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Production Flexibility and Inventory Management: A Decision Support Model For Inventory Optimization

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Extensive Summary

Uncertainty is one of the major factors considered by companies in order to gain competitive advantage. Shorter product life-cycles and delivery times, higher technology and global competition and more personalized products cause internal and external uncertainties (Jain et al., 2013: 5946). Demand is one of the most important uncertainty sources for a company in a highly competitive environment (De Toni and Tonchia, 1998: 1588). Increases or decreases in demands directly affects the production and inventory policies of the companies. Thus, companies try to change production systems into flexible system to decrease negative effects of demand uncertainties.

Flexibility for businesses can be defined as the skill of adaptation to the internal or external based uncertainties (Gustavson, 1984: 802). Flexibility provides a competitive advantage for companies by enabling manufacturing a wider range of products in their facilities (Upton, 1995: 206). For instance, BMW minimizes the negative effects of 2008 economic crisis with the implementation of flexibility in their production system (Rogers et al., 2011: 3767). According to Sethi and Sethi (1990: 289-328), the major flexibility variations can be listed as; machine flexibility (multi-functional machines), process flexibility (manufacturing two or more products in a single facility), product flexibility (ability to change product specifications without high costs), routing flexibility (ability of adding new production lines into the current system) and volume flexibility (ability to increase or decrease production volume with small changes in production system).

Process flexibility is the ability of changing the product variety or quantity in a facility with minimum resources (Jordan and Graves, 1995: 578). Process flexibility aims to change production from one product to another without enduring long machine setup times and high setup costs (Browne et al., 1984: 114). Improvements in production technologies allow companies to implement process flexibility for tackling with demand uncertainties. Equipping production systems with high technology multi-functional machines makes building facilities which can perform different tasks possible (Jain et al. 2013: 5948).

Academic interest in process flexibility began to increase in early 80's with developments of new technologies in production systems. The preliminary studies on process flexibility generally focused on either dedicated systems (a single product is manufactured in each facility) or full flexibility (each facility can manufacture every product). Due to the high setup costs, full flexibility restricts the applicability of process flexibility in real world applications. Hence, academic and practical interest remained limited until the seminal work of Jordan and Graves (1995: 577- 594). Jordan and Graves suggest a new flexibility variation, limited process flexibility. They show that limited flexibility can procure almost all of the benefits of full flexibility with significantly less investment, if it is designed properly. They suggest chaining the production links between the factories and the products. They define chains as "a group of products and plants which are all connected, directly or indirectly, by product assignment decisions". This strategy allows the decision maker to shift the production along the chain, so that higher demand variations can be accommodated through a limited flexibility investment, even by producing only two products in each factory. Figure 1 illustrates a sample design of different flexibility systems for 5 products and 5 facilities.

Even though process flexibility is a useful tool for tackling with demand uncertainty, it has a potential to increase production costs because of acquiring high technology machines, training employees and redesigning facility layout. Furthermore, process flexibility complicates production and inventory policies. Manufacturing two or more products in facilities turns finding the optimal production decisions into a multi-dimensional decision problem.

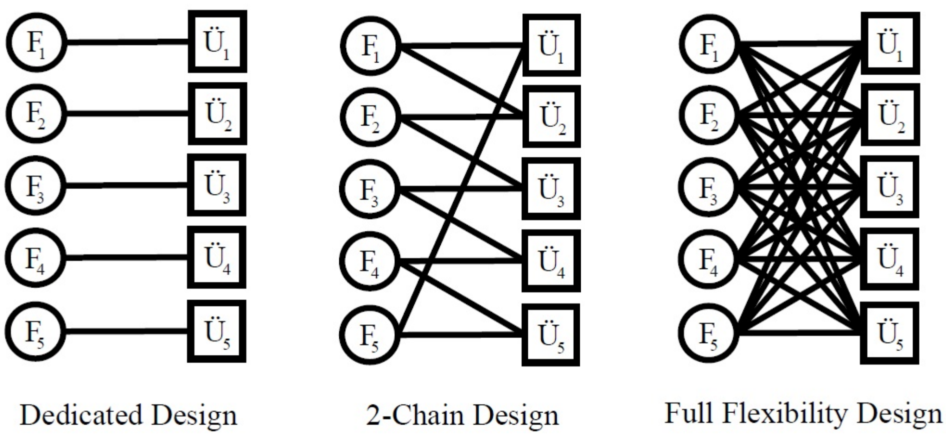

Figure 1: Sample System Designs for a 5-Product, 5-Factory System

This study aims to investigate the problem of determining the optimal production decisions with considering process flexibility in finite planning horizon. A Linear Programming (LP) model is developed and solved for this purpose. Moreover, using the LP model we made comparisons among different types of flexibility designs in terms of inventory costs.

We address a multi-product, multi-facility deterministic inventory optimization problem under process flexibility assumption. It is assumed that each product may be produced by one or more facilities and each facility may produce more than one product; however, any chaining strategy or full flexibility is not required. The ability of factory *f* to produce product *p* is called a *link* between factory *f* and product *p*. Periodic review is assumed, meaning that the state of the system is checked and replenishment decisions are made periodically. The predefined time points to make these decisions are called the review points, and the fixed time between each review point is called a period or cycle.

The production cost of a product may vary among factories, because of specialization, different transportation costs, different technologies, etc., and is defined separately for each factory-product pair. Holding and penalty costs are defined for each product. Throwing away the excess inventory which exceeds the storage limit is assumed to have no cost, except for the production costs of the unused inventory. Finally, we use a discount rate in order to take the time value of money into account. The immediate costs and future costs are assumed to have different importance to the decision maker. Holding/not holding an amount of money by paying for any cost later/earlier causes an opportunity reward/cost. Hence, all of the future costs are discounted by a discount rate, reflecting the importance of this time value.

For this problem, the objective function of the developed LP model aims to minimize the inventory costs comprised of production, holding and shortage costs. This objective function is optimized subject to a number of constraints, including tracking inventory levels for calculating shortage and excess inventory quantities and ensuring that production and inventory amounts do not exceed corresponding capacities. The decision variables in the model to be optimized are the production amounts in each facility for each product.

The applicability of the model is tested on a hypothetical problem. The problem comprises three different process flexibility options (i.e., dedicated, 2-chain and full flexibility; see Figure 2) in a production system with 10 products and 10 facilities. Demands for the products are generated from Poisson distribution where average demand for each product is equal $\left(d_1 = d_2 = d_3 = \overline{d}\right)$. The planning horizon has five periods and the demand is a priori for each period. Sensitivity analyses have been done through using different capacity limits and demand averages.

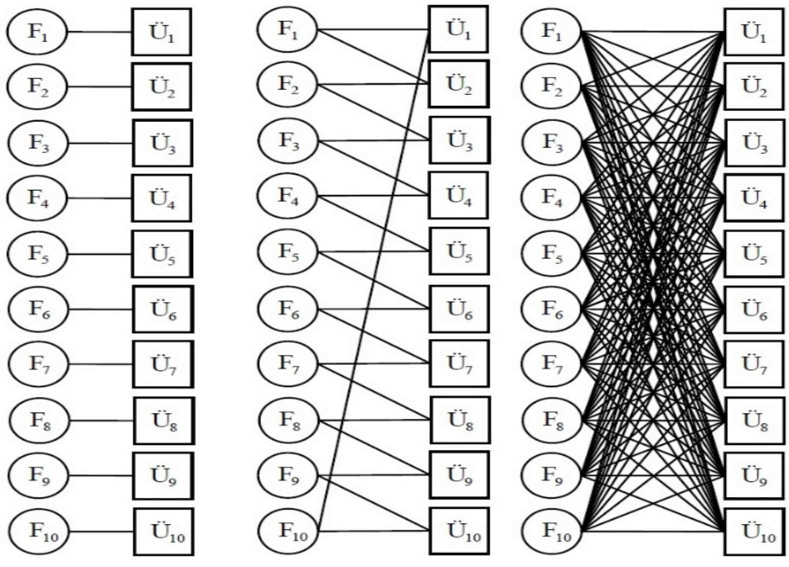

Figure 2: Experimental Flexibility Designs For Production and Inventory Systems

The results presented in Table 1 show that the systems with process flexibility (2-chain, full flexibility) outperform dedicated designs in terms of total inventory cost. Process flexibility integrated systems can provide up to 40% reductions in average total inventory costs compared to dedicated systems (Table 1). These savings are more significant especially for the cases where the production capacities are higher than average demand. This is due to the fact that process flexibility allows employing the excess capacity by manufacturing multiple products. In scenarios with lower capacities, facilities focus on manufacturing a single product to satisfy its demand, and do not have room for producing a second product. One more insight worth to be mentioned here is that the cost savings obtained from limited process flexibility and full flexibility systems are almost the same.

The literature on the topic claims that limited flexibility provides most of the benefits of using full flexibility in terms of demand coverage and capacity usage rate (see for instance Graves and Tomlin, 2003: 907-919; Chou et al., 2008: 59-94). Our findings, therefore, comply with the existing literature and extend it by showing that these systems perform closely to each other in terms of inventory costs as well.

Table 1: Average Total Inventory Costs of Different Flexibility Designs

		$\overline{d}^*$=5	$\overline{d}$=10	$\overline{d}$=50	$\overline{d}$=100
Capacity = 0,9 x $\overline{d}$	Dedicated Design	1093,66	1436,97	6063,35	11813,60
	2-Chain Design	972,67	1182,89	5848,45	11687,80
	Full Flexibility Design	969,64	1181,76	5848,45	11687,80
Capacity = $\overline{d}$	Dedicated Design	610,66	993,75	3382,19	5905,46
	2-Chain Design	345,87	616,02	2493,92	4689,54
	Full Flexibility Design	337,00	613,60	2493,92	4689,54
Capacity = 1,1 x $\overline{d}$	Dedicated Design	361,03	718,09	2287,12	4267,30

	2-Chain Design	215,94	436,97	2054,18	4101,92
	Full Flexibility Design	213,76	435,88	2054,18	4101,92

* $\overline{d}$ refers to average demand.

In this study we present a decision support tool that can be used by decision makers in production management. The developed model also allows us to present the benefits of process flexibility in terms of total inventory costs. Moreover, we provide a comparison of dedicated, 2-chain and full flexibility designs by means of the model. The comparison shows that investing in limited flexibility can sufficiently provide most of the benefits of full flexibility in terms of inventory cost without bearing the high initialization costs of full flexibility.