**The impact of production interruptions in kitting, an analytical study**

**Abstract**

The practice of *Kitting* (collecting components required for assembly) is essential in determining system performance, especially when it operates in a stochastic production environment. This paper discusses the performance of kitting operations in a stochastic assembly system, treating it as an assembly-like queue model. Specially, the impact of production inefficiencies in the subparts is investigated. To model this inefficiency, the subparts arrive according to an *Interrupted Poisson Process* instead of a *Poisson Process*. Performance measures for the kitting models such as the stock-out probability are calculated and displayed in numerical examples which are showed in this article.

Unlike previous studies in this domain, we use *sparse matrix techniques* to solve linear equations. Results show that this technique is a valuable queuing theoretic numerical approach in terms of solution speed and accuracy to estimate the performance of the kitting process.

1. **Introduction**

Nowadays customers put a lot of pressure on the market to afford customized products. This result in the handling of a large number of components in the production systems. The problem of keeping many and varied components is met by applying *kitting*.

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Nowadays manufacturing systems are often composed of multiple in-house fabrication units [8]. The semi-finished products stemming from these units are the input materials for other fabrication units or for assembly lines. Hence, efficient transport of materials between the different stages of the production process is a key issue for overall production cost minimization. Therefore the *Kitting* method was introduced.

Kitting is a particular strategy for supplying materials to an assembly line. Instead of delivering parts at the assembly line in containers of equal parts, in kitting prior to arriving at an assembly unit the necessary parts are collected into a specific container, referred to as “kit” [1,2,8,11-13]. This contrasts with the more traditional line stocking where the parts are delivered at the assembly line in containers of equal parts [1].

Kitting mitigates storage space requirements at the assembly station since no part inventories need to be kept there. Moreover, parts are placed in proper positions in the container such that assembly time reductions can be realized. Additional benefits include reduced learning time of the workers at the assembly stations and increased quality of the product [11]. The advantages above do not come for free since the kitting operation itself also incurs additional costs. There are mostly the time and effort for the additional planning of the parts allocation into kits and the kit preparation itself. A storage space will also be essential to store the already prepared kits.

Although kitting is a non-value adding activity, its application can reduce the overall materials handling time [Ramakrishnan and Krishnamurthy, 2008]. However, the introduction of a kitting operation in a production process involves a major investment. Therefore it is important to analyze the performance of kitting in a production environment prior to the actual introduction of this operation. The goal of this paper is to better understand the kitting process in a production environment, taking possible production inefficiencies of the subparts into account. Special attention is put on queuing models and queuing analysis techniques.

1. **Model description**

Most authors consider a kitting process as a queuing system in a stochastic environment.

Hopp and Simon (1989) have developed a model that is often used to describe the performance of an assembly line analysis. In their article "Bounds and Heuristics for Assembly-like queues" they have a model with exponentially distributed processing times and between arrival times according to a Poisson process. Out of their model, they deduce boundaries for the capacity of the buffers. This model is mainly based on the model of Lipper and Sengupta (1986). The method of Hopp and Simon is easier to implement and the definition of an optimal upper limit of capacity is more accurate, but it is limited to processes with two basic components. The method of Lipper and Sengupta on the other hand, can be applied to more general systems. We also restrict our analysis to two types of parts.  
  
Som, Wilhelm, and Disney (1994) consider a kitting process as a delivery system for assembly that is mainly based on the model of Hopp and Simon. In their model, two processes are studied, namely the assembly and the kitting process. We focus on studying the kitting process wherein the parts, after they have entered the process, are collected as kits and sent according to an exponential distribution to the kitbuffer.

An important similarity with the described model is the assumption of a finite capacity buffer. Of course a buffer has always a finite capacity. However, if the capacity is large enough, we can have a good approximation of a process with a finite capacity on the basis of a model with unlimited capacity. This means that there is always enough room for upcoming parts, which simplifies the analysis. Unfortunately, the assumption of an infinite buffer is not valid for kitting processes. If the capacity is assumed as infinite, then the model will degrade to an unstable stochastic model. This was demonstrated by Latouche (1981) that studied waiting lines with paired customers. We can consider his analysis as an abstraction of a kitting process with two types of parts. In the article "Assembly-like queues" Harrison (1973) confirms that, to ensure stability in the operations of a kitting process, it is necessary to impose a restriction on the size of the buffer. Under this assumption, the probability to have a certain long-term stock position is equal and independent of the current stock position. We assume that the ceiling on the buffering capacity of the two components is equivalent to and.

This paper models the kitting process as a Markov process, assuming that component arrival streams follow independent distributions. The assembly system is assumed to have a structure similar to that described in Som, Wilhelm and Disney and is shown in figure 1.

Two independent input streams arrive at part inventories and “wait” there till they are collected into a kit. We assume that buffers of components have limited capacity and that each component is processed according to an exponential distribution (before kitting) to prepare it for assembly.

Three mathematical queuing models are constructed and analyzed to assess the impact of production interruptions on the performance of kitting. In the first model, both components arrive according to a *Poisson Process* with the same parameter λ. In the first extensive model, parts of type 1 are subject to interruptions in the production. The arrivals of components are modeled as an *Interrupted Poisson Process*, abbreviated as IPP. This is a stochastic process in which two states are possible and which one of these two has an intensity equal to zero. Note that between the arrival times for both the Poisson Process and the IPP are independent. For IPP these are no longer exponential but hyper-exponential distributed.

In the queuing analysis, an IPP is divided into two periods, namely the active and inactive period (Heyman and Sobel, 1982). We start with an active period and during this interval there are components arriving according to a Poisson process with intensity λ\*. The length of this period is exponential distributed with mean α-1. At the end of an active period begins a period of inactive components which do not arrive, the length is exponentially distributed with mean β-1. At the end of this period begins another new active period and so on. All active and inactive periods are i.i.d. The parameter α (β) describes the intensity to go from an active (inactive) to an inactive (active) period in an infinitesimal time interval.

1. **Formulation of a Continuous Time Markov Chain**

The concept of uncertainty being central in queuing theory, a queuing theoretic approach is used in order to assess the performance of a kitting process under uncertainty of inventory replenishments and/or product demand. Often, neither the product demand nor the inventory replenishment can be fully controlled such that Kitting processes are preferably modeled as stochastic processes.

The kitting process modeled as a Markov Chain allows us to determine the probability that a certain state e.g. the number of components in the two part inventories, occurs. This gives us the ability to calculate performance measures such as the average buffer occupancy. We discuss the steps to determine the performance measures.

Deel 2.3.2 en 2.3.3

Luisteren

Fonetisch lezen

Woordenboek - [Gedetailleerd woordenboek weergeven](http://www.google.be/dictionary?source=translation&hl=nl&q=google%20maps&langpair=en|nl)

1. **zelfstandig naamwoord** 
   1. woe
   2. pain
2. **Methodology**

We describe the kitting process as a Continuous Time Markov Chain.

Queuing models for kitting processes are rather complicated. Since two queues are involved (one for each part in the kit) and the process can be whether in a productive or unproductive state, the *state space* of the associated Markov chain is inherently *multidimensional*. The state of the Markov chain roughly corresponding to the number of distinct parts in the different inventories, the state space includes all possible part inventory levels. Multidimensionality leads to huge state spaces; this is the state space explosion problem. A second complication is more intricate. Obviously, inventories always have a finite capacity. However, if this capacity is sufficiently large, one may assume that the capacity is infinite. This means that there is always room for arriving parts, which simplifies the analysis. Unfortunately, the *infinite-buffer-capacity* *assumption is not applicable* for kitting processes. If the capacity is assumed infinite, the model degrades to an instable stochastic model in which some or all of the queues have an unlimited number of parts available all the time with a positive probability. This was already showed in [6] which studies queues with paired customers, an abstraction of a kitting process with two types of parts.

Having established these complications, it is clear that not every queuing model of a kitting operation is mathematically tractable.

Intricate performance models are developed taking realistic assumptions into account.

Efficient numerical algorithms are developed which generate the performance measures of interest fast.

* 1. *Sparse matrix method*

1. **Numerical examples**
   1. *Input parameters*
   2. *Performance measures*

A good queuing model can accurately predict the performance measures of a real system in terms of this system’s parameters. For the kitting operation, the queuing analysis focuses on performance measures such as the throughput of the kits as well as the mean and variance of the kit buffers. The stock-out probability, the probability that one of the part inventories is empty such that the kitting operation is disrupted is another important measure.

[8] L. MEDBO, Assembly work execution and materials kit functionality in parallel flow assembly systems, International Journal of Industrial Ergonomics, 2003, vol. 31:263-281.

[1] Y.A. BOZER, L.F. MCGINNIS, Kitting versus line stocking: A conceptual framework and a descriptive model, International Journal of Production Economics, 1992, vol. 28:1-19.

Kitting process in a stochastic assembly system:

Under the special condition of identical component arrival streams having the same Poisson parameter, we show that the output stream of kits approximates a Poisson process with parameter equal to that of the input streams