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COMPARISON OF TWO STOCHASTIC ECONOMIC LOT SCHEDULING PROBLEM (SELSP) CLASSIFICATION SCHEMES

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ABSTRACT

Two seminal review papers on SELSP and their approaches to classifying existing literature in the area are compared. One of the approaches is found to be based on the modeling methods presented by academicians, while the other classifies them based on critical elements of the production plan as seen by practitioners. A brief treatment on the positive and negative implications of both approaches is given. Recommendations are provided for future lines of work, including notably, one related to the lack of systematic reviews of the types of production constraints encountered in different real-world production environments in open literature.

INTRODUCTION

This research paper implements a review and critique of two literature classification approaches attempted for the classical Stochastic Economic Lot Scheduling Problem (SELSP). The SELSP problem has been a focus of sustained research activity over the past two decades. Two seminal review papers have been found by the author from his literature review, namely by Sox *et. al.* [1] from 1999, and Winands *et. al.* [2] from 2011. Both papers offer distinct classification approaches of studies of SELSP, provide a structure and roadmap for future practitioners in the area, whilst also providing an overview of the apparent gaps in literature. This paper will provide an historical overview of the problem, and summarize the findings of the above two publications. The author, based on his understanding of the problem, will then present a critical review of the positives and negatives of both approaches, and then furnish some recommendations.

HISTORICAL PERSPECTIVE OF LOT SCHEDULING AND SIZING

In a production facility capable of producing multiple items, the questions of:

(1) In which production sequences to manufacture?, and
(2) In what lot sizes?,

have been a problem that has occupied production mangers since at least the early part of the twentieth century. Some pertinent extensions to the afore-mentioned questions are:

(3) What is the optimum level of safety stock to keep for each product?, and
(4) When, and for how long, to produce or idle?

Ford Whitman Harris, who is considered the father of the Economic Order Quantity (EOQ), tackled the question of “How many parts to make at once” in his seminal 1913 paper [3], and gave the expression for total cost of an item (Y) as:

Where

M – Demand per month
C – Unit cost of production per item
S – Total Set-up Cost for X units
X – Number of units of item

The first term on the right-hand-side of the above expression represents the interest and depreciation charge per piece at 10% (or 1/10 of the total set-up and production cost per unit), and can also equivalently characterized as the holding cost per unit in

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more modern terminology. The second term corresponds to the set-up cost per unit, and the third (and final) term represents the unit cost of production.

The below figure 1 shows the sum of the holding (interest and depreciation) costs and set- up costs for the example given by Harris [3] for M=1000, S=2 and C=0.1. The lot sizing problem simply stated then becomes one of finding the appropriate manufacturing quantity (X) that minimizes the total cost, which is 2,200 units in this case.

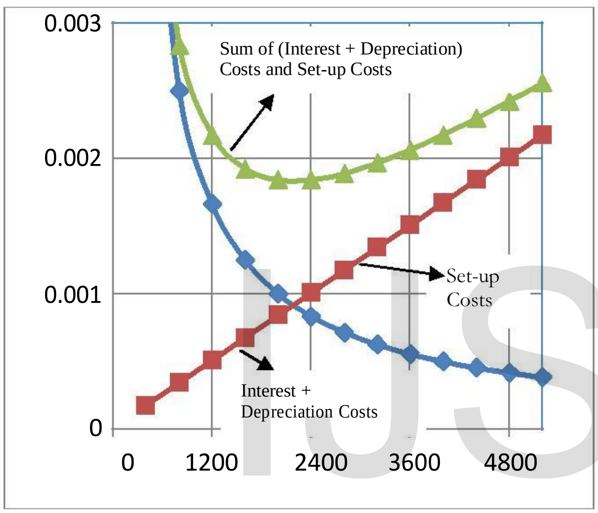

Figure 1: Manufacturing Quantities Curves (reproduced in Excel from [3])

The minimum value of X may then be derived as: [3]

This formulation is equivalent to the modern calculation for Economic Order Quantity (as provided in class). [4]

Building on this foundation, there has been steady progress in the area of lot sizing and scheduling. Notable works include that of Maxwell [5] from 1964, who extended the single-product, single-machine, deterministic-demand model to a multiple-products, single-machine, deterministic-demand model, and Elmaghraby [6] from 1978, who considered and reviewed the then state-of-the-art of the same problem of cyclic production patterns for multiple-products in a single facility under deterministic-demand conditions, the so-called Economic Lot Sizing Problem (ELSP).

As outlined in [2], the solutions of the ELSP are only really relevant in an *ideal* plant, where machines are perfectly reliable, set-up and production rates are constant, raw material and tools are always available, and demand is known. Winands *et. al.* argue in [2] that a ELSP model will not suffice in a real-world environment which is inherently stochastic. Two major requirements introduced in the stochastic situation are:

(1) Dynamic lot sizing and production sequencing will be required in a dynamic, stochastic environment; and
(2) Inventory levels for individual items play an even more important role in a stochastic environment, acting as a hedge against stock-outs and scheduling conflicts due to random variations in demand, production and set-up times.

The above is the fundamental argument for analysis of the stochastic-equivalent of the ELSP, also termed the Stochastic Lot Sizing Problem (SLSP), and its *sub-set*: the SELSP or the Stochastic Economic Lot Scheduling Problem

SELSP

The SELSP can be simply defined as the problem of finding the optimum production schedule for multiple-items in a single production facility that incurs set-up costs for each item, and must meet a random (stochastic) demand profile for each product. To add further complexities to the problem, one may also specify random set-up times and random production times for each item or product. [2]

According to Sox *et. al.* [1] and Winands *et. al.* [2], the SELSP is a common problem encountered in many Industries, including glass and paper production, bottling, injection moulding, metal stamping, semi-continuous

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chemical processes, and bulk production of consumer products such as beer and detergent.

Sox *et. al.* [1] consider the problem as being of significantly more complex as a result of the introduction of the stochastic nature of the demand, in comparison with its deterministic counterpart. They articulate that, in a stochastic demand situation, the finite production capacity of the production line must be *dynamically* allocated to actual demand. This inherent competition for production capacity amongst the different products increases the importance of safety stock to ensure a certain Service Level. They also go on to define the inventory of each product as serving a three-fold purpose in this situation:

(1) Reducing the total economic costs of performing change-overs through lot sizing;
(2) As a hedge or buffer against stock-outs due to variation in demand between the production runs for that product; and finally
(3) As a hedge against scheduling conflicts that arise from variation in demand for other products, which they also describe, alternatively, as a form of safety stock: *"It is the notion that the benefits of safety stock invested in one product can be shared among all the products."*

THE SJBM CLASSIFICATION SCHEME

In this section, we study the classification scheme proposed by Sox *et. al.* [1] in 1999. In this paper, we also refer to their approach as the SJBM classification scheme, obtained from the concatenation of the initials of the last names of the authors, as a more convenient notation.

In their approach, Sox *et. al.* present their terminology for the stochastic problem in a harmonious and consistent manner with the deterministic literature.

The bulk of literature on the deterministic lot sizing problem, based off of the seminal work of Maxwell [5] from 1964, can itself be broken down into two categories depending on their treatment of time in the analysis: the Capacitated Lot Sizing Problem (CLSP) for the discrete-time approach and the Economic Lot Scheduling Problem (ELSP) for the continuous-time approach.

Table 1: The differences between SELSP and SCLSP according to Sox *et. al.* [1]

Stochastic Economic Lot Scheduling Problem (SELSP): continuous-time model	- Change-over times are independent; - Infinite planning horizon; - Stationary demand; and - Appropriate for applications in real-time operational control with relatively low inventory such as production control of work-in-progress inventory
Stochastic Capacitated Lot Sizing Problem (SCLSP): discrete-time model	- Change-over times and costs are independent of production sequence; - Finite planning horizon; - Permits non-stationary, but independent, demand; and - Applicable for planning production of finished goods inventories or for MRP-controlled systems where demand is periodically processed.

Correspondingly, they have termed the stochastic equivalents of CSLP and ELSP, as the Stochastic Capacitated Lot Sizing Problem (SCLSP) and the Stochastic Economic Lot Scheduling Problem (SELSP), respectively. Refer to Table 2 for the distinction between SELSP and SCLSP.

According to Sox *et. al.*, traditional approaches to handle SELSP and SCLSP in actual practice fall into two categories of management control or decisions:

(1) Independent Stochastic Control: using an independent inventory control policy; or
(2) Joint Deterministic Control

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Independent Stochastic Control schemes use the Fixed order-Quantity (s, Q) model or the Fixed order-Period (s, S) model for each product to determine their production quantities and release times. Lead-times, and safety stocks are established based on past experience, and this approach does not benefit from joint scheduling of multiple products. Consequently, this approach generally results in a higher inventory level to achieve the desired Service Level.

The Joint Deterministic Control method constructs a production and inventory plan for all items simultaneously, but under an assumption of deterministic demand. This approach lacks a rigorous approach to determine the safety stock level.

On the other hand control policies for the solution of the SLSP have two critical components: lot sizing and sequencing. They classify the SLSP literature in two broad categories.

They state that the first group of authors basically adapt the analysis of the ELSP to construct simple control rules for the SLSP. This group of authors can be further categorized according to whether they use dynamic or cyclic production sequencing. Cyclic sequencing uses a fixed, predetermined production cycle, but varies the production lot to meet the demand variations. Dynamic sequencing on the other hand can vary both. They cite papers by Gallego [1a,1b], Bourland and Yano [1c] as using a cyclical sequence, and cite papers by Graves [1d], Qiu and Loulou [1e], Vergin and Lee [1f]. Leachman and Gascon [1g,1h] and Sox and Muckstadt [1i] as using the dynamic sequencing.

The second group of authors directly incorporate stochastic elements of the problem and apply non-linear optimization, queuing analysis (*see next paragraph*), or simulation (Anupindi and Tayur [1j]) to construct a control policy.

The queuing analysis method can be further broken down to those that use Markovian (Federgruen and Katalan [1k]) or heavy-traffic approximations (Markowitz et. al. [1l]) to generate solutions.

The reader is referred to the original paper [2] for a more exhaustive treatment of this subject.

THE WAH CLASSIFICATION SCHEME

In this section, we analyze the classification scheme proposed by Winands *et. al.* [2] in 2008. Once again, we also refer to their approach as the WAH classification scheme, obtained from the concatenation of the initials of the last names of the authors, as a more convenient notation.

They classify the analytical models presented in literature by the critical decisions a production planner will have to make or have control over, rather than by the actual analytic/computational method used. They have identified three constraints with respect to production sequencing, and two with respect to lot sizing, resulting in a 3x2 matrix in which all the literature they reviewed can be binned.

The three branches of production sequencing are:

(1) Dynamic sequence and cycle length: In a dynamic production sequence, the prioritization of the products is the key decision that a production manager will make;

(2) Fixed sequence + Dynamic cycle length: In this strategy, the production manager is constrained on using a pre-determined production sequence, but has the flexibility to deicide the production cycle length, or the time between two successive production lot completions.

(3) Fixed sequence + Fixed cycle length: In this strategy, the production manager is again constrained on using a pre-determined production sequence, but also lacks the flexibility to deicide the production cycle length.

The two branches of the lot sizing strategy are:

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(1) Global lot sizing strategy: In this strategy, lot sizing decisions are based on the complete state of the system including stock levels of all products and the state of the machines; and

(2) Local lot sizing strategy: In this strategy, the lot sizing decision only depends on the stock of the product currently set-up.

Table 2: An overview of SLESP literature according to the WAH classification.*

	Lot-sizing strategy	
Production sequence	Global	Local
Dynamic	Karmarkar and Yoo Qiu and Loulou Sox and Muckstadt	Altiok and Shiue Brander et al. Paternina-Arboleda and Das Winands et al. Zipkin
Fixed + dynamic cycle length	Bourland and Yano Fransoo et al.	Anupindi and Tayur Brander and Forsberg
	Gallego Gascon et al. Leachman and Gascon Leachman et al.	Eisenstein Federgruen and Katalan
	Markowitz et al.	Grasman et al Wagner and Smits Krieg and Kuhn Smits et al. Vaughan Winands et al.
Fixed + fixed cycle length	Giezenaar	Bruin Erkip et al.

*** Table above adapted from original paper [2]. References for above are given at end of paper.**

A CRITICAL COMPARISON OF BOTH APPROACHES

In broad terms, and as mentioned in [2] the SJBM approach classifies papers based on the modelling methods presented by academicians, while the WAH approach classifies them based on critical elements of the production plan as seen by practitioners. This is perhaps the most important distinction between the two approaches. Whilst the WAH scheme results in a convenient 3x2 matrix as seen in Table 2, the SJBM approach is messier, resulting in at least six main classifications on one branch based on the modeling method used, and depending on the chosen criteria, two classifications or more on another branch.

The presentation of literature on Table 2 also clearly identifies areas of prior research history, as well as potential gaps. For instance, one can readily see a relative dearth of literature in the "Fixed + fixed cycle length" row. This could point to two conclusions, one that there is an opportunity for more research in this area, or to another that this is a relatively obscure area with relatively-less *market-pull*. The author has a recommendation to make in this regard in the next section.

The author of this paper clearly prefers the SJBM approach for its physical insight. However, this approach also potentially leads to a lack of flexibility in mixed-production sequencing and mixed lot sizing strategies for different products in the same production line.

RECOMMENDATIONS

This paper is concluded in this section with a set of recommendations and some final observations. Whilst both Sox *et. al.* [1], and Winands *et. al.* [2] agree that SLESP is a fertile ground for future research activities and further progress, they also outline a series of gaps and recommendations for future lines of work.

From this author's perspective, perhaps the most glaring gap in literature, at least from his own preliminary literature survey, is a lack of understanding of which models are most applicable to which Industries and/or situations. For the practitioner, as opposed to the academician, it would help to have a rich experience set from which to base his/her production decisions on. There is a related dearth of knowledge of the types of production constraints encountered in different real-world production environments, which if readily available would also help in classifying the utility or *market-demand* of various SELSP models and their assumptions.

A related gap, as identified by Winands *et. al.*, is the observation that most papers focus on the optimization of their selected strategies, rather than a comparison of the various strategies. They, however, also rightly note that for there to be a meaningful and fair comparison, standardized test sets would have

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to be used. Large-scale simulation studies would be required to compare the different strategies in different production environments, and also against heuristics (experience-based findings) used as benchmarks.

These types of studies will provide a range of answers to commonly asked questions in both papers, such as: Should production lengths be fixed or dynamic with stochastic demand?, What influence should the coefficient of variation of demand have on the selected strategy?, Which has the greater influence on a stochastic production environment: production scheduling, or production lengths or lot sizing?, etc.

Winands *et. al.* also note the following recommendations for future lines of work that deserve rich attention:

(1) Only optimal strategies for at most up to three products have been surveyed in literature as of their publication. They strongly advocate the development of near-optimal SELSP strategies with a large number of different products.

(2) As seen in Table 2, there is a relative dearth of literature in the "Fixed + fixed cycle length" area. They deem further research in the area as desirable.

(3) Another interesting area of study is in the area of assessing the impact of different probability distributions affecting the demand, set-up and production in the stochastic environment. Present SELSP studies assume a Poisson distribution for the stochastic demand, though the authors find this non-realistic. A parametric study comparing various probability profile distributions and their impacts on SELSP solutions is recommended.

(4) The typical assumption in SELSP literature is that products are non-perishable. The limited shelf-life of many finished products, raw materials and their work-in-progress demand more refined models. Research into SELSP instances of limited life-time of finished products is also encouraged by the authors.

NOMENCLATURE

CLSP: Capacitated Lot Sizing Problem

ELSP: Economic Lot Scheduling Problem (Deterministic)

EOQ: Economic Order Quantity

SLSP: Stochastic Lot Scheduling Problem

SCLSP: Stochastic Capacitated Lot Sizing Problem

SELSP: Stochastic Economic Lot Scheduling Problem

SJBM: The classification scheme proposed by Sox *et. al.* [1]

(s,Q) model: Fixed order-quantity (Q) model where Q-quantity is ordered when inventory levels dip below reorder-point

(s, S) model: Fixed order-Period (T) models where quantity(=S-Safety Stock) is ordered at fixed intervals

WAH: The classification scheme proposed by Winands *et. al.* [2]

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