İstanbul Ticaret Üniversitesi Fen Bilimleri Dergisi Yıl: 6 Sayı:11 Bahar 2007/1 s . 129-142

A REVIEW ON LOT STREAMING PROBLEMS WITH TRANSPORTATION ACTIVITIES

Rahime SANCAR EDIS[*] , Arslan M. ORNEK[**] , Deniz TURSEL ELIIYI[***]

ABSTRACT

Lot streaming is the process that splits the production lot into sublots and streams these sublots among the machines with regard to some performance criteria. A performance criterion can be time-based (e.g., makespan) or cost-based (e.g., total cost), while some studies consider both of them together. In lot streaming problems, the production system characteristics are important. The case that the production system is single/multi stage or single/multi product determines the complexity of the lot streaming problems. Such systems may also involve a number of activities (e.g., production, setup, transportation) that further complicate the problem. This paper reviews the lot streaming problems with transportation activities. The number of transporters, their capacities and performing the schedule of these transporters are the components of this type of problems. Including transportation activities makes the problem more realistic. This review is based on the single/multi stage and single/multi product cases. It also aims to provide open perspectives and future research directions on lot streaming problems with transportation activities.

Keywords: Lot Streaming, Transportation, Review

TAŞIMA AKTİVİTELERİNİ İÇEREN PARTİ BÖLME PROBLEMLERİNİN LİTERATÜR TARAMASI

ÖZET

Parti bölme işlemi, üretim partisini daha küçük alt partilere bölmek ve bu alt partileri performans ölçütlerine göre makinelerde sıralamak şeklinde tanımlanabilir. Performans ölçütü zaman tabanlı (tamamlanma süresi) ya da maliyet tabanlı (toplam maliyet) olabilir. Ama bazı çalışmalarda ikisinin entegre edildiği de görülmektedir. Parti bölme problemlerinde, üretim sisteminin karakteristikleri önemlidir. Üretim sisteminin tek/çok aşamalı, ya da tek/çok ürünlü olması, parti bölme probleminin çözüm karmaşıklığını belirler. Bu sistemler aynı zamanda problemin çözümünü zorlaştıran bazı aktiviteleri de (üretim, hazırlık, taşıma gibi) içerebilir. Bu makale literatürdeki taşıma aktivitelerini içeren parti bölme problemlerini incelemektedir. Taşıyıcıların sayısı, kapasiteleri ve taşıyıcıların çizelgelenmesi bu tip parti bölme problemlerinin bileşenleridir. Parti bölme problemlerinde taşıma aktivitelerini dikkate almak, problemi gerçek hayat problemlerine yaklaştırmaktadır. Bu literatür taraması, tek/çok aşamalı ve tek/çok ürünlü kategorilerinde yapılmıştır. Ayrıca bu makale, taşıma aktivitelerini içeren parti bölme problemlerine farklı perspektifler geliştirme ve geleceğe yönelik araştırma çalışmalarına ışık tutma amacındadır.

Anahtar Kelimeler: Parti Bölme, Taşıma, Tarama

[*] Dokuz Eylul University, Industrial Engineering Department, Bornova-IZMIR
[**] Izmir University of Economics, Department of Industrial Systems Engineering, Balcova- IZMIR
[***] Izmir University of Economics, Department of Business Administration, Balcova- IZMIR

1. INTRODUCTION

Lot streaming technique splits the production lot into smaller sublots. Each sublot can be considered as individual jobs so that two different sublots of the same type can be processed on two different machines simultaneously. This makes the manufacturing lead time (MLT) be shortened. Lot streaming also provides a reduction on the average work-in-process (WIP). If the production lot is processed without splitting, the average WIP will be equal to production lot size. However, in case of splitting the production lot into sublots, departure of the first sublot reduces the WIP level by its size and the remaining sublots continue to reduce the WIP level by their sublot sizes. Reduction in space requirements and material handling system capacity requirements can be thought as the other benefits of lot streaming.

If there are no setup or transportation activities, the MLT is minimized by reducing sublot sizes to one-unit. However, when setup and transportation activities are taken into account, a trade-off between production and these activities incurs. This enforces the sublot size to be greater than one. The aim is then to find the optimal or near-optimal sublot allocations according to a performance criterion.

In this paper, we consider lot streaming problems with transportation activities. This paper is organized as follows. The next section describes the components of lot streaming problems. Section 3 details the related literature about lot streaming problems with transportation activities. Concluding remarks, open perspectives and future directions are given in the last section.

2. COMPONENTS OF LOT STREAMING PROBLEMS

In order to better understand the studies undertaken in literature review section, we first describe the components of lot streaming problems. These components are derived from Chang and Chui (2005), and Feldman and Biskup (2005) are summarized in Table 1. The definitions of these components are given below.

Product Type: A *single* product or *multiple* products
Production Type: Flow shop, job shop, open shop, arborescent shop

Jobs visit a number of operations according to a sequence through manufacturing systems. If the route of all job types is the same, this system is called *flow shop*. If jobs have different routes, this is called *job shop.* In a job shop environment, jobs may visit the same machines once or more.

The *open shop* scheduling model consists of *m* machines and *n* jobs. Each job has *m* operations. A machine can process at most one job at a time and operations of a job cannot be processed simultaneously. The routing for a job is the order of machines that the job visits. If each job is to be processed consecutively on a machine, the shop is called a non-preemptive open shop; otherwise it is a preemptive open shop (Sen and Benli, 1999).

The *arborescent shop* is an *m*-stage production system, in which each stage has at least one immediate successor except for the last stage (i.e., the finished goods stage), and has only one immediate predecessor except for the first stage (i.e., the raw materials or purchased parts stage) (Chang and Chiu, 2005).

Table 1. Components of Lot Streaming Problems

Dimension	**Level**	
Product Type	*Single-product	*Multi-product
Production Type	*Flow shop *Job shop	*Open shop *Arborescent shop
Sublot Type	*Fix *Equal	*Consistent *Variable
Divisibility of the Sublot Size	*Discrete	*Continuous
Sequence of the Sublots	*Intermingling	*Non-Intermingling
Operation Continuity	*Idling	*No Idling
Transfer Timing	*No-wait schedules	*Wait schedules
Performance Measures	Time models	*Makespan *Mean flow time *Total flow time *Mean tardiness *Number of tardy jobs *Total deviation from due date
	Cost models	*Total cost *Total cost with makespan
Activities Involved	Setup	*No setup *Attached setup *Detached setup
	Production	*Raw materials *Work-In-Process *Finished goods
	Transportation	*Transportation Time *Return Time *Capacities of transporters *Number of transporters

Sublot Type: Fix, Equal, Consistent, Variable sublots

Fix sublots means that all sublots for all products consist of the identical number of items on all stages.

Equal sublots means that sublot sizes are fix for each product. The sizes of equal sublots between any two adjacent stages are the same for different sublot counts (i.e. $q_{ij} = q$, $i = 1,\ldots,m$, $j = 1,\ldots,k$, where q_{ij} is the size of sublot j at stage i and q is a constant). The difference between fix and equal sublots applies to multiple products only (Feldman and Biskup, 2005).

A sublot is called *consistent* if its size does not change over the stages of processing. In other words, the sizes of consistent sublots between any two adjacent stages are identical, given the same sublot count. Symbolically, $q_{ij} = q_j$, $i = 1,\ldots,m$, $j = 1,\ldots,k$, where q_j is the size of sublot j. (Chang and Chiu, 2005)

An example is given for three machines and two sublots in Figure 1.

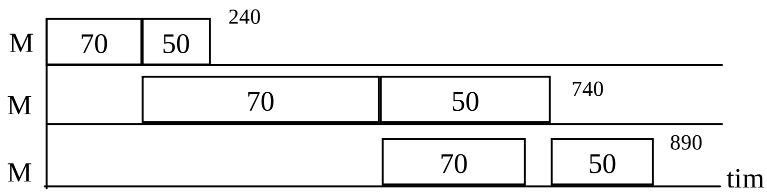

Figure 1. Consistent Sublot (Chang and Chiu, 2005)

In *variable* sublot case, the sublot sizes between stages i and i+1 are not equal to those between stages i+1 and i+2, given the same sublot count. That is, in an m-stage production system with k sublots, $q_{ij} \neq q_{i(j+1)}$, $i = 1,\ldots,m$, $j = 1,\ldots k$-1 and $q_{ij} \neq q_{(i+1)\,j}$, $i = 1,\ldots,m$-1, $j = 1,\ldots k$. A schedule obtained by variable sublots is given in Figure 2 (Chang and Chiu, 2005).

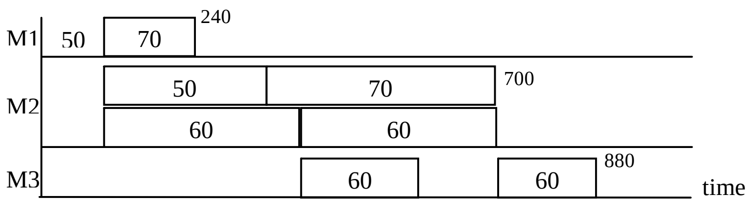

Figure 2. Variable Sublot (Chang and Chiu, 2005)

Obviously, equal sublot is a special case of consistent sublots, which is also a special case of variable sublots.

Divisibility of the Sublot Size: Discrete and Continuous sublots
In *discrete* version, the sublot size has to be integer, while in the *continuous* version it can be a real number.

Sequence of the Sublots: Intermingling and Non-Intermingling sublots
In the multi-product case, if *intermingling* sublots are allowed, the sequence of sublots of product *j* may be interrupted by sublots of product *k*. In this case, each sublot is treated as an independent product. For *non-intermingling* sublots, no interruption in the sequence of sublots of a product is allowed, which is obviously always given in one-product settings and can be forced in multi-product settings (Feldman and Biskup, 2005).

Operation Continuity: Idling and No Idling case
In *no idling* case, when the sublots start their operation on the same stage, they must finish their operation without interruption. However, the *idling* case allows idle times. As known, under the same sublot type, the makespan with idle times generates better results than no idling case. This situation can be viewed in Figures 3 and 4.

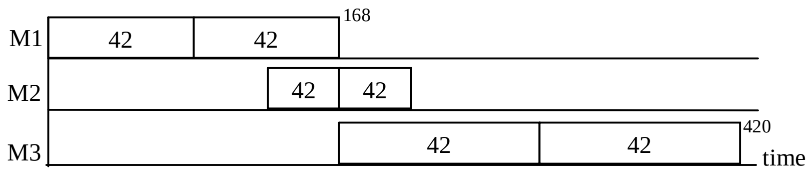

Figure 3. No Idling Case (Trietsch and Baker, 1993)

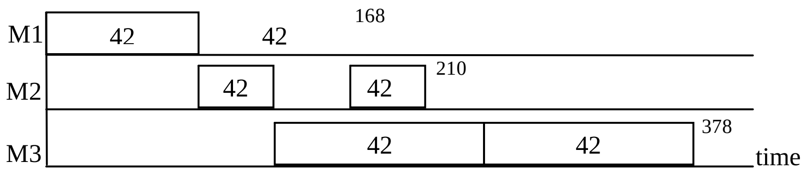

Figure 4. Idling Case (Trietsch and Baker, 1993)

Transfer Timing: Wait and No-wait schedules
In *no-wait* schedules, each sublot has to be transferred to and processed on the next stage immediately after it has been finished on the preceding stage. In a *wait* schedule, a sublot may wait for processing between consecutive stages (Feldman and Biskup, 2005).

Consider that 12 units of a single product must be processed on three machines. The unit processing times are 1, 3, and 2 on machines M1, M2, and M3, respectively.

Suppose that maximum allowable number of sublots is three. If the batch is processed as a single lot, the makespan would be 12(1+3+2) = 72. However, if the batch is split into three sublots with 2, 6, and 4 units, respectively, then the makespan is only 46. No-wait schedule of this example is given in Figure 5 (Hall et al., 2003).

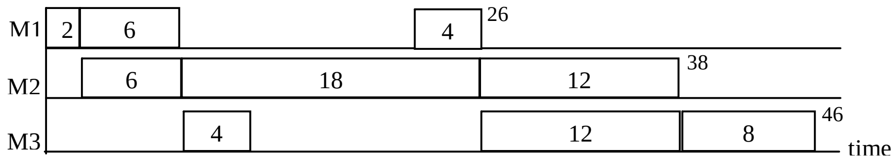

Figure 5. No-Wait Schedule (Hall et al., 2003)

Performance Measures: Time models and Cost models
For the *time* models, the performance measures can be makespan, mean flow time, total flow time, mean tardiness, number of tardy jobs and total deviation from due date. The minimization of total cost is considered as the performance measure for *cost* models.

Another measure can be derived by transforming the makespan value to a cost function and adding this to the total cost.

Activities Involved: Setup, Production, Transportation

Setup**:** No setup, Attached setup, Detached setup
Some production environments may not involve a setup activity, i.e., *no setup*. In the case of *attached* setup, a machine can be setup if and only if at least one unit is received from the previous stage. In a *detached* setup, a machine can be setup without receiving any unit from the previous stage.

Whether the setup type is attached or detached, the setup has an effect in cost models.

Production: Raw materials, Work-In-Process, Finished goods
For the time models, only the production time is important. However, for the cost models, the type of inventory should be taken into account. A cost model may only consider the WIP inventory and its associated cost. In some cases, either the WIP and finished good inventories or all the inventories (*raw materials*, *WIP*, *finished goods*) can be involved in cost functions.

Transportation:
Transportation activity includes the movement of a sublot between stages and the return of an empty transporter. For cost models, the transportation cost per trip is the only important component. For time models, the load and unload times,

transportation time, return time of the transporter and the number of capacitated transporters should be taken into account. Sublot size dependent transfer times can also be considered. Note that the extent to which the transportation activity affects the makespan depends on the number of capacitated transporters.

In this section, we described the components of lot streaming problems in detail in order to understand the related literature about the lot streaming problems with transportation activities which we review in the next section.

3. REVIEW OF LOT STREAMING PROBLEMS WITH TRANSPORTATION ACTIVITIES

There are a number of studies dealing with lot streaming problems including transportation activities. These papers are classified with respect to a number of characteristics and are given in Table 2.

The characteristics, except the transportation activities given in the last column, have been mentioned in the previous section. For the transportation activities, the number of transporters may be *single* or *multiple*; the capacities of transporters may be *limited* or *unlimited.* If the transportation time differs by the sublot sizes (e.g., an increase in sublot size causes an increase in transportation time), this case is called *sublot size dependent.* In a similar manner, if the transportation time depends on the distance travelled, this case is called *distance dependent.*

Many of the papers deal with the cost based performance measures. Szendrovits (1975) is one of the earliest papers that introduces the lot streaming concept with the objective of total cost minimization. This study does not include transportation activities; however many of the researchers address his paper and expanded it with some other activities. He studies the single product, multi-stage lot streaming problem in flow shops with continuous and equal sublots also considering no-idling case. In his paper, also the effect of lot streaming on minimizing manufacturing cycle time is discussed.

In an earlier paper, Goyal (1976) studies the problem of Szendrovits (1975) by adding transportation cost, i.e., cost of moving a sublot through all machines. He revises the total cost function and proposes a search algorithm to determine the production lot size and the number of sublots for the single-product multi-stage production system.

In a later paper Szendrovits (1976) further extends the model of Goyal (1976). He proposes a simpler and faster computational procedure to minimize the total cost. This search procedure is compared with that of the Goyal's by using various transportation costs. The results show that his search procedure requires less iteration than Goyal's.

Another lot streaming problem with transportation activities and cost objective is by Bogaschewsky et al. (2001). They presented a deterministic lot size model for a single-product, multi-stage flow shop problem. A total cost model was developed to determine the economic lot size and the optimal sublot sizes for each stage. The total cost function was the sum of setup cost, inventory holding cost and the transportation cost. The transportation cost assumed to be independent from the sublot size. The equal and variable sublot sizes were separately investigated by changing the number of sublots at each stage. For equal sublots, they proposed an algorithm that finds optimal number of sublots. For the variable sublot case, they suggested two algorithms: one for heuristic solutions, the other for optimal results.

Van Nieuwenhuyse and Vandaele (2003) describe a cost minimization model for a single-product deterministic flow-shop lot streaming problem. The sublot sizes are assumed to be discrete and equal. Total cost function includes inventory holding costs, transportation costs and gap costs. They assign a transporter between every machine and schedule them as they are machines on the routings which make the problem much easier. The empty travel time of the transporters and a setup requiring the whole sublot at the beginning of stages are also considered. In this study, idling case is allowed but also the gaps between consecutive sublots at each machine including the transporters are punished by the gap costs. They also investigate the behaviour of average lead time and the total gap time in terms of number of transfer batches. The results show that adding gap cost to the total cost function may address a no lot splitting case.

Riezebos (2004) investigate the effect of the time bucket length and the number of sublots on the total cost objective for a multi-product multi-stage production system. The components of the total cost function were the inventory holding costs, setup (ordering) costs and the transfer costs. The transfer cost is calculated by using the number of sublots at an operation and cost of transport and administration effort required at that operation. The cost of transport varies per product and operation, depending on the location. The performance of the fix and equal sublot strategies are compared with each other. An experimental design is conducted and different sublot strategies and time bucket lengths are investigated. The results indicate that the length of time bucket has an important effect on the performance of fix and equal sublots.

Chiu and Chang (2005) study two cost models for lot streaming in a multi-stage flow shop. The first model includes inventory holding costs, setup cost, transfer batch movement cost and finished goods (FG) shipment cost. In the second model, an imputed cost associated with the makespan time is added to these costs. The sublot sizes are assumed to be equal and production is not interrupted between any two adjacent sublots. The number of transporters and the capacity of each transporter are assumed to be infinite. They consider the sublot movement and finished goods shipment costs are independent from the sublot size. Also the buffer areas between the stages are assumed to be sufficient to store the sublots. They carry

Table 2. Review of Lot Streaming Papers that Include Transportation Activities

Author (Year)	Product Type	Production Type	Sublot Type	Divisibility of Sublot Size	Objective	Activities Involved	Transportation Activities
Goyal (1976)	Single	Multistage flow shop	Equal	Continuous	Total cost	Setup Holding (WIP, FG)	Sublot size independent Distance independent
Szendrovits (1976)	Single	Multistage flow shop	Equal	Continuous	Total cost	Setup Holding (WIP, FG)	Sublot size independent Distance independent
Truscott (1986)	Single	Multistage	Variable	Discrete	Total production time Number of load movements	Setup Production	Capacitated transporters Single transporter
Kropp and Smunt (1990)	Single	Multistage Flow shop	Equal Consistent	Discrete	Mean flow time Makespan	Setup Production	Sublot size dependent/independent Distance independent
Trietsch and Baker (1993)	Single	2-machine flow shop	Variable	Continuous Discrete	Makespan	Production	Capacitated transporters Multi transporters
Steiner and Truscott (1993)	Single	Multistage	Equal	Continuous	Cycle time Total flow time	Production Holding (WIP)	Sublot size independent Distance independent
Ramasesh et al. (2000)	Single	Multistage	Equal	Continuous	Manufacturing cycle time Total cost	Setup Production	Sublot size independent Distance independent
Bogaschewsky (2001)	Single	Multistage Flow shop	Equal Variable	Continuous	Total cost	Setup Holding	Sublot size independent Distance independent
Kalir and Sarin (2001)	Single	Multistage flowshop	Equal	Continuous Discrete	Makespan	Setup (Attached) Production	Sublot size independent Distance independent
Van Nieuwenhuyse and Vandaele (2003)	Single	Multistage flowshop	Equal	Discrete	Total cost	Holding Gap cost	Sublot size independent Distance independent
Chiu et al. (2004)	Single	Multistage	Variable	Discrete	Total cost including Makespan	Setup Holding	Capacitated transporters Multi transporters
Riezebos (2004)	Multi	Multistage	Fix Equal	Continuous	Total cost	Setup Holding (WIP)	Sublot size independent Distance dependent
Chiu and Chang (2005)	Single	Multistage flowshop	Equal	Continuous	Total cost	Setup Holding	Sublot size independent Distance independent

out an experimental design for the cost factors and analyze a number of different levels.

So far, the papers related with cost based objectives are discussed. Since only an ordinary transportation cost per trip is the case, these studies do not consider the schedule of transporters.

A time based objective function was first studied by Truscott (1986). He scheduled the production activities in a multistage batch manufacturing system introducing capacity-constrained transportation activities with a single transporter. He specified two types of constraints on the transportation activity; one for determining a maximum number of units per load for each transportation activity, the other for specifying a limit on the availability of the transporters for moving loads from operations. The transportation time, the return time of the transporters and the maximum number of units per load were taken into consideration. He developed a zero-one mixed-integer mathematical programming model and proposed a special purpose algorithm. The results of his proposed algorithm were compared with the optimal values. The computation time of the special purpose algorithm was much smaller than the mathematical programming model. However, in that paper, all the components required to schedule the batches are known and the proposed algorithm only schedules the batches as early as possible. It does not try to find the optimal sublot sizes for each product at each stage.

Kropp and Smunt (1990) addressed the single-product multi-stage lot streaming problem in a flow shop environment to minimize either the mean flow time or the makespan. The makespan problem was modelled as a linear programming model, while the mean flow time model as a quadratic programming model. The transportation activities were not directly included in the models but for the cases that the transportation time is either sublot size dependent or independent, the modifications on the models were determined.

Trietsch and Baker (1993) studied the single-product two-machine flow-shop lot streaming problem with limited transporter capacity. They solved the problem for more than one transporter to minimize the makespan. The time to load the transporters, the transportation time, the time to unload the transporters and the return time were added up to determine a fixed time for all sublots. They suggested solution procedures for continuous and discrete versions of sublots. They also modified the expressions for the case of transporters with limited capacity by determining an upper bound for the sublot sizes.

Kalir and Sarin (2001) considered the single-product multi-stage flow shop problem. They considered the sublot sizes as equal and rounded the real values of sublot sizes to up or down to obtain discrete sublot sizes. They investigated the impact of transportation and setup times on makespan objective and proposed an optimal solution algorithm for this criterion.

Some of the studies not only consider the makespan, but also add some cost functions. One of these papers was presented by Steiner and Truscott (1993). They dealt with the single-product multi-stage manufacturing system to determine the interaction of sublots and the operation sequences for minimizing the cycle time, the flow time and processing costs. The processing cost included inventory holding cost and transportation cost. The transportation cost was calculated by multiplying the transportation cost of one sublot through the whole system and the number of equal sublots. The transportation time of a sublot was constant and independent from the sublot size or the operations. They assumed no idling case and generated different expressions by considering unit processing times for three different objectives.

Ramasesh et al. (2000) presented an economic production lot size model using lot streaming. The model aims to minimize the total relevant cost including the cost of setup, transportation, and holding of WIP and finished goods. The transportation cost was calculated by multiplying the number of sublots with the fixed cost of moving one sublot through all machines. The problem was to determine the optimal lot size for a single-item multi-stage manufacturing system with equal sublot size and no-idling case. They proposed a model that yields a substantial percentage reduction in the total annual cost relative to the classical lot sizing models. Another performance measure was manufacturing cycle time. The transportation time, wait time, setup time and the processing time were considered as the components that affect the flow of work. The transportation time was defined to be the time required to move a sublot from one stage to the next. It was assumed to be sublot size independent but distance dependent. Another component, wait time, is the amount of time a sublot is expected to wait at each stage before being taken up for processing.

Chiu et al. (2004) studied a single-product, multi-stage lot streaming problem for minimizing the total cost including the transportation and the makespan cost. Their problem differs from Truscott (1986) from the ways of multiple transporters and variable sublots. The number of transporters and their capacities between any two adjacent stages, and the sublot transportation and return times were fixed and known. Also the transportation and unit time costs were known and fixed. Transportation time and cost were independent of the sublot size. This problem also dealt with no-idling, attached and detached setup cases for discrete sublot sizes. A binary mixed integer programming model was built. However, solving this model required more computational effort, so they proposed two efficient heuristic procedures. The first heuristic relaxes the transporter capacity constraints and uses binary mixed integer programming model. The second one extended the two-stage method of Trietsch and Baker (1993).

In recent years, the importance of supply chain management has grown rapidly and the lot streaming has also been applied to this area. The lot streaming studies including transportation activities applied in supply chain environments are Van Nieuwenhuyse and Vandaele (2006), Kim and Ha (2003) and Li and Xiao (2004).

4. CONCLUSION

In this paper, we firstly describe the components of lot streaming problems in detail, and then present a brief review of lot streaming studies with transportation activities. The studies show that most of the papers consider only the single product case. Although the multi product lot streaming problems are rather difficult to solve, they reflect real-life applications and are worth to study.

Transportation activities in cost models are only related with the unit transportation cost. However, most of the studies assume that the unit transportation cost is independent from the sublot size and the distance travelled. For more realistic cases, the transportation costs should be based on the sublot size and the travelled distance.

The time-related objective models deal with the transportation time as well as return time. However, the number of transporters and their capacities are assumed to be infinite in most studies, which are not typical for real-world environments.

The transportation times are assumed to be sublot size and distance independent. In fact, the sublot sizes affect the load and unload times of the transporters. Also the transportation time differs by the distance travelled.

Finally, all the studies are deterministic on every aspect as well as transportation times, however real applications may require stochastic behaviours and should be modelled accordingly.

For further studies, the cases concerning

- multi product
- limited number of transporters with limited capacities
- distance and sublot dependent transportation times
- load-unload times, return time of empty transporters
- stochastic times (transportation, load-unload, return time etc.)
- stochastic transportation costs

are potential areas for researchers. These cases make the problem more difficult to solve however, they are more realistic and appear in real life problems.

5. REFERENCES

Bogaschewsky, R. W., Buscher, U. D., and Lindner, G., (2001), “Optimizing Multi-Stage Production with Constant Lot Size and Varying Number of Unequal Sized Batches”, Omega, 29, 183-191.

Chang, J. H., and Chiu, H. N., (2005), “Comprehensive Review of Lot Streaming”, International Journal of Production Research, 43, 8, 1515-1536.

Chiu, H. N., and Chang, J. H., (2005), "Cost Models for Lot Streaming in a Multistage Flow Shop", Omega, 33, 435-450.

Chiu, H. N., Chang, J. H., and Lee, C. H., (2004), "Lot Streaming Models with a Limited Number of Capacitated Transporters in Multistage Batch Production Systems", Computers & Operations Research, 31, 2003-2020.

Feldman, M., and Biskup, D., (2005), "On Lot Streaming with Multiple Products", Discussion Paper, No. 542, Bielefeld University, Germany.

Goyal, S. K., (1976), "Notes on Manufacturing Cycle Time Determination for a Multi-Stage Economic Production Quantity Model", Management Science, 23, 332-333.

Hall, N. G., Laporte, G., Selvarajah, E., and Sriskandarajah, C., (2003), "Scheduling and Lot Streaming in Flow Shops with No-Wait in Process", Journal of Scheduling, 6, 339-354.

Kalir, A. A., and Sarin, S. C., (2001), "Optimal Solutions for The Single Batch, Flow Shop, Lot-Streaming Problem with Equal Sublots", Decision Science, 32, 387-397.

Kim, S. L., and Ha, D., (2003), "A JIT Lot-Splitting Model for Supply Chain Management: Enhancing Buyer-Supplier Linkage", International Journal of Production Economics, 86, 1, 1-10.

Kropp, D. H., and Smunt, T. L., (1990), "Optimal and Heuristic Models for Lot Splitting in a Flow Shop", Decision Sciences, 21, 691-709.

Li, C. L., and Xiao, W. Q., (2004), "Lot Streaming with Supplier-Manufacturer Coordination", Naval Research Logistics, 51, 4, 522-542.

Ramasesh, V. R., Haizhen, F., Duncan, K. H. F., and Jack, C. H., (2000), "Lot Streaming in Multistage Production Systems", International Journal on Production Economics, 66, 199-211.

Riezebos, J., (2004), "Time Bucket Length and Lot Splitting Approach", International Journal of Production Research, 42, 2325-2338.

Sen, A., and Benli, O. S., (1999), "Lot Streaming in Open Shops", Operations Research Letters, 23, 135-142.

Steiner, G., and Truscott, W. G., (1993), "Batch Scheduling to Minimize Cycle Time, Flow Time, and Processing Cost", IIE Transactions, 25, 90-97.

Szendrovits, A. Z., (1975), "Manufacturing Cycle Time Determination for a Multi-Stage Economic Production Quantity Model", Management Science, 22, 298-308.

Szendrovits, A. Z., (1976), "On The Optimality of Sub-Batch for a Multi-Stage EPQ Model - A Rejoinder", Management Science, 23, 334-338.

Trietsch, D., and Baker, K. R., (1993), "Basic Techniques for Lot Streaming", Operations Research, 41, 1065-1076.

Truscott, W. G., (1986), "Production Scheduling with Capacity-Constrained Transportation Activities", Journal of Operations Management, 6, 333-348.

Van Nieuwenhuyse, I., and Vandaele, N., (2003), "Minimizing Total Costs in Flow Shops with Overlapping Operations: The Importance of Gap Costs", Proceedings of the POMS 2003 Annual Meeting, Savannah.

Van Nieuwenhuyse, I., and Vandaele, N., (2006), "The Impact of Delivery Lot Splitting on Delivery Reliability in a Two-Stage Supply Chain", International Journal of Production Economics, 104, 2, 694-708.