A New Fuzzy Modeling Approach for Joint Manufacturing Scheduling and Shipping Decisions

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Abstract

This paper discusses a new fuzzy modeling approach for an integrated manufacturing scheduling and shipment decisions within a supply chain network. The aim of this study is to maximize the total net profit while minimizing the *risks* caused by selecting alternative transportation modes. Alternative transportation modes such as train, truck and airplane modes are considered. Briefly, a fuzzy multi-objective mixed integer mathematical model is proposed to simultaneously integrate manufacturing scheduling and shipment decisions in a cellular manufacturing environment. Based on the manufacturing system capacity, production sequences of each product are determined in each cell and then alternative transportation methods are identified while considering the capacity of chosen transportation mode as well as the *risks* of associated transportation mode for each smaller lot of every product to maximize the total net profit. The preliminary results indicated that, although it is safer to ship via train which is the safest transportation mode, it is not possible to manufacture and ship each and every time due to the capacity restrictions of the manufacturing system. Therefore, the system triggers to use more *risky* alternative transportation modes which affect the total net profit of the considered system. The proposed model guides decision makers to find the optimal solution for an integrated manufacturing scheduling and shipping decisions of a company.

Keywords: Fuzzy Multi-Objectives, Integrated Scheduling and Shipping decisions, Alternative Transportation Modes,

1. Introduction

An integrated manufacturing scheduling and shipping decisions are one of the key performance indicators within supply chain management. This integration has a paramount importance on supply chain excellence where the manufacturer is taking the incentive of manufacturing, shipping and meeting customer demands within a specified time period or due date. In some cases where the manufacturing capacity is not sufficient to complete and ship a product on time by using a regular transportation mode, the customer due date still can be met by choosing faster transportation modes in order to avoid customer penalty or even loss (Celikbilek and Suer, 2014).

Similarly, when the manufacturing capacity is sufficient and a product can be manufactured early on time, one can ship that product by using the cheapest and the safest transportation mode. In this paper, make-to-order demand management environment is considered in a cellular manufacturing system. Briefly in a cellular manufacturing system (CMS), similar products are grouped into product families and they are allocated to corresponding cells. Each cell consists of different machines that process those product families. Süer et al., (1996) indicated that cell loading is performed by considering demand, processing times, due dates of jobs, as well as the production rate of the manufacturing cell. Therefore, a significant attention should be given to optimize this integrated decision. Previously, Celikbilek and Suer (2014) elaborated the concept of an integrated manufacturing scheduling and transportation mode decisions in a cellular manufacturing system by considering both customer due date and alternative manufacturing due dates. Manufacturing due dates are linked with the transportation mode chosen by considering capacity restrictions. The main motivation of this research is to consider the fuzzy aspect of the aforementioned research.

All in all, the purpose of this paper is to explore the possibility of performing cell loading, product sequencing and shipping decisions simultaneously by considering fuzzy multiple objectives in multiple cells. The flow of the paper is as follows; the background related with this research will be discussed in section 2, the research problem will be stated in section 3 and fuzzy-multi objective mathematical model will be presented in section 4. The preliminary experimentation will be discussed in section 5 and conclusions and future work will be discussed in section 6.

2. Background

In this section, a brief background related with integrated manufacturing-distribution modeling, cell loading, product sequencing within multiple cells and fuzzy theory are presented.

2.1 Integrated Manufacturing-Distribution Optimization

Various studies related with integrated manufacturing-distribution problem have been observed increasingly in recent decades. Wang and Lee (2005) discussed the manufacturing and transportation integration problem in a single machine environment by considering two different transportation modes. Higher cost is charged for the faster transportation modes and lower cost is charged for the slower transportation modes. As in our study, each job is first manufactured in the manufacturing facility and then shipped to the customer within a predetermined due date. The objective of their study was to minimize the sum of the total transportation cost and the total weighted tardiness cost.

Chen and Pundoor (2009) presented a mixed integer programming (MIP) model for single production line by assigning a weight for each customer order within the system. Orders are treated as batches and those batches are delivered to customers by considering the capacity of the delivered vehicle. Each deliver batch has a fixed distribution cost as well. The objective of the study was to minimize the total cost of distribution in the presence of requiring the average lead-time of orders to be within a given threshold.

In the meantime, various artificial intelligence (AI) techniques have been developed and used to support many manufacturing scheduling and shipment optimization decisions. Cakici et al. (2012) tackled the manufacturing and distribution problem by minimizing the total weighted tardiness and total distribution costs. Weighted customer orders/jobs are manufactured in a single machine and then delivered to customers by a capacitated vehicle. A multi-objective mathematical model was proposed along with different heuristics and a genetic algorithm (GA). Recently, Celikbilek and Süer (2013) elaborated the integrated manufacturing and distribution problem in a cellular manufacturing system. Each product is assigned to corresponding cells, sequenced by considering setup time and then shipped via multiple transportation modes to meet customer due dates to maximize the total net profit. Süer et al. (2014) presented a new mathematical model and a new genetic algorithms (GA) approach for simultaneous optimization of manufacturing scheduling and transportation mode decisions in a cellular manufacturing environment. Three cells and three alternative manufacturing due dates for each product, thus three alternative transportation methods are considered. Once products are assigned to cells and sequenced accordingly, the best transportation method for each product is identified. Proposed GA for cell loading and due date selection mathematical model found optimal and near-optimal solutions in most of problem sizes and used as a main solution methodology in large problem instances to obtain the maximum net profit of the manufacturer. Moreover, Celikbilek and Süer (2015) proposed a two-stage methodology and combined both designed and operational aspects of a manufacturing environment. In that paper, first *layered* cellular manufacturing system design is performed and then based on the designed cellular manufacturing system, cell loading, product sequencing and shipping patterns are identified.

2.2. Fuzzy Logic Theory

Fuzzy sets are used for modeling for uncertainty. Fuzzy membership functions are used to define how well a given value fits into the fuzzy set. There are various membership function types: Linear and Parabolic (Süer and Allard, 2009). In this study, linear fuzzy membership function is used. The linear fuzzy function determines the solution based on the linear relationship as shown in Figure 1.

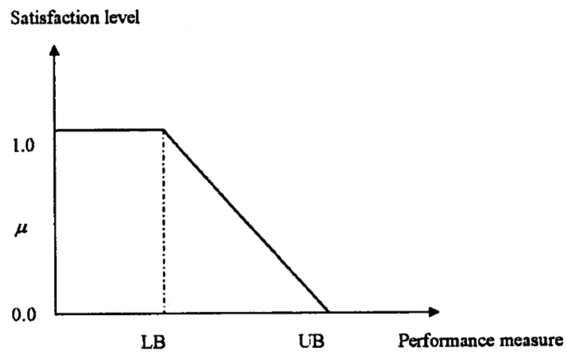

Figure 1: Linear membership function

The lower bound (LB) and upper bound (UB) are specified by the decision maker or scheduler. The LB is the 'most desirable' value and condition of the performance measure and UB is the 'unacceptable value' of the performance measure (PM). For example in our case, if the decision maker or scheduler specifies that having the highest profit (zero tardy jobs) in a manufacturing system would be ideal and having five tardy job with its profit value is unacceptable, then the LB would be highest profit with zero tardy jobs and UB would be the profit with five tardy jobs. All values between LB and UB are linearly scaled to have membership values between 0-1. The satisfaction levels are computed as given in equation (1).

$$\mu = 1 \; if \; PM \leq PM_{LB},$$

$$\mu = 0 \;\; if \; PM \geq PM_{UB} \; and$$

$$\mu = 1 - \left(\frac{(PM - PM_{LB})}{(PM_{UB} - PM_{LB})}\right) \; if \; PM_{LB} < PM < PM_{UB} \qquad (1)$$

Vlach (2000) presented the fuzzy membership functions to model the uncertainty in manufacturing scheduling. Non-preemptive single machine scheduling problem without deadlines are considered. Fuzzy precedence relations are discussed along with fuzzy due dates and processing times. Fuzzy aspect is used to determine the satisfaction level of scheduler by the given parameters. Süer et al. (2009) developed a fuzzy bi-objective cell loading mathematical model in labor-intensive cellular environment. The objective of this research was to minimize both the number of tardy jobs and the total manpower needed. Six different fuzzy operators applied and these were; min, fuzzy and, fuzzy or, minimum bounded sum, add, and product. Experimentation results revealed that, the fuzzy and-operator and product-operator found efficient solutions for the problem domain. Additionally, Süer et al. (2010) extended this work by considering various schedules with multiple objectives, multiple schedulers and multiple scheduler profiles for different data sets. The experimentation results revealed that, scheduler profiles, selection operators affected the selections. Minimum fuzzy fitness evaluation type led to selection of all schedules in most of the experimentation. Singh et al. (2014) focused on fuzzy multi-objective scheduling problem in a job-shop environment. Fuzzy operators are used and three mathematical models are presented and combined as a multiple objective scheduling model where the number of tardy jobs, total tardiness and maximum tardiness objectives are minimized respectively.

3. Problem Statement

The problem studied in this paper is inspired from an integrated manufacturing scheduling and transportation mode selection environment observed in a pharmaceutical company (Celikbilek C., and Süer G., 2014). It is assumed that the cell design is performed previously and three cells exist in the manufacturing area and each cell performs three operations sequentially. The number of machines within each cell varies for each cell based on their type and speed. The production rate for each cell is different and so does for cells as well. The products are manufactured within a cellular manufacturing area and then shipped by using alternative transportation modes such as air, truck and rail. The demand and the sales price for each job are known and setup time is fixed and specific for each job. The transportation safety risks for alternative transportation modes are determined according to the study conducted by Savage (2013). Savage's (2013) study conducted a report and analysis related to the passenger fatalities per billion miles during 2000-2009.

This study differentiates customer due date and manufacturing due date. Different manufacturing due dates lead to different transportation leadtimes, thus different transportation modes. All in all, based on the availability and capacity of manufacturing cells and also alternative manufacturing due dates, a product can be divided into smaller lots and manufactured in different time periods & cells and shipped via different transportation modes. These sub-lots are shipped considering the capacities of each transportation mode such that entire customer products arrives to customers by their desired due date. By doing that, proposed fuzzy model will consider the transportation safety aspect while maximizing the total net profit of the manufacturer.

4. Proposed Multi-Objective Fuzzy Mathematical Model

A fuzzy multi-objective mixed integer mathematical model is proposed in order to maximize total profit while minimizing the transportation safety risk associated with selecting alternative transportation mode. Total profit is obtained by assigning products to cells, determine product sequence in each cell and identify the transportation methods for each smaller lot of every product in a multi-cell manufacturing environment. The notation is as follows;

<u>Notation:</u>

Indices:

v *job index*
z *cell index*
u *due date index*

Parameters:

n *number of jobs*
s *number of cells*

nd_v *number of alternative manufacturing due dates for job v*
$d_{[k]}$ *k^{th} smallest manufacturing due date*
W_k *set of jobs with due date less than or equal to d_k*
N *sum of number of alternative manufacturing due dates*
pr_{vz} *profit for job v when built in cell z*
r_u *transportation safety risk when manufactured/shipped with a due date u*
pc_{vz} *penalty cost for job v when it is tardy in cell z*
cr_z *cell rate for cell z*
C_u *capacity of chosen transportation mode*
st_{vzu} *setup time for job v when built in cell z with a due date u*
c_{vu} *transportation cost for product v if manufacturing due date u (transportation cost) is used*
t_{vz} *in-cell time of job v in cell z*
λ_1 *total net profit*
λ_2 *total transportation mode safety risks*

Decision variables:

x_{vzu} *percent of job v assigned to cell z with due date u*
y_{vzu} *1 if setup is performed for job v assigned to cell z with a due date u, 0 otherwise.*
ζ_v *1 if penalty is charged for job v, 0 otherwise.*

The proposed fuzzy multi-objective, multi-cell loading mathematical model with lot splitting feature is described below. First, all manufacturing due dates are sorted in the increasing order (including all alternative due dates as well). Then, the mathematical model is solved.

Objective Function:

$$\textbf{Maximize} = \lambda_1 + \lambda_2 \tag{2}$$

Subject to:

$$z_1 = \sum_{v=1}^{n}\sum_{z=1}^{s}\sum_{u=1}^{nd_v} pr_{vz} * x_{vzu} - \sum_{v=1}^{n}\sum_{z=1}^{s}\sum_{u=1}^{nd_v} c_{vu} * x_{vzu} - \sum_{v=1}^{n}\sum_{z=1}^{s}\sum_{u=1}^{nd_v} pc_{vz} * \zeta_v \tag{3}$$

$$z_2 = \sum_{u=1}^{nd_v} r_u \sum_{v=1}^{n}\sum_{z=1}^{s} x_{vzu} \tag{4}$$

$$\sum_{z=1}^{s}\sum_{u=1}^{nd_v} x_{vzu} \le 1, \qquad v = 1 \dots n \tag{5}$$

$$x_{vzu} \le y_{vzu}, \qquad z = 1 \dots s \;\; \& \;\; v = 1 \dots n \;\; \& \;\; u = 1 \dots nd_v \tag{6}$$

$$\zeta_v = 1 - \sum_{z=1}^{s}\sum_{u=1}^{nd_v} x_{vzu}, \qquad v = 1 \dots n \tag{7}$$

$$\sum_{v=1}^{n}\sum_{z=1}^{s} x_{vzu} * cr_z \le C_u, \qquad u = 1 \dots nd_v \tag{8}$$

$$\sum_{v \in Wk} (t_{vz} * x_{vzu} + y_{vzu} * st_{vzu}) \leq \; d_{[k]}, \qquad z = 1 \dots s \;\; \& \;\; k = 1 \dots N \tag{9}$$

$$\lambda_1 \leq 1 - \left(\frac{z_1 - ub_{z1}}{lb_{z1} - ub_{z1}}\right) \tag{10}$$

$$\lambda_2 \leq 1 - \left(\frac{z_2 - \; lb_{z1}}{ub_{z1} - lb_{z1}}\right) \tag{11}$$

The objective is to maximize the total satisfaction level by considering two conflicting objectives: maximize the total net profit and minimize the transportation safety risks shown in Equation 2. The net profit is obtained by assigning jobs to cells with selected manufacturing due dates as shown in Equation 3. Net profit is computed by subtracting transportation costs and penalty costs (if any) from the profit to be obtained from the sales of products in a cellular manufacturing environment. Equation 4 minimizes the total transportation safety risks associated with alternative transportation modes. Equation 5 indicates that total percent of assignment of a job cannot exceed 100%. Equation 6 enforces that setup should be performed for all the jobs that are assigned to cells with a corresponding due date. Equation 7 indicates that only one penalty cost can be charged for a job. Equation 8 restricts that each selected mode has certain capacity limit that should not be exceeded. Equation 9 enforces that, setup time is considered for jobs that need setup for processing and the jobs from set Wk assigned to cell z cannot violate due date k. Equation (10) and (11) are the linear fuzzy membership constraints.

5. Preliminary Experimentation & Results

In this study, demand of each product is used for determining the processing times of each product by dividing the demand of a product by the corresponding cell rate. The cell rate is different for each cell and the output rate of a product depends on which cell it is manufactured. It is assumed that the sales price, setup time, the penalty cost for each product and the capacities of each transportation mode is known in advance. The total net profit of the system is obtained by deducting the revenue (product demand multiplied with the sales price for each product) from the penalty cost of each product as well as the cost of transportation mode chosen and the manufacturing cost of the system. The transportation safety risks are associated with the transportation mode chosen. The safest, yet the slowest and the cheapest transportation mode is train. The next safest yet the fastest and the most expensive transportation mode is airplane. The riskiest transportation mode is truck, yet it has more flexibility in terms of cost and meeting the customer demand on a timely manner. The lower and upper bounds are determined based on the similar study conducted in this problem without a fuzzy restriction (Celikbilek and Süer, 2014). Due to the space limitation, only 10-product problem size is shown and discussed in this paper.

5.1. Experimentation with 10-product 3 cells and 3 alternative transportation modes

The optimal solution for the 10-product problem shows different results depending on the constraint in transportation capacity. The experimentation is performed with small and large transportation capacities for different transportation modes. Different types of capacities for different transportation modes are shown below Table 1. The fuzzy decision bounds for profit are determined based on the study outcomes in (Celikbilek and Süer, 2014). The LB and UB for profit and transportation risks for both small and large capacity restrictions are shown in Table 2.

Table 1: Transportation capacity of different modes

Mode	**Transportation Capacity (units)**	
	Small	**Large**
Train	20,000	30,000
Truck	12,000	20,000
Plane	14,000	26,000

Table 2: Fuzzy Bounds for problems

Performance Indicators	**Fuzzy Bounds**	
	LB	**UB (small capacity, large capacity)**
Profit	20,000	(32278, 35783)
Transportation Risk	0.07	7.23

Satisfaction levels for different fuzzy functions in the small capacity case of transportation modes are shown in below Table 3 and Figure 2.

Table 3: 10-product problem solutions with small capacity restriction

Lamda Weights	**lambda1**	**lambda2**				
	λ1	λ2		z1	z2	Total λ
λ1+λ2	60.4%	68.4%	$	28,809	2.3575	1.288
0.1*λ1+0.9*λ2	16.3%	86.8%	$	22,332	1.025	79.7
0.25*λ1+0.75*λ2	41.5%	80.8%	$	25,930	1.455	71.0
0.5*λ1+0.5*λ2	61.7%	68.4%	$	28,809	2.3575	65.7
0.75*λ1+0.25*λ2	63.6%	65.8%	$	29,081	2.543	64.2
0.9*λ1+0.1*λ2	63.9%	64.9%	$	29,117	2.6046	64.0

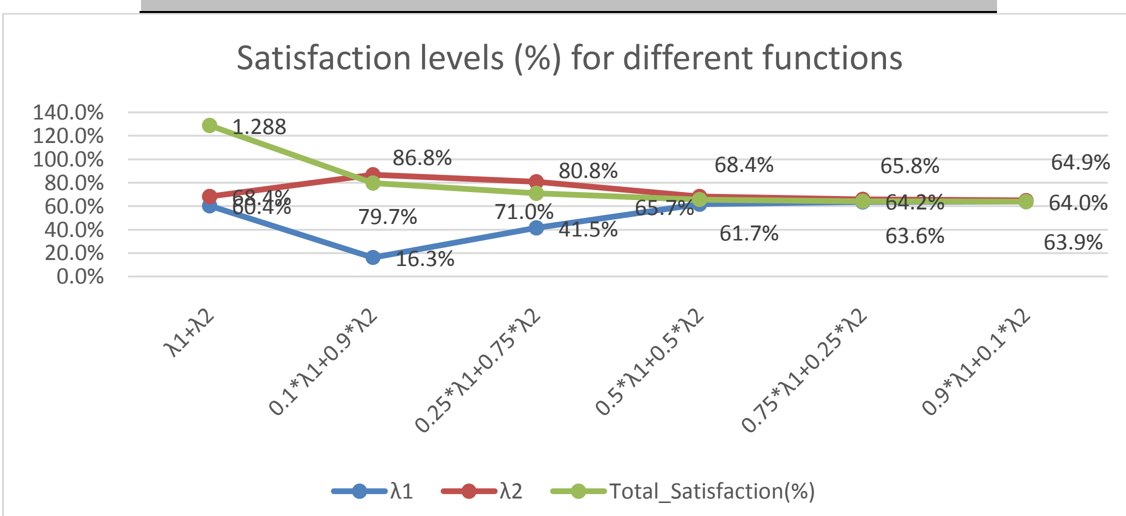

Figure 2: Satisfaction levels for different fuzzy function- Small capacities

Satisfaction levels for different fuzzy functions in the large capacity case of transportation modes are shown in below Table 4 and Figure 3.

Table 4: Satisfaction levels for different fuzzy functions with large capacity restriction

Lamda Weights	**lambda1**	**lambda2**			
	λ1	λ2	z1	z2	Total λ
λ1+λ2	75.9%	73.3%	$ 31,962	2	1.491
0.1*λ1+0.9*λ2	11.5%	91.5%	$ 21,821	0.6875	83.5
0.25*λ1+0.75*λ2	75.5%	73.6%	$ 31,910	1.997	74.1
0.5*λ1+0.5*λ2	75.8%	73.3%	$ 31,962	2	74.5
0.75*λ1+0.25*λ2	77.0%	71.4%	$ 32,153	2.1378	75.6
0.9*λ1+0.1*λ2	89.5%	21.2%	$ 34,129	5.76	82.7

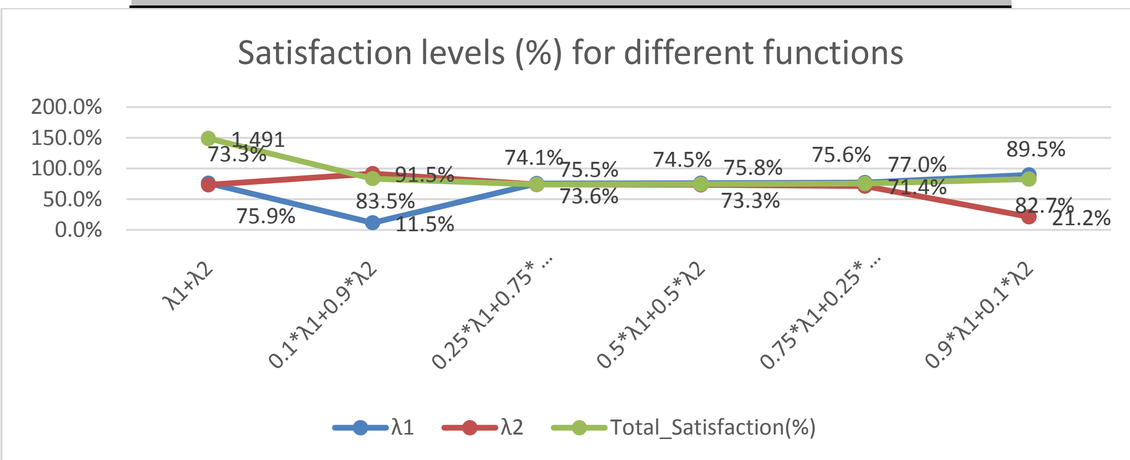

Figure 3: Satisfaction levels for different fuzzy function- Large capacities

6. Conclusions, Discussions and Future Work

The results indicated that, the model tries to maximize the total net profit while minimizing the total transportation safety. The highest total net profit is obtained by manufacturing all the products earlier in time/due date and shipped in cheapest (in that case train) transportation mode. However due to availability and capacity of manufacturing cells and also alternative manufacturing due dates, a product is manufactured in later in time and shipped with alternative transportation modes. This triggers the second objective which is minimizing the transportation safety risks. Therefore, there is a tradeoff between objectives and eventually the balance between them is reached in an optimal fashion. Based on the priority of the decision maker, one can assign different weights and the outcome can change accordingly. It is observed that the total satisfaction levels are higher in large transportation capacity case and assigning equal weights to each objectives and giving relatively higher weight to profit objective result equal satisfaction levels on both conflicting objectives. Expanding this research to multiple products and cells, applying other membership functions, considering stochasticity, sustainability concepts and also conducting this research with real data sets will be considered as future work.

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