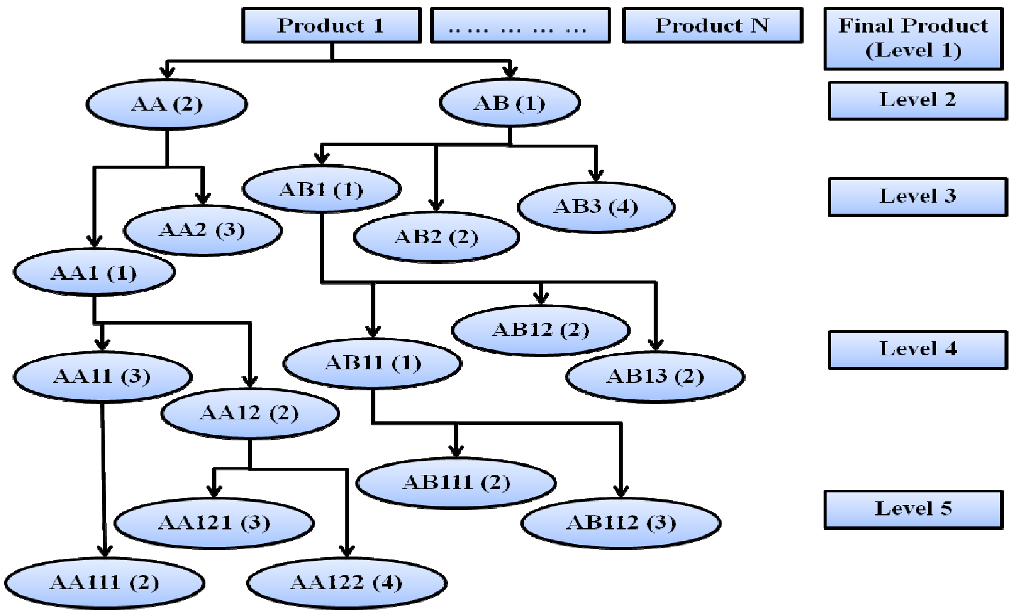


Figure 2. The general structure of final products with levels.

per components at a certain time to satisfy the periodical demands of the independent products. The inputs to the model are: End product demand by period (settled), resource capacities, bill-of-material (BOM), routing and cost information. The decision variables are quantities of each end product and its sub components by each time period at a specific point in the floor. Finally, the quality and breakdown issues and part commonality concept are integrated to the model to prepare a dependable material requirement schedule for each place of consumption.

Deterministic models

The authors introduce a class of models that is based on the simplest assumption: Demand, lead time, quality and breakdowns are deterministic and stationary. The information of the factors is constant and not anticipated to change. Although the assumption of deterministic and stationary factors seems quite restrictive, models requiring that assumption are still important for the following reasons. First, many results are quite robust with respect to the model parameters, such as the demand rate and costs. Second, the results obtained from these simple models are often good starting solutions for more complex models.

We consider a K-stage assembly/manufacturing line that produces $ENDP$ products as illustrated in Figure 3 (a- end product, b- component and c- manufacturing/assembly line). The production/assembly process of a product starts at stage 1. When a component moves along the line, component (module) is added onto it at some of the K stages. In general, each production line is specified for a product if sharing of resources is not permitted. The resources are identified by the product, P it producing and stage, K of the system. Component C_{Pkit} is assembled to the product $i\ (i=1,..,N)$ in period $t\ (t=1,..,T)$ at resource $WC(P,K)$ $for\ P=1,..,ENDP\ \ and\ k=1,..,K$.

Based on the illustration, the demand and component requirement constraints can be written as

$$I_{pkit-1} + \sum_{\tau=1}^{t-LT(p,k,i)} x_{pki\tau} - I_{pkit} \geq D(p,k,i,t) \qquad p=1,..,ENDP; \quad k=1,..,K; \quad i=p; t=1,..,T$$

$$I_{pkit-1} + \sum_{\tau=1}^{t-LT(p,k,i)} x_{pki\tau} - I_{pkit} \geq \sum_{\tau=1}^{t} \sum_{j=1}^{N} R(i,j)(x_{pkj\tau} + I_{pki\tau})$$
$$p=1,..,ENDP; \quad i=1,..,N \setminus ENDP; \quad k=1,..,K; \quad t=1,..,T$$

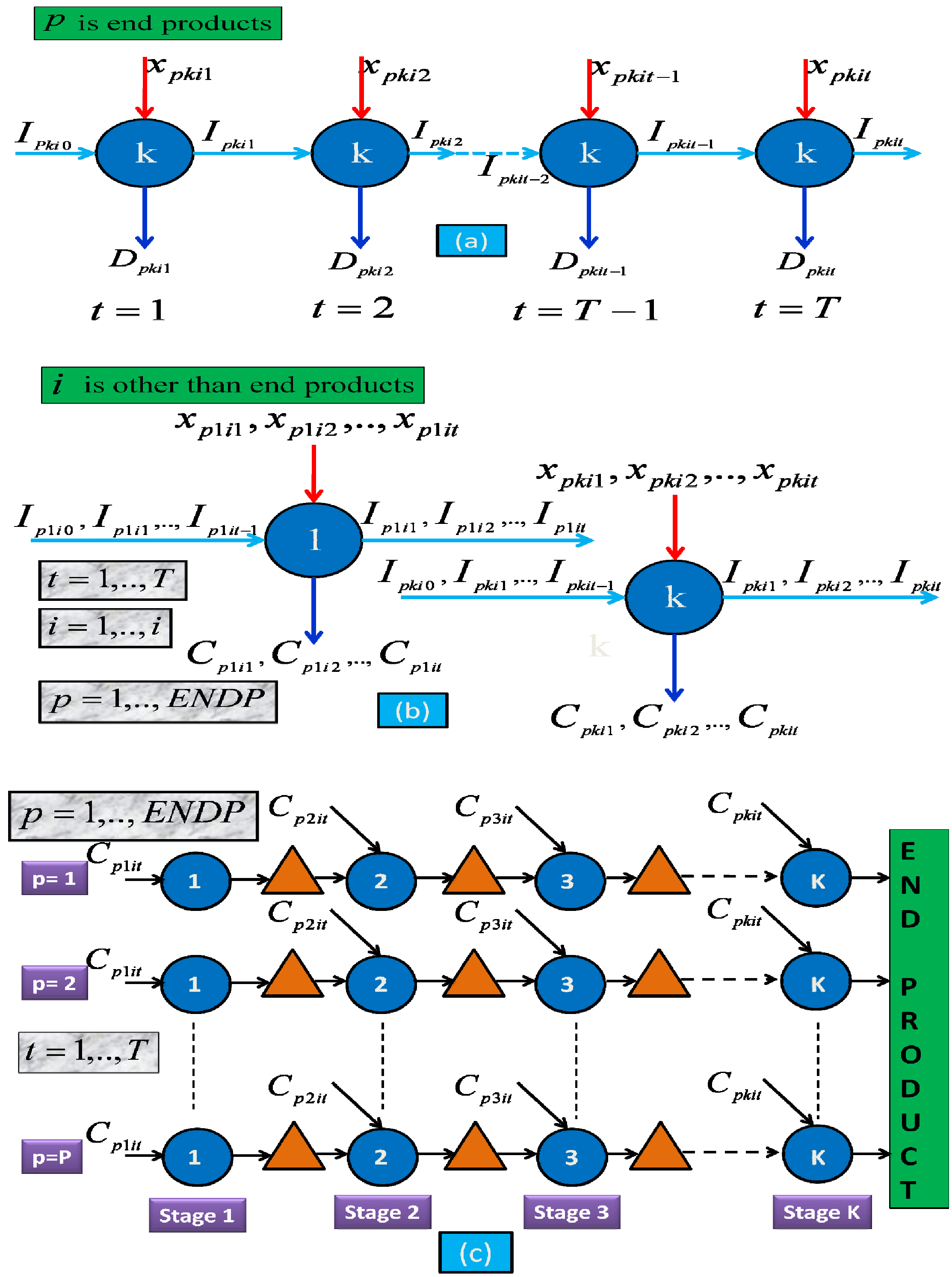


Figure 3. A multistage production system.

$$C_{pkit} \geq \sum_{\tau=1}^{t} \sum_{j=1}^{N} R(i,j)\left(x_{pkj\tau} + I_{pki\tau}\right) \quad p = 1,..,ENDP, \quad i = 1,..,N \setminus ENDP, \quad k = 1,..,K; \quad t = 1,..,T$$

Objective function

$$Minimize \quad z = \sum_{WC(P,K)} \sum_{I} \sum_{T} \left(v_i x_{pkit} + q_i I_{pkit}\right) + \sum_{WC(P,K)} \sum_{I} \sum_{T} f_{pk}\left(y_{pkit} - \gamma_{pkit}\right) + \sum_{WC(P,K)} \sum_{T} c_{WC} OT_{pkt}$$

Subject to

$$I_{pkit-1} + \sum_{\tau=1}^{t-LT(p,k,i)} x_{pki\tau} - I_{pkit} \geq D(p,k,i,t) \quad p = 1,..,ENDP; \quad k = 1,..,K; \quad i = p; t = 1,..,T$$

$$I_{pkit-1} + \sum_{\tau=1}^{t-LT(p,k,i)} x_{pki\tau} - I_{pkit} \geq \sum_{\tau=1}^{t} \sum_{j=1}^{N} R(i,j)\left(x_{pkj\tau} + I_{pki\tau}\right)$$

$$p = 1,..,ENDP; \quad i = 1,..,N \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$C_{pkit} \geq \sum_{\tau=1}^{t} \sum_{j=1}^{N} R(i,j)\left(x_{pkj\tau} + I_{pki\tau}\right) \quad p = 1,..,ENDP; \quad i = 1,..,N \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$x_{pkit} - ny_{pkit} LS(i) = 0 \quad p = 1,..,ENDP; i = 1,..,N \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$x_{pkit} \leq My_{pkit} \quad p = 1,..,ENDP; i = 1,..,N \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$LS(i) \leq My_{pkit} \quad p = 1,..,ENDP; i = 1,..,N \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

The capacity constraints:

$$\sum_{I} \left\{U(p,k,i) x_{pkit} + ST(p,k,i)\left(y_{pkit} - \gamma_{pkit}\right)\right\} - OT_{Pkt} + UT_{pkt} \leq 1 \quad p = 1,..,ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$OT_{Pkt} \times UT_{pkt} = 0 \quad p = 1,..,ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$y_{pkit-1} + y_{pkit} \geq 2\gamma_{pkit} \quad p = 1,..,ENDP; i = 1,..,N; \quad k = 1,..,K; \quad t = 1,..,T$$

$$\gamma_{pkit} \leq MU(p,k,i) \quad p = 1,..,ENDP; i = 1,..,N; \quad k = 1,..,K; \quad t = 1,..,T$$

$$\sum_{i=1}^{N} \gamma_{pkit} \leq 1 \quad p = 1,..,ENDP; k = 1,..,K; \quad t = 1,..,T$$

Non-negativity constraints:

$$\text{All variables} \geq 0; \quad y_{pkit} = \{0,1\}; \quad n = Integer$$

Figure 4. Model for multistage system under deterministic situations.

The complete model for multistage system under ideal conditions is shown in Figure 4. Component purchasing cost, variable production cost and inventory costs for products and components and setup cost of the machines are taken into consideration.

The third equation of the capacity constraints allow γ to be one for i on machine $WC(p,k)$ only if there is production of p in both periods. The fourth constraints ensure that we only set γ to one for i that are to be routed to machine $WC(p,k)$, which is done mainly to avoid spurious values of γ that can be confusing when reading the solution. The last constraints ensure that at most one product can span the time boundary on a specific resource $WC(p,k)$.

If backlog is allowed, the demand/component requirement constraints and the cost function will be change.

$$Minimize \quad z=\sum_{WC(P,K)}\sum_{I}\sum_{T}\left(v_i x_{pkit}+q_i I_{pkit}+b_i B_{pkit}\right)+\sum_{WC(P,K)}\sum_{I}\sum_{T} f_{pk}\left(y_{pkit}-\gamma_{pkit}\right)+\sum_{WC(P,K)}\sum_{T} c_{WC} OT_{pkt}$$

Demand and component requirement constraints

$$IP_{pkit-1}+\sum_{\tau=1}^{t-LT(p,k,i)} x_{pki\tau}-I_{pkit}+B_{pkit}-B_{pkit-1}\geq D(p,k,i,t)$$
$$p=1,..,ENDP; i=p; \quad k=K; \quad t=1,..,T$$

$$I_{pkit-1}+\sum_{\tau=1}^{t-LT(p,k,i)} x_{pki\tau}-I_{pkit}+B_{pkit}-B_{pkit-1}\geq \sum_{\tau=1}^{t}\sum_{j=1}^{N} R(i,j)\left(x_{pkj\tau}+I_{pkit}+B_{pkit}\right)$$
$$p=1,..,ENDP; i=1,..,N \setminus ENDP; \quad k=1,..,K; \quad t=1,..,T$$

$$I_{pkit}\times B_{pkit}=0 \quad p=1,..,ENDP; i=1,..,N\setminus ENDP; \quad k=1,..,K; \quad t=1,..,T$$

When common component is introduced in manufacturing

$$I_{pkct-1}+\sum_{\tau=1}^{t-LT(p,k,c)} x_{pkc\tau}-I_{pkct}+B_{pkct}-B_{pkct-1}\geq \sum_{\tau=1}^{t}\left[\sum_{j=1}^{N} R(c,j)\left(x_{pkj\tau}+I_{pkj\tau}+B_{pkj\tau}\right)\right]$$
$$p=1,..,ENDP; c=1,..,C; \quad k=1,..,K; \quad t=1,..,T$$

$$I_{pkit-1}+\sum_{\tau=1}^{t-LT(p,k,i)} x_{pki\tau}-I_{ikt}+B_{pkit}-B_{pkit-1}\geq \sum_{\tau=1}^{t}\left[\sum_{j=1}^{N} R(i,j)\left(x_{pkj\tau}+I_{pkj\tau}+B_{pkj\tau}\right)\right]$$
$$i\neq c; \quad p=1,..,ENDP; i=1,..,N\setminus ENDP; \quad k=1,..,K; \quad t=1,..,T$$

$$C_{pkit}\geq \sum_{\tau=1}^{t}\left[\sum_{j=1}^{N} R(i,j)\left(x_{pkj\tau}+I_{pkj\tau}+B_{pkj\tau}\right)\right] i\neq c; \quad p=1,..,ENDP; i=1,..,N\setminus ENDP; \quad k=1,..,K; \quad t=1,..,T$$

$$C_{pkct}\geq \sum_{\tau=1}^{t}\left[\sum_{j=1}^{N} R(c,j)\left(x_{pkj\tau}+I_{pkj\tau}+B_{pkj\tau}\right)\right] \quad p=1,..,ENDP; c=1,..,C; \quad k=1,..,K; \quad t=1,..,T$$

Models with known quality information

In a multi-stage manufacturing products move from one stage to the next stage, and every stage may yield a certain proportion of defective items. This proportion of defectives may vary from stage to stage and also from cycle to cycle. The non-reworked items become waste, creating additional costs for producers and the environment in general. Furthermore, during changeover, meaning the effort required to switch from the production of one SKU to the production of another, some defective parts may produce. The idea is that when one changes from one SKU to another, some material can be destroyed (that is, wasted). A very common example is that when production for $SKU\ j$ is begun, a few items of that SKU have to be destroyed for quality control testing or a few defective items are produced while the machine is adjusted. In fact, it is changeover avoidance that results in the need for lots that are larger than what would be needed to satisfy immediate customer demands. The scenario repeats when the manufacturing resumes from any stoppage or breakdown.

Therefore, the quality modeling can be quite involved in manufacturing. It consumes the materials and capacity of the system. It is assumed that the defective parts are simply rejected. Let, $W(i,j)$ represents the number of defective product/component i when system switches to product/component j. It means when the machine requires setup. It could be either initiation or may resume from breakdown or both. The number of defective parts is certainly known for each stage in any epoch. If β_i is the faction of defectives of all arrival part i, then $(1-\beta_i)$ represent the portion of usable raw materials. The capacity constraints will remain unaffected but the material requirement constraints will be changed.

The material requirement constraints:

$$I_{pkit-1} + \sum_{\tau=1}^{t-LT(p,k,i)} x_{pki\tau} - I_{pkit} + B_{pkit} - B_{pkit-1} \geq \sum_{\tau=1}^{t}\left[\sum_{j=1}^{N}\left\{(1+\beta_i)R(i,j)\left(x_{pkj\tau} + I_{pkj\tau} + B_{pkj\tau}\right) + W(i,j)y_{pkj\tau}\right\}\right]$$

$$p = 1,.., ENDP;\ i = 1,.., N \setminus ENDP;\quad k = 1,.., K;\quad t = 1,.., T$$

$$C_{pkit} \geq \sum_{\tau=1}^{t}\left[\sum_{j=1}^{N}\left\{(1+\beta_i)R(i,j)\left(x_{pkj\tau} + I_{pkj\tau} + B_{pkj\tau}\right) + W(i,j)y_{pkj\tau}\right\}\right]$$

$$p = 1,.., ENDP;\ i = 1,.., N \setminus ENDP;\quad k = 1,.., K;\quad t = 1,.., T$$

When common component is introduced in manufacturing

$$I_{pkct-1} + \sum_{\tau=1}^{t-LT(p,k,c)} x_{pkc\tau} - I_{pkct} + B_{pkct} - B_{pkct-1} \geq \sum_{\tau=1}^{t}\left[\sum_{j=1}^{N}\left\{(1+\beta_c)R(c,j)\left(x_{pkj\tau} + I_{pkj\tau} + B_{pkj\tau}\right) + W(c,j)y_{pkj\tau}\right\}\right]$$

$$p = 1,.., ENDP;\ c = 1,.., C;\quad k = 1,.., K;\quad t = 1,.., T$$

$$I_{pkit-1} + \sum_{\tau=1}^{t-LT(p,k,i)} x_{pki\tau} - I_{ikt} + B_{pkit} - B_{pkit-1} \geq \sum_{\tau=1}^{t-LT(i,k)}\left[\sum_{j=1}^{N}\left\{(1+\beta_i)R(i,j)\left(x_{pkj\tau} + I_{pkj\tau} + B_{pkj\tau}\right) + W(i,j)y_{pkj\tau}\right\}\right]$$

$$i \neq c;\quad p = 1,.., ENDP;\ i = 1,.., N \setminus ENDP;\quad k = 1,.., K;\quad t = 1,.., T$$

$$C_{pkit} \geq \sum_{\tau=1}^{t-LT(p,k,i)}\left[\sum_{j=1}^{N}\left\{(1+\beta_i)R(i,j)\left(x_{pkj\tau} + I_{pkj\tau} + B_{pkj\tau}\right) + W(i,j)y_{pkj\tau}\right\}\right]$$

$$i \neq c;\quad p = 1,.., ENDP;\ i = 1,.., N \ ENDP;\quad k = 1,.., K;\quad t = 1,.., T$$

$$C_{pkct} \geq \sum_{\tau=1}^{t}\left[\sum_{j=1}^{N}\left\{(1+\beta_c)R(c,j)(x_{pkj\tau}+I_{pkj\tau}+B_{pkj\tau})+W(c,j)y_{pkj\tau}\right\}\right]$$
$$p=1,..,ENDP;\ c=1,..,C;\quad k=1,..,K;\quad t=1,..,T$$

Models with known quality information and certain breakdown schedule

For this moment, it assumes that the number of failures, l_{pkt} in a time period t when works on $WC(p,k)$ and the repair time, r_{pk} of any breakdown machine $WC(p,k)$ is known. The processing time T_{pki} is believed to remain constant regardless of the number of failures during the task accomplishment. The breakdown increases the number of required setup and wastes a fraction, $V(p,k,t)$ of usable time of the machine. When a manufacturing system suffers with the breakdown and quality problem, the material requirement will be higher and system will consume more capacity. The number of defective items produced due to regular setup is $W(i,j)y_{pkit}$.When the system resume from breakdown, it will be $W(i,j)y_{pkit}l_{pkt}$. Under the situations, the material requirement and capacity constraints would be is follows.

$$I_{pkit-1}+\sum_{\tau=1}^{t-LT(p,k,i)}x_{pki\tau}-I_{pkit}+B_{pkit}-B_{pkit-1}\geq\sum_{\tau=1}^{t}\left[\sum_{j=1}^{N}\left\{(1+\beta_i)R(i,j)(x_{pkj\tau}+I_{pkj\tau}+B_{pkj\tau})+(1+l_{pk\tau})W(i,j)y_{pkj\tau}\right\}\right]$$
$$p=1,..,ENDP, i=1,..,N\setminus ENDP,\quad k=1,..,K;\quad t=1,..,T$$

$$C_{pkit} \geq \sum_{\tau=1}^{t}\left[\sum_{j=1}^{N}\left\{(1+\beta_i)R(i,j)(x_{pkj\tau}+I_{pkj\tau}+B_{pkj\tau})+(1+l_{pk\tau})W(i,j)y_{pkj\tau}\right\}\right]$$
$$p=1,..,ENDP;\ i=1,..,N\setminus ENDP;\quad k=1,..,K;\quad t=1,..,T$$

The capacity constraints:

$$\sum_{I}\left\{U(p,k,i)x_{pkit}+ST(p,k,i)(y_{pkit}-\gamma_{pkit})+ST(p,k,i)l_{pkt}y_{pkit}\right\}+V(p,k,t)l_{pkt}y_{pkit}-OT_{Pkt}+UT_{pkt}\leq CAP_{pkt}$$
$$p=1,..,ENDP;\quad k=1,..,K;\quad t=1,..,T$$

$$OT_{Pkt}\times UT_{pkt}=0\quad p=1,..,ENDP;\quad k=1,..,K;\quad t=1,..,T$$

$$y_{pkit-1}+y_{pkit}\geq 2\gamma_{pkit}\qquad p=1,..,ENDP;\ i=1,..,N;\quad k=1,..,K;\quad t=1,..,T$$

$$\gamma_{pkit}\leq MU(p,k,i)\quad p=1,..,ENDP;\ i=1,..,N;\quad k=1,..,K;\quad t=1,..,T$$

$$\sum_{i=1}^{N}\gamma_{pkit}\leq 1\quad p=1,..,ENDP;\ k=1,..,K;\quad t=1,..,T$$

When common component is introduced in manufacturing

$$I_{pkct-1}+\sum_{\tau=1}^{t-LT(p,k,c)}x_{pkc\tau}-I_{pkct}+B_{pkct}-B_{pkct-1}\geq\sum_{\tau=1}^{t}\left[\sum_{j=1}^{N}\left\{(1+\beta_c)R(c,j)(x_{pkj\tau}+I_{pkj\tau}+B_{pkj\tau})+(1+l_{pk\tau})W(c,j)y_{pkj\tau}\right\}\right]$$
$$p=1,..,ENDP, c=1,..,C\setminus ENDP,\quad k=1,..,K;\quad t=1,..,T$$

$$I_{pkit-1} + \sum_{\tau=1}^{t-LT(p,k,i)} x_{pki\tau} - I_{pkit} + B_{pkit} - B_{pkit-1} \geq \sum_{\tau=1}^{t}\left[\sum_{j=1}^{N}\left\{(1+\beta_i)R(i,j)\left(x_{pkj\tau} + I_{pkj\tau} + B_{pkj\tau}\right) + \left(1+l_{pk\tau}\right)W(i,j)y_{pkj\tau}\right\}\right]$$

$$p = 1,..,ENDP; i \neq c; i = 1,..,N \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$C_{pkit} \geq \sum_{\tau=1}^{t}\left[\sum_{j=1}^{N}\left\{(1+\beta_i)R(i,j)\left(x_{pkj\tau} + I_{pkj\tau} + B_{pkj\tau}\right) + \left(1+l_{pk\tau}\right)W(i,j)y_{pkj\tau}\right\}\right]$$

$$p = 1,..,ENDP; i \neq c; i = 1,..,N \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$C_{pkct} \geq \sum_{\tau=1}^{t}\left[\sum_{j=1}^{N}\left\{(1+\beta_c)R(c,j)\left(x_{pkj\tau} + I_{pkj\tau} + B_{pkj\tau}\right) + \left(1+l_{pk\tau}\right)W(c,j)y_{pkj\tau}\right\}\right]$$

$$p = 1,..,ENDP; c = 1,..,C \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

The complete models under the quality and breakdown is shown in Figure 5

The fundamental MRP II models (Figure 1) are used to make a requirement list with deterministic information like demand, lead time of products and component, etc. on an existing production. The company, namely ABC (a given name), is producing air filter products for diverse air filtration system. The details of the company are found in Wazed et al. (2010d). The same data with the layout information is also employed in proposed mathematical models to prepare a timely requirement schedule of the systems. Both the existing and proposed models are solved in Lingo systems with global solver, and their outputs are compared. The product structure and manufacturing cell layout of the system are shown in Figure 6. The model validation is performed to test the overall accuracy of the model and the ability to meet the real value. Tables 1 and 2 are showing the timely requirements of components generated respectively by the basic MRP II and proposed mathematical models of the company.

The models are further employed to a multiple lines multistage production for checking convergence of their outputs. It is also a live story of a company namely XDE (a given name) located in Malaysia produces bicycle wheels. The details of the company and its production information are available in Wazed et al. (2011). The product structures and production layout of the company is shown in Figure 7 (a- product structure and b- production layout). Tables 3 and 4 shows the timely requirement schedules for a multistage, multiproduct system respectively generated by the basic MRP II and by the proposed mathematical models.

It is really a good matching found between the two schedules generated by the basic MRP II and proposed models. The later was bearing additional information of the location that was partly available in a time frame.

EFFECT OF COMPONENT COMMONALITY

The basic mathematical models for multistage manufacturing are validated in single and multiple production lines in the earlier section. Here, the effect of component commonality is observed using the proposed commonality models and the outcomes are compared with their basic forms. The models are executed for 18 periods under various created scenarios. For the commonality models, we assumed two different scenarios (Table 5).

EFFECT OF COMMONALITY ON PRODUCTION COST AND CAPACITY REQUIREMENT

The authors have executed the models in Lingo system to observe the impact of common parts under the individual and joint actions of quality and breakdown in production. It is considered that the demand (Table 6) and procurement lead time is known and constant. This article assumes that all incoming raw materials bear the 3% and final products 1% defective. Table 7 shows the breakdown schedule of resources in the different epoch. The number of defective parts produced during changeovers is shown in Table 8. The cost components, setup and processing times, demand, lead times are known and constant. It is assumed that 0.9% of the processing time is consumed in repairing a breakdown resource. Common parts usually require higher cost and

Objective function

$$Minimize \quad z = \sum_{WC(P,K)} \sum_{I} \sum_{T} \left(v_i x_{pkit} + b_i B_{pkit} + q_i I_{pkit} \right) + \sum_{WC(P,K)} \sum_{I} \sum_{T} f_{pk} \left(y_{pkit} - \gamma_{pkit} \right) + \sum_{WC(P,K)} \sum_{T} c_{WC} OT_{pkt}$$

Subject to

$$IP_{pkit-1} + \sum_{\tau=1}^{t-LT(p,k,i)} x_{pki\tau} - I_{pkit} + B_{pkit} - B_{pkit-1} \geq D(p,k,i,t) \quad p = 1,.., ENDP;\ i = p; \quad k = K; \quad t = 1,..,T$$

$$I_{pkit-1} + \sum_{\tau=1}^{t-LT(p,k,i)} x_{pki\tau} - I_{pkit} + B_{pkit} - B_{pkit-1} \geq \sum_{\tau=1}^{t} \left[\sum_{j=1}^{N} \left\{ (1+\beta_i) R(i,j) \left(x_{pkj\tau} + I_{pkj\tau} + B_{pkj\tau} \right) + \left(1 + l_{pk\tau}\right) W(i,j) y_{pkj\tau} \right\} \right]$$

$$p = 1,.., ENDP;\ i = 1,..,N \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$C_{pkit} \geq \sum_{\tau=1}^{t} \left[\sum_{j=1}^{N} \left\{ (1+\beta_i) R(i,j) \left(x_{pkj\tau} + I_{pkj\tau} + B_{pkj\tau} \right) + \left(1 + l_{pk\tau}\right) W(i,j) y_{pkj\tau} \right\} \right]$$

$$p = 1,.., ENDP;\ i = 1,..,N \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$x_{pkit} - n y_{pkit} LS(i) = 0 \qquad p = 1,.., ENDP;\ i = 1,..,N \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$x_{pkit} \leq M y_{pkit} \qquad p = 1,.., ENDP;\ i = 1,..,N \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$LS(i) \leq M y_{pkit} \qquad p = 1,.., ENDP;\ i = 1,..,N \setminus ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

The capacity constraints:

$$\sum_{I} \left\{ U(p,k,i) x_{pkit} + ST(p,k,i) \left(y_{pkit} - \gamma_{pkit} \right) + ST(p,k,i) l_{pkt} y_{pkit} \right\} + V(p,k,t) l_{pkt} y_{pkit} - OT_{Pkt} + UT_{pkt} \leq CAP_{pkt}$$

$$p = 1,.., ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$OT_{Pkt} \times UT_{pkt} = 0 \quad p = 1,.., ENDP; \quad k = 1,..,K; \quad t = 1,..,T$$

$$y_{pkit-1} + y_{pkit} \geq 2\gamma_{pkit} \quad p = 1,.., ENDP;\ i = 1,..,N; \quad k = 1,..,K; \quad t = 1,..,T$$

$$\gamma_{pkit} \leq MU(p,k,i) \quad p = 1,.., ENDP;\ i = 1,..,N; \quad k = 1,..,K; \quad t = 1,..,T$$

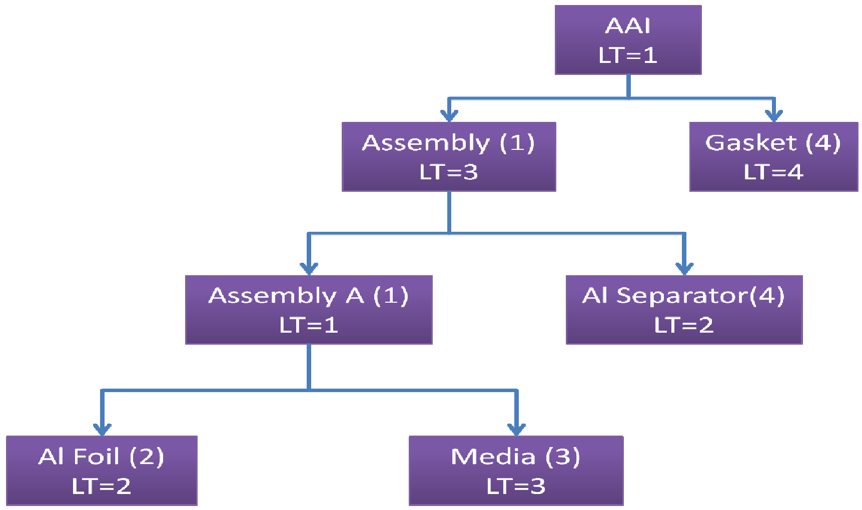
$$\sum_{i=1}^{N} \gamma_{pkit} \leq 1 \quad p = 1,.., ENDP;\ k = 1,..,K; \quad t = 1,..,T$$

Non-negativity constraints:

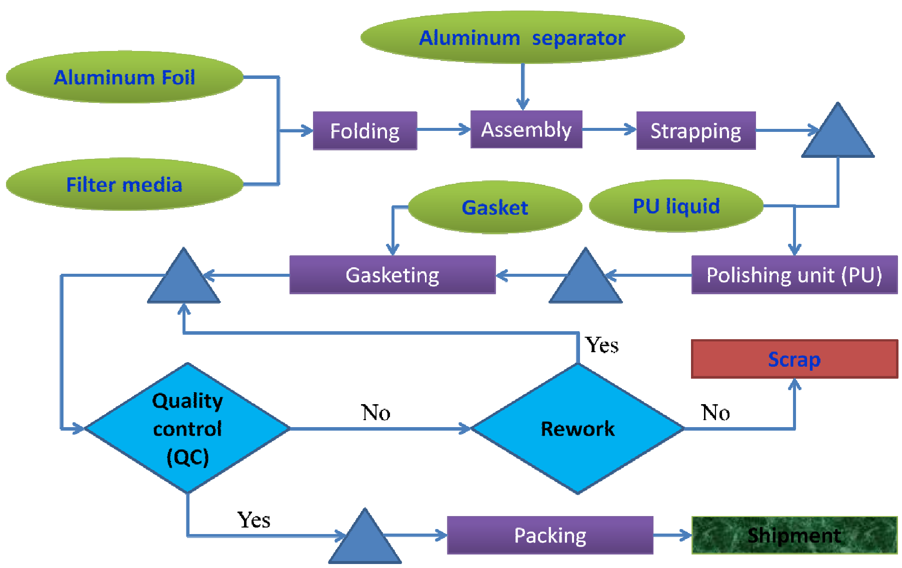
All variables ≥ 0; $\quad y_{pkit} = \{0,1\}; \quad n = Integer$

Figure 5. Models under known breakdown and quality problem of the system validation of mathematical models.

processing time (that is, processing cost) than the others. It is assumed that the common parts are able to fulfill the purpose of the replaced component. The other cost parameters are considered same under any scenario Figure 8. Figures 9 and 10 are showing the effect of cost of common parts on the total cost incurred and capacity



(a) Product structure



(b) Manufacturing layout

Figure 6. Manufacturing cell layout of the factory (Wazed et al., 2010d).

Table 1. MRP II generated timely requirement schedule for single line production.

Part/product	Period								
	1	2	3	4	5	6	7	8	9
AAI	0	0	0	0	0	0	0	50	0
Assembly	0	0	0	0	50	0	0	0	0
Gasket	0	0	0	0	0	0	200	0	0
Assembly A	0	0	0	50	0	0	0	0	0
Al Separator	0	0	200	0	0	0	0	0	0
Al Foil	0	100	0	0	0	0	0	0	0
Media	150	0	0	0	0	0	0	0	0

Table 2. Timely requirement schedule generated by proposed mathematical models for single line production.

Machine/stage	Part/product	Period								
		1	2	3	4	5	6	7	8	9
Folding	Al Foil	0	100	0	0	0	0	0	0	0
Folding	Media	150	0	0	0	0	0	0	0	0
Assembly	Assembly A	0	0	0	50	0	0	0	0	0
Assembly	Al Separator	0	0	200	0	0	0	0	0	0
Strapping	Assembly	0	0	0	0	50	0	0	0	0
Gasketing	Gasket	0	0	0	0	0	0	200	0	0
Packaging	AAI	0	0	0	0	0	0	0	50	0

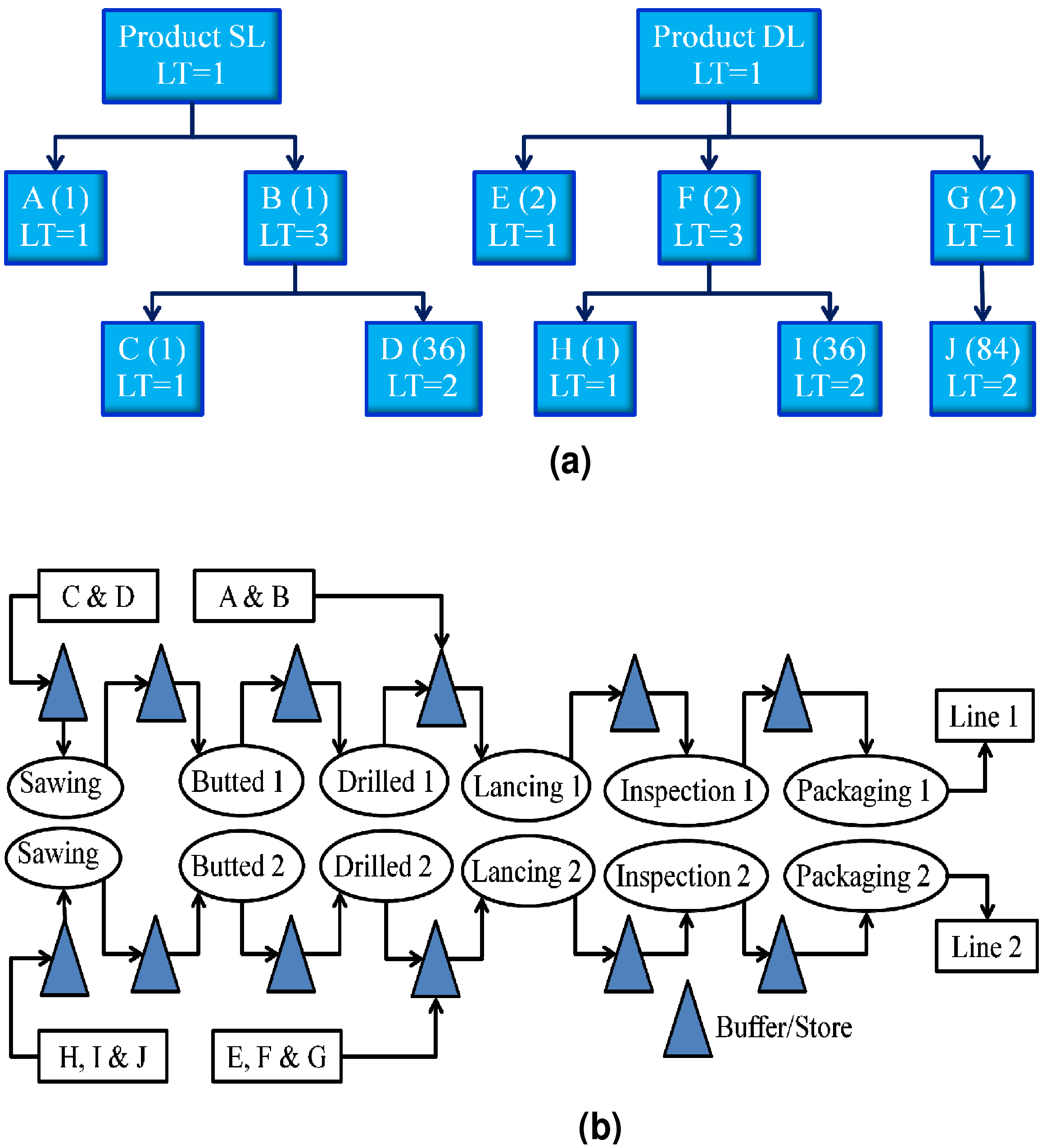


Figure 7. Product structure and (b) production layout of a Malaysian company.

Table 3. MRP II generated timely requirement schedule for double line production.

Part/product	Period								
	1	2	3	4	5	6	7	8	9
Product SL	0	0	0	0	0	0	0	120	0
Product DL	0	0	0	0	0	0	0	140	0
A	0	0	0	0	0	0	120	0	0
B	0	0	0	0	120	0	0	0	0
C	0	0	0	120	0	0	0	0	0
D	0	0	4320	0	0	0	0	0	0
E	0	0	0	0	0	0	280	0	0
F	0	0	0	0	280	0	0	0	0
G	0	0	0	0	0	0	280	0	0
H	0	0	0	280	0	0	0	0	0
I	0	0	10080	0	0	0	0	0	0
J	0	0	0	0	23520	0	0	0	0

Table 4. Timely requirement schedule generated by proposed models for double line production.

Part/product	Machine/stage	Period								
		1	2	3	4	5	6	7	8	9
Product SL	Packaging 1	0	0	0	0	0	0	0	120	0
Product DL	Packaging 2	0	0	0	0	0	0	0	140	0
A	Lancing 1	0	0	0	0	0	0	120	0	0
B	Lancing 1	0	0	0	0	120	0	0	0	0
C	Sawing	0	0	0	120	0	0	0	0	0
D	Sawing	0	0	4320	0	0	0	0	0	0
E	Lancing 2	0	0	0	0	0	0	280	0	0
F	Lancing 2	0	0	0	0	280	0	0	0	0
G	Lancing 2	0	0	0	0	0	0	280	0	0
H	Sawing	0	0	0	280	0	0	0	0	0
I	Sawing	0	0	10080	0	0	0	0	0	0
J	Sawing	0	0	0	0	23520	0	0	0	0

Table 5. Commonality design.

Scenario	Component in Line 1	Component in Line 2	Common component	Layout
1	C D	H I	C D	Figure 8a
2	A B	E F	A B	Figure 8b

requirement respectively. The timely requirement schedules of the dependent items for both of the cases are generated from the models. Appendix A shows the timely requirements of products and their dependent items for non-commonality case. The same for commonality cases (1 and 2) are respectively shown in Appendix B and C. The Appendices (Appendices A, B and C) show that the requirements of common parts are always higher than the individual part it replaces in deterministic situation.

Figure 9 shows that the cost of production is always less for commonality cases. The cost increases with the

Table 6. Timely demand of the end products.

Period	9	10	11	12	13	14	15	16	17	18
Demand of Product SL	120	120	120	120	120	120	120	120	120	120
Demand of Product DL	140	140	140	140	140	140	140	140	140	140

Table 7. Number of breakdowns of the resources in different epoch.

Product	Process	Period																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Product SL	Sawing	0	2	2	2	0	2	1	3	1	1	1	1	0	2	2	1	2	2
	Butted 1	3	3	0	3	3	1	2	1	1	0	3	0	2	2	0	2	2	3
	Drilling 1	1	0	1	2	0	1	0	0	1	3	2	1	1	1	0	1	1	3
	Lancing 1	1	0	2	1	2	1	1	0	2	1	2	3	1	2	1	0	0	0
	Inspection 1	0	3	1	0	0	2	3	2	3	3	2	0	2	1	1	2	1	1
	Packaging 1	0	3	0	1	2	2	2	0	1	0	3	3	1	0	3	0	1	1
Product DL	Sawing	1	3	2	2	0	3	0	3	2	0	3	1	2	1	0	2	2	1
	Butted 2	2	3	0	0	0	0	2	3	0	1	3	1	0	3	0	0	3	3
	Drilling 2	3	3	0	2	2	3	1	0	3	0	0	2	1	2	3	2	3	3
	Lancing 2	1	3	2	1	0	0	1	1	1	2	0	1	0	3	1	0	3	2
	Inspection 2	1	3	3	3	1	1	3	3	2	3	2	1	3	2	3	0	3	2
	Packaging 2	3	3	3	3	1	2	2	0	1	1	3	3	1	3	2	3	1	3

Table 8a. Number of defective items produced during changeover (non- commonality).

Part	Part									
	A	B	C	D	E	F	G	H	I	J
A	0	3	3	3	4	4	4	2	3	3
B	1	0	4	1	2	4	2	3	2	1
C	3	4	0	1	2	2	1	4	3	1
D	1	2	4	0	2	4	2	4	4	1
E	3	2	3	4	0	2	1	1	3	1
F	4	1	4	4	4	0	4	4	1	4
G	3	2	2	2	2	1	0	3	1	2
H	1	4	3	4	2	2	1	0	2	2

cost ratio for both scenarios. Cost ration represents how much expensive the common part is in comparison to the components it substituted. For example, 1.10 means that the cost (both purchasing and processing) of common parts is 10% more than the cost of the components it replaced. It is observed that commonality offers a better choice, even if the cost (both purchasing and processing) of the common parts is 60% higher than the substituted parts (Scenario 1). The disparity in cost with a cost ratio is not significantly sensitive in scenario 2. The least cost offers come from the scenario 2 when the cost ratio is higher than 1.2 for a specific condition. It is obvious because of few common components are required for this scenario. These trends are valid even under quality and breakdown occurrences for a multistage production when information is known and remain unchanged. However, the cost increases under the actions of quality and combination of both quality and breakdowns. The cost saving in commonality models mainly comes from the processing cost. Inclusion of common parts at the lower level (Scenario 1) is always beneficial than higher level (Scenario 2). Generally, at the downstream of a production requires fewer parts and processing than the upstream components. This is the main reason of a

Table 8b. Number of defective items produced during changeover (Commonality scenario 1).

Part	Part							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**J**
A	0	3	3	3	4	4	4	3
B	1	0	4	1	2	4	2	1
C	3	4	0	1	2	2	1	1
D	1	2	4	0	2	4	2	1
E	3	2	3	4	0	2	1	1
F	4	1	4	4	4	0	4	4
G	3	2	2	2	2	1	0	2
J	2	1	4	3	2	3	4	0

Table 8c. Number of defective items produced during changeover (Commonality scenario 2).

Part	Part							
	A	**B**	**C**	**D**	**G**	**H**	**I**	**J**
A	0	0	0	0	0	0	0	0
B	0	3	3	3	4	4	4	3
C	1	0	4	1	2	4	2	1
D	3	4	0	1	2	2	1	1
G	1	2	4	0	2	4	2	1
H	3	2	3	4	0	2	1	1
I	4	1	4	4	4	0	4	4
J	3	2	2	2	2	1	0	2

higher cost saving offer comes from the inclusion of common part at the lower level than its successor.

Defective parts (that is, quality) contribute 18% more costs on production under the non-commonality cases. This figure is less (that is, 15%) in case of commonality scenarios when the cost of all components are same. Part commonality offers 11.5% less cost under perfect working environment and it is 13 when the system suffers with quality problem. The reduction in cost is 13.25% when the production continues under the combined storm of quality and breakdown in a commonality design (scenario 1). The cost saving is less in scenario 2. Therefore, blow of breakdown and quality variation in raw material and products may shrink by using commoncomponents in manufacturing. It is pellucid that the part commonality has little control over the breakdowns.

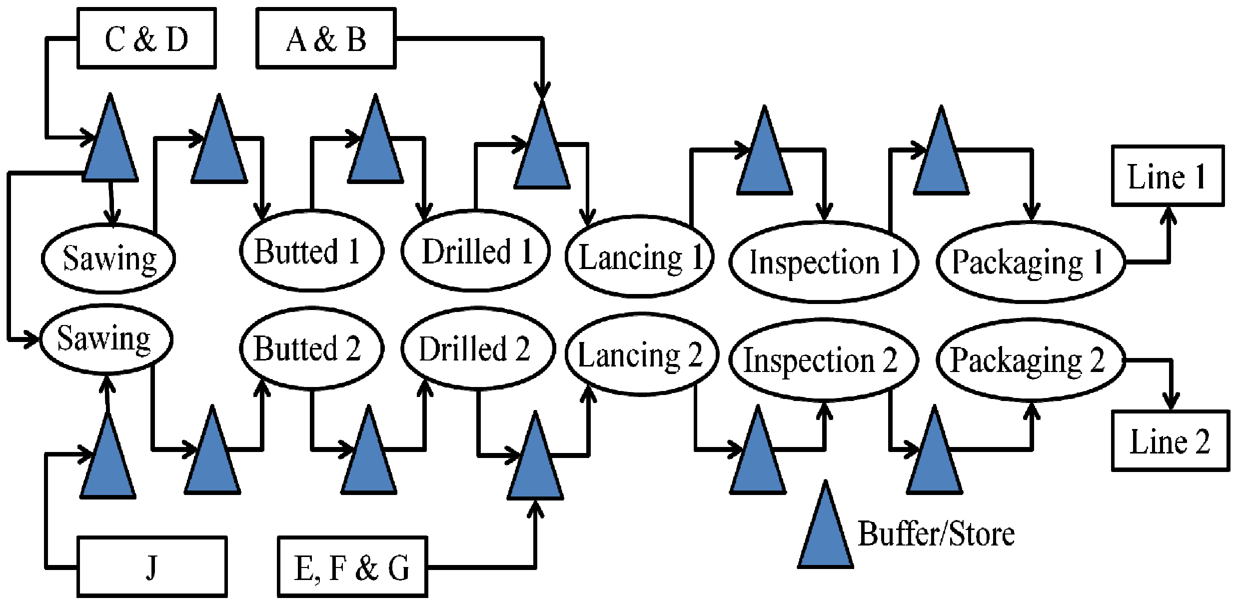
Figure 10 illustrates the capacity requirements of the manufacturing system under various situations. Inclusion of common parts at a lower level (Scenario 1) is advantageous than higher level (Scenario 2). It is always true that commonality designs require less capacity. The same processing and setup time data are used for both commonality and no-commonality designs. The time saves mainly from the required number of setup of the parts. As commonality offers fewer varieties of parts, resources required less setup.

The commonality scenario 1 shows a better option than its counterpart scenario 2 under all factors. It is obvious because of few common components are required for scenario 2 and hence time saving from the setup is less. Generally, at the downstream of a production requires fewer parts and processing than the upstream components. These inclinations are legitimate even under quality and breakdown incidences for a multistage production when information is known and remain unchanged. Nevertheless, the required capacity increases under the actions of quality and blend of both quality and breakdowns.

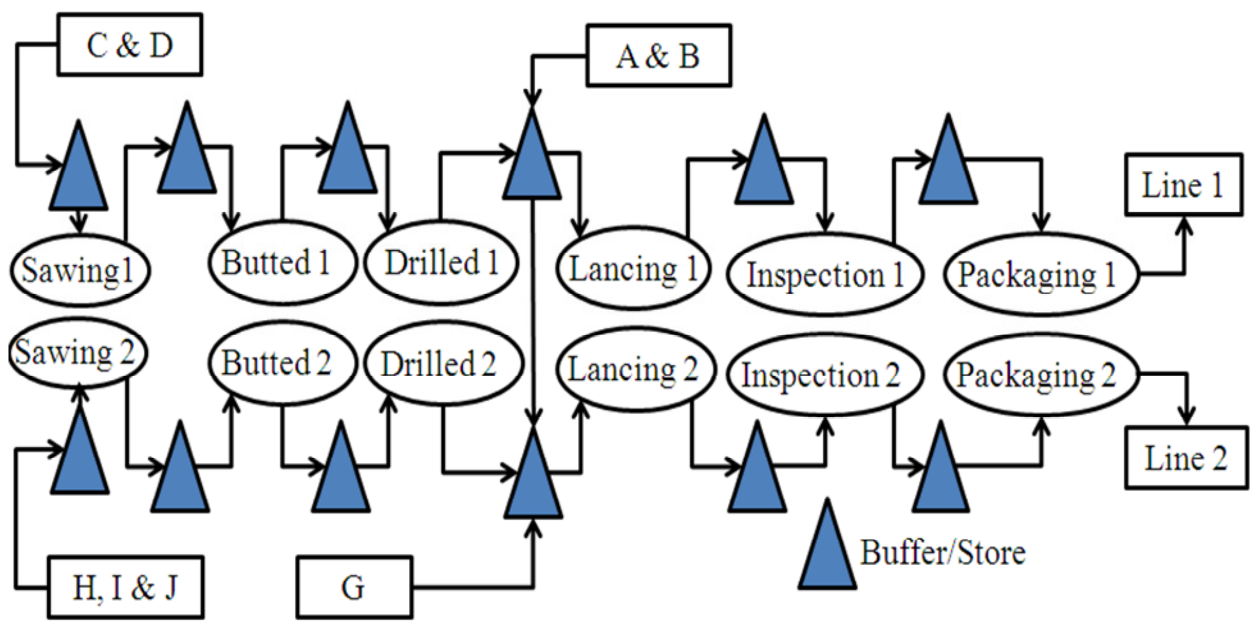
Conclusion

From this study and analysis, the authors like to conclude that

1. Under stable and stationary condition, the proposed models can provide exact planning like MRP II. Additionally, the parts routes are easily traced in the floor for each planning period, even in the storm of quality and resources breakdowns.
2. Use of common parts in manufacturing is always better



(a)



(b)

Figure 8. Production layout for commonality (a- Scenario 1 and b- Scenario 2) of the Malaysian company.

over the non-commonality scenario in term of production cost and capacity requirements.
3. The requirements of common parts are always higher than the individual part it replaces.
4. The impact of applying component commonality at stages is different due to the lead time dynamics in the system. Inclusion of common parts at the upstream is always beneficial than at the downstream of the production line. Cost and capacity saving under the quality and blend of quality and breakdowns are significant.

Future research direction

This work mainly focuses in mathematical models when the parameters and information are certainly known. However, most of the information and parameters in

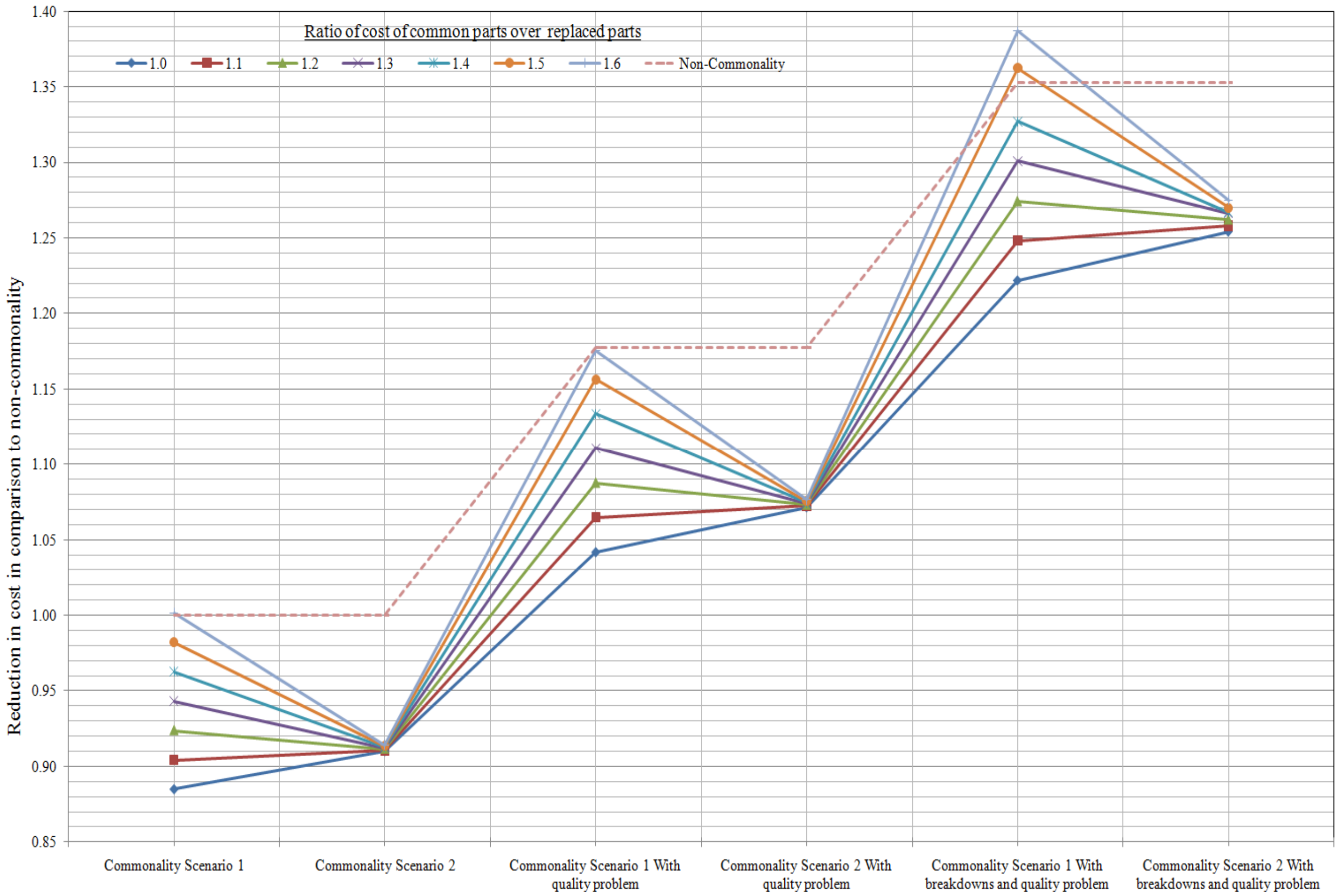


Figure 9. Effect of common parts on total cost incurred under various scenarios

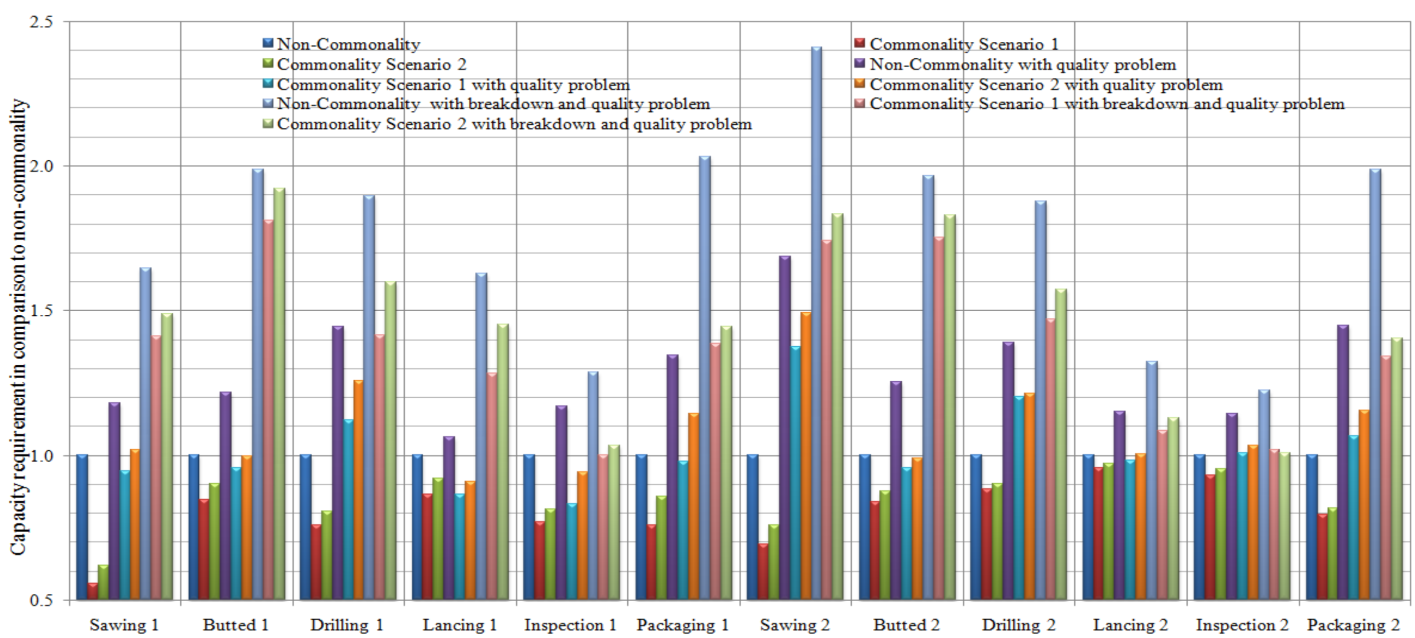


Figure 10. Effect of common parts on capacity requirement in a multistage manufacturing.

reality are uncertain. Hence, there are scopes for prospective researchers to develop models when the issues are unpredictable and vary arbitrarily with time.

Nomenclature: N, Number of SKUs/parts/components subscripted as i; $ENDP$, number of end products, subscripted as p; T, number of time buckets (that is, the planning horizon) subscripted as t; C, number of common components/modules subscripted as c; K, number of resources/machines/stations; $LT(p,k,i)$, lead time for product/component/module/SKU i at $WC(p,k)$; $R(i, j)$, number of i's needed to make one j; $D(p,k,i,t)$, external demand for product/component/module/SKU i in period t at $WC(p,k)$; $LS(i)$, minimum lot size for product/component/module/SKU i; I_{pkit}, inventory level of product/component/module/SKU i in front of resource $WC(p,k)$ in period t; C_{pkit}, number of component/module/SKU i at resource $WC(p,k)$ in period t; $U(p,k,i)$, fraction of available time of resource $WC(p,k)$ needed to make one unit of SKU i; $ST(i,k)$, fraction of available time of resources used to setup for product/component/SKU i; y_{pkit} = 1, if product/component/ SKU i starts on resource $WC(p,k)$ at period t; 0 otherwise; γ_{pkit} = 1, if product/component/module/SKU i will be the last product produced on resource $WC(p,k)$ in period $t-1$ and the first produced in time bucket t; 0 otherwise; M, a large number; q_i, cost of carrying inventory of product/component/module/SKU i per unit time; v_i, production cost of product/component/module/SKU i; f_{pk}, cost for setting up resource $WC(p,k)$; x_{pkit}, number of component/module/SKU i produced at resource $WC(p,k)$ in period t; C_{pkit}, number of component/module/SKU i needed at resource $WC(p,k)$ in period t;

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APPENDIX

Appendix A. Timely requirement of product and components (non commonality case).

	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Product SL	0	0	0	0	120	120	120	120	120	120	120	120	120	120
Product DL	0	0	0	0	140	140	140	140	140	140	140	140	140	140
A	0	0	0	120	120	120	120	120	120	120	120	120	120	0
B	0	0	0	120	120	120	120	120	120	120	120	120	120	0
C	240	240	240	240	240	240	240	240	240	240	0	0	0	0
D	8640	8640	8640	8640	8640	8640	8640	8640	8640	8640	0	0	0	0
E	0	0	0	280	280	280	280	280	280	280	280	280	280	0
F	0	0	0	280	280	280	280	280	280	280	280	280	280	0
G	0	0	0	280	280	280	280	280	280	280	280	280	280	0
H	560	560	560	560	560	560	560	560	560	560	0	0	0	0
I	20160	20160	20160	20160	20160	20160	20160	20160	20160	20160	0	0	0	0
J	0	0	47040	47040	47040	47040	47040	47040	47040	47040	47040	47040	0	0

Appendix B. Timely requirement of products and components (Scenario 1).

	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Product SL	0	0	0	0	120	120	120	120	120	120	120	120	120	120
Product DL	0	0	0	0	140	140	140	140	140	140	140	140	140	140
A	0	0	0	120	120	120	120	120	120	120	120	120	120	0
B	0	0	0	120	120	120	120	120	120	120	120	120	120	0
C	800	800	800	800	800	800	800	800	800	800	0	0	0	0
D	28800	28800	28800	28800	28800	28800	28800	28800	28800	28800	0	0	0	0
E	0	0	0	280	280	280	280	280	280	280	280	280	280	0
F	0	0	0	280	280	280	280	280	280	280	280	280	280	0
G	0	0	0	280	280	280	280	280	280	280	280	280	280	0
J	0	0	47040	47040	47040	47040	47040	47040	47040	47040	47040	47040	0	0

Appendix C. Timely requirement of products and components (Scenario 2).

	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Product SL	0	0	0	0	120	120	120	120	120	120	120	120	120	120
Product DL	0	0	0	0	140	140	140	140	140	140	140	140	140	140
A	0	0	0	400	400	400	400	400	400	400	400	400	400	0
B	0	0	0	400	400	400	400	400	400	400	400	400	400	0
C	800	800	800	800	800	800	800	800	800	800	0	0	0	0
D	28800	28800	28800	28800	28800	28800	28800	28800	28800	28800	0	0	0	0
G	0	0	0	280	280	280	280	280	280	280	280	280	280	0
H	800	800	800	800	800	800	800	800	800	800	0	0	0	0
I	28800	28800	28800	28800	28800	28800	28800	28800	28800	28800	0	0	0	0
J	0	0	47040	47040	47040	47040	47040	47040	47040	47040	47040	47040	0	0