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Sewing Machine Selection Using Linear Physical Programming

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ABSTRACT

Sewing is a critical operation in garment production process. Therefore, alternative sewing machines must carefully be evaluated prior to procurement. Multiple criteria decision making (MCDM) techniques can effectively be used in sewing machine evaluation process since multiple evaluation criteria including speed and price must be considered. However, physically meaningless subjective weights are assigned to evaluation criteria in most MCDM techniques. Linear Physical Programming (LPP) is a MCDM methodology that eliminates this subjective weight assignment process by allowing decision makers to express their preferences in a physically meaningful way. In this study, a sewing machine selection problem faced by a textile company is solved using LPP.

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multiple criteria decision making, linear physical programming, sewing, machine selection, textile company

1. INTRODUCTION

Sewing is one of the most critical operations in garment production [1, 2]. Industrial sewing operations are usually carried out by using industrial sewing machines. There are many industrial sewing machine alternatives since various companies produce many different types of industrial sewing machines. Hence a textile company must evaluate those alternatives by considering multiple criteria including price, speed, weight and power consumption.

Multi-criteria decision making techniques were commonly used in industrial sewing machine evaluation due to the above-mentioned multi-criteria nature of the problem. Ertuğrul and Öztaş, 2015 applied MOORA (multi-objective optimization on the basis of ratio analysis) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) multi criteria decision making techniques to a sewing machine selection problem [3]. The rankings proposed by those two techniques were compared. Ulutaş, 2017 employed EDAS (Evaluation based on Distance from Average Solution) for the evaluation of alternative sewing machines for a textile company [4].

The weights for the evaluation criteria were assigned subjectively in both of the above-cited studies. In this study, the subjective weight assignment process is eliminated by using linear physical programming (LPP). In LPP, the decision maker expresses his/her preferences for each criterion in a flexible and natural way. Then a weight algorithm is used to determine the criteria weights based on the preferences of the decision maker.

The rest of the paper is organized as follows. Section 2 provides brief information on LPP. The details on the application of LPP to a sewing machine selection problem faced by a company are presented in section 3. Finally, conclusions and future research directions are presented in section 4.

2. LINEAR PHYSICAL PROGRAMMING

Linear Physical Programming (LPP) was proposed by Messac et al., 1996 as an alternative to traditional optimization techniques [5]. LPP lets the decision maker define a multi objective decision making problem in a natural and flexible way. The decision maker can use one of

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the following four LPP classes for each criterion in the problem formulation [6, 7]: 1S (smaller is better), 2S (larger is better), 3S (value is better) and 4S (range is better). Figure 1 presents the LPP classes. The horizontal axis in this figure represents the preference ranges. These ranges can be presented for Class 2S as follows:

- Unacceptable range : $c_k \leq s_{k5}^{-}$
- Highly undesirable range : $s_{k5}^{-} \leq c_k \leq s_{k4}^{-}$
- Undesirable range : $s_{k4}^{-} \leq c_k \leq s_{k3}^{-}$
- Tolerable range : $s_{k3}^{-} \leq c_k \leq s_{k2}^{-}$
- Desirable range : $s_{k2}^{-} \leq c_k \leq s_{k1}^{-}$
- Ideal range : $c_k \geq s_{k1}^{-}$

The quantities s_{k1}^{-} through s_{k5}^{-} are specified by the decision maker for the k^{th} generic criterion. Let us assume that the decision maker specifies the values of s_{k1}^{-} through s_{k5}^{-} as 300, 250, 200, 150, 100, respectively. If the criterion value of an alternative is 280, it would locate in the desirable range. If the criterion value is 180, it would be in the undesirable range [8].

The class function f_k is presented on the vertical axis. Criteria values are mapped into non-dimensional, strictly positive real numbers using this function. In other words, the class function creates a common scale with dimensionless values for each criterion. Considering Class 2S as an example, we can see that the value of the class function is very small if the criterion value is in the desirable range. If the criterion value is in the highly undesirable range, the value of the class function becomes too large.

The application steps of LPP can be presented as follows:

1. Appropriate class functions are determined for the criteria.
2. The limits for the desirability ranges are determined.
3. The following LPP weight algorithm [5] is employed for the calculation of the incremental weights:

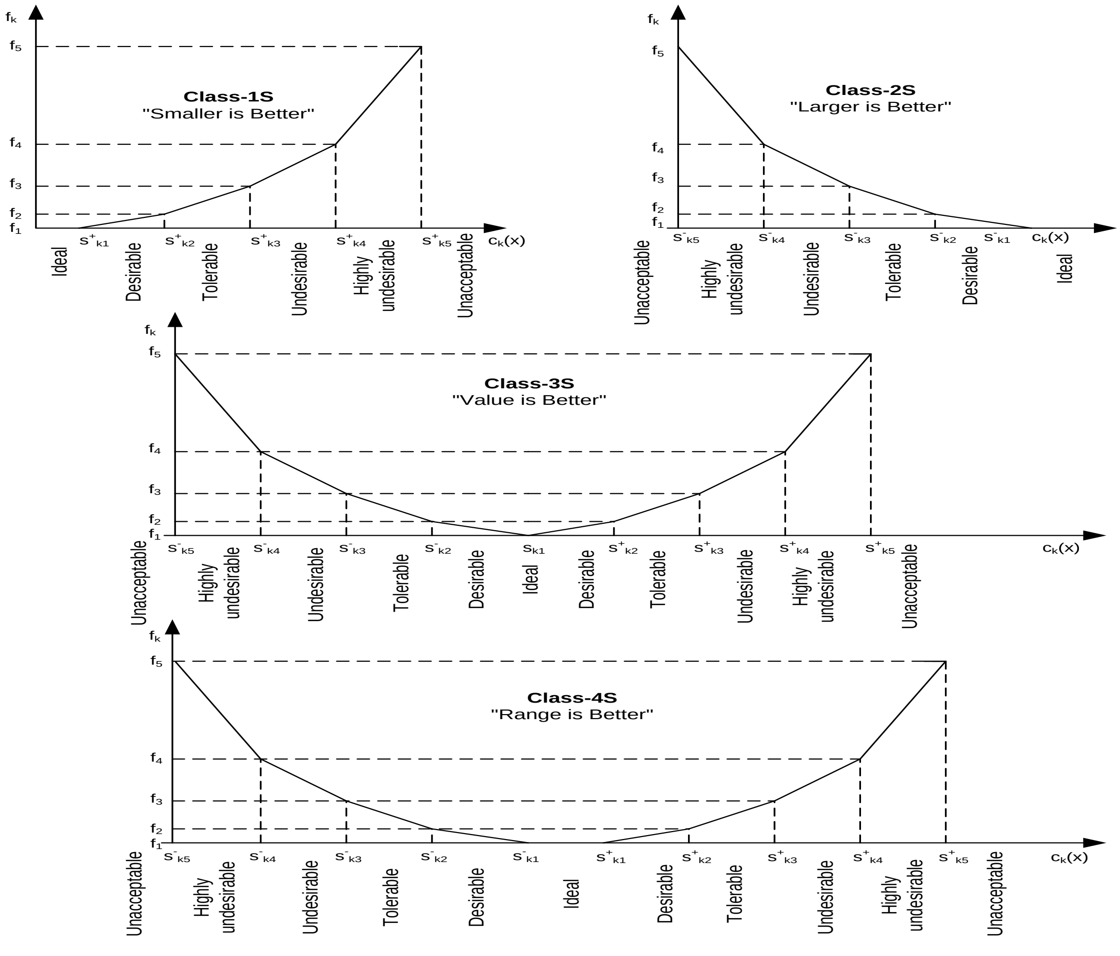

Figure 1. Classes in LPP

3.1. Initialize:

$\beta = 1.1, w_{k1}^{+} = 0, w_{k1}^{-} = 0, \tilde{f}^{2} =$ small positive number (say, 0.01), k=0; j=1, NC: number of criteria.

3.2. Set $k = k + 1$

3.3. Set $j = j + 1$

Evaluate, in sequence,

$\tilde{f}^{\,j}$, $\tilde{s}^{+}_{kj}$, $\tilde{s}^{-}_{kj}$, w^{+}_{kj} , w^{-}_{kj}, $\tilde{w}_{\min}$

If $\tilde{w}_{\min}$ is less than a small positive number (say, 0.01), then increase β , and go to 3.2.

3.4. If $j \neq 5$, go to 3.3.

3.5. If $k \neq NC$, go to 3.2.

where k represents criterion, j represents range, β is a parameter of convexity (see [5]), f_k is the class function for the criterion k, $\tilde{f}^{\,j}$ represents the change in f_k that occurs as one travels across the range j, $\tilde{s}^{-}_{kj}$ and $\tilde{s}^{+}_{kj}$ represent the widths of the j^{th} ranges on the negative and positive sides of criterion k, w^{-}_{kj} and w^{+}_{kj} are negative and positive weights, respectively, for the range j of criterion k and $\tilde{w}_{\min}$ is the minimum of w^{-}_{kj} and w^{+}_{kj} .

In class function, the slope increments between different desirability ranges are represented with positive and negative weights [7]. The following equations can be used for the calculation of those weights:

$$w^{+}_{kj} = \frac{\tilde{f}^{\,j}}{\tilde{s}^{+}_{kj}} \quad (1)$$

$$w^{-}_{kj} = \frac{\tilde{f}^{\,j}}{\tilde{s}^{-}_{kj}} \quad (2)$$

In those equations, $\tilde{f}^{\,j}$, $\tilde{s}^{+}_{kj}$ and $\tilde{s}^{-}_{kj}$ are calculated as follows:

$$\tilde{f}^{\,j} = \beta(NC-1)\tilde{f}^{\,j-1} \quad (3)$$

$$\tilde{s}^{+}_{kj} = s^{+}_{kj} - s^{+}_{k(j-1)} \quad (4)$$

$$\tilde{s}^{-}_{kj} = s^{-}_{kj} - s^{-}_{k(j-1)} \quad (5)$$

4. A total score (T) for each alternative is calculated by taking the weighted sum of deviations:

$$\min_{d^{-}_{kj},\, d^{+}_{kj}} T = \sum_{k=1}^{NC}\sum_{j=2}^{5}(w^{-}_{kj}\cdot d^{-}_{kj} + w^{+}_{kj}\cdot d^{+}_{kj}) \quad (6)$$

where d^{-}_{kj} and d^{+}_{kj} represent the deviations from the corresponding target values for the k^{th} criterion value of the alternative of interest. Alternatives are ranked using total scores. The best alternative is the one with the lowest total score value.

LPP-based solution methodologies were developed in order solve various problems in different domains including production planning [9], reverse logistics [10] and robot selection [11]. The interested reader is referred to a comprehensive review by Ilgin and Gupta, 2012 for more information on LPP applications [6].

3. INDUSTRIAL SEWING MACHINE SELECTION USING LPP

This section presents the application of LPP to a sewing machine selection problem faced by a textile company. The company tries to determine the most suitable single-needle lockstitch industrial sewing machine. The following five evaluation criteria were determined by interviewing the managers of the company:

- *Price*: Average market price in dollars ($) was used. Price must be minimized in order to minimize the total cost of investment.
- *Power Consumption*: The company prefers industrial sewing machines with low power consumption in order to minimize its energy costs. The unit for power consumption is Volt-Amperes (VA).
- *Weight*: The weight of machine head in kilogram (kg) was considered as a criterion. The weight should be as low as possible for ease of transportation.
- *Maximum Speed*: Maximum speed in stitches per minute (spm) was considered as a criterion. Maximum speed of the machine should be as high as possible.
- *After-sale Support*: The quality of the after-sale support services offered by a sewing machine manufacturer is a vital criterion. This criterion is evaluated using a 10-point scale (10 being the highest after-sale support and 1 being the lowest after-sale support).

Table 1 presents the criteria values for the eight alternative industrial sewing machines (ISM) considered in this study. Target values for each criterion were presented in Table 2. Those values were determined by interviewing the managers of the company. The three criteria (Price, Power Consumption and Weight) were modeled as Class 1S while the other two criteria (Maximum Speed and After-sale Support) were modeled as Class 2S.

C++ programming language was used to code the LPP weight algorithm and the criteria weights presented in Table 3 were obtained using this algorithm. A screenshot from this algorithm is presented in Figure 2.

An LPP model for each ISM was constructed using Lingo (v17) mathematical programming software. Deviations from the target values for each ISM were determined using this model. As an example, deviations for ISM 1 are presented in Table 4. For instance, consider the first criterion (*price* - f_1). The deviation for j=2 can be determined in two steps. First, the value of the criterion (i.e., 1495, see the bolded number in Table 1) is subtracted from the target value (i.e., 1250; see the bolded number in Table 2). Then the absolute value (i.e., 245, see the bolded number in Table 4) of this difference is taken.

The total score for each ISM (see Table 5) was determined by solving the associated LPP model. For instance, the total score for ISM 1 is calculated by using the deviations from Table 4 and the criteria weights from Table 3:

$Total\_Score_{ISM1}$ = 245*0.04+100*0.2+50*0.138462+7*2+2*2.4+500*0.01+5*1=65.5231

A ranking of alternative ISMs is also presented in Table 5. ISM 1 with the lowest total score is the best ISM based on the preferences of the decision makers.

Table 1. Characteristics of alternative ISMs

Machines	Price ($)	Power Consumption (VA)	Weight (kg)	Maximum Speed (spm)	After-sale Support
ISM 1	**1495**	400	37	5000	8
ISM 2	1800	415	46	5000	8
ISM 3	2150	520	40.5	5000	6
ISM 4	1300	250	36	4000	6
ISM 5	2049	320	30	5000	6
ISM 6	1825	450	34.5	5000	8
ISM 7	2079	390	28	5500	6
ISM 8	1850	320	38	5000	6

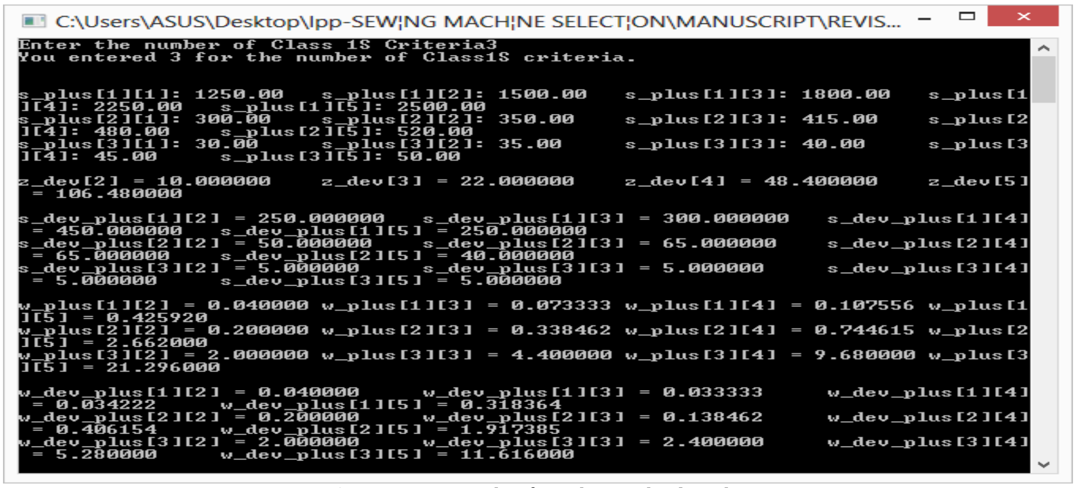

Figure 2. A screenshot from the weight algorithm

Table 2. Target values for the evaluation criteria

Criterion 1 (*k*=1): Price
Class 1S

Preference	Preference Range	Limit	Limit Value
I	$\leq s^-_{11}$	s^-_{11}	**1250**
D	(s^-_{11}, s^-_{12})	s^-_{12}	1500
T	(s^-_{12}, s^-_{13})	s^-_{13}	1800
UD	(s^-_{13}, s^-_{14})	s^-_{14}	2250
HU	(s^-_{14}, s^-_{15})	s^-_{15}	2500
UA	$\geq s^-_{15}$		

Criterion 2 (*k*=2):Power Consumption
Class 1S

Preference	Preference Range	Limit	Limit Value
I	$\leq s^-_{21}$	s^-_{21}	300
D	(s^-_{21}, s^-_{22})	s^-_{22}	350
T	(s^-_{22}, s^-_{23})	s^-_{23}	415
UD	(s^-_{23}, s^-_{24})	s^-_{24}	480
HU	(s^-_{24}, s^-_{25})	s^-_{25}	520
UA	$\geq s^-_{25}$		

Criterion (*k*=3): Weight
Class 1S

Preference	Preference Range	Limit	Limit Value
I	$\leq s^-_{31}$	s^-_{31}	30
D	(s^-_{31}, s^-_{32})	s^-_{32}	35
T	(s^-_{32}, s^-_{33})	s^-_{33}	40
UD	(s^-_{33}, s^-_{34})	s^-_{34}	45
HU	(s^-_{34}, s^-_{35})	s^-_{35}	50
UA	$\geq s^-_{35}$		

Criterion 4 (*k*=4): Maximum Speed
Class 2S

Preference	Preference Range	Limit	Limit Value
I	$\geq s^+_{41}$	s^+_{41}	5500
D	(s^+_{41}, s^+_{42})	s^+_{42}	5000
T	(s^+_{42}, s^+_{43})	s^+_{43}	4500
UD	(s^+_{43}, s^+_{44})	s^+_{44}	4000
HU	(s^+_{44}, s^+_{45})	s^+_{45}	3000
UA	$\leq s^+_{45}$		

Criterion 5 (*k*=5): After-sale Support
Class 2S

Preference	Preference Range	Limit	Limit Value
I	$\geq s^+_{51}$	s^+_{51}	9
D	(s^+_{51}, s^+_{52})	s^+_{52}	7
T	(s^+_{52}, s^+_{53})	s^+_{53}	5
UD	(s^+_{53}, s^+_{54})	s^+_{54}	3
HU	(s^+_{54}, s^+_{55})	s^+_{55}	1
UA	$\leq s^+_{55}$		

I: Ideal
D: Desirable
T: Tolerable
UD: Undesirable
HU: Highly Undesirable
UA: Unacceptable

Table 3. Weights for each criterion

Criteria	w_{k2}^{+}	w_{k3}^{+}	w_{k4}^{+}	w_{k5}^{+}	w_{k2}^{-}	w_{k3}^{-}	w_{k4}^{-}	w_{k5}^{-}
Price (*k*=1)	0.04	0.033333	0.034222	0.318364	-	-	-	-
Power Consumption (*k*=2)	0.2	0.138462	0.406154	1.917385	-	-	-	-
Weight (*k*=3)	2	2.4	5.28	11.616	-	-	-	-
Max. Speed (*k*=4)	-	-	-	-	0.01	0.017400	0.010138	0.013889
After-sale Support (*k*=5)	-	-	-	-	5	1.85	2.5345	3.472265

Table 4. Deviations for ISM 1

Criteria	*j*=2	*j*=3	*j*=4	*j*=5
Price (*k*=1)	**245**	0	0	0
Power Consumption (*k*=2)	100	50	0	0
Weight (*k*=3)	7	2	0	0
Max. Speed (*k*=4)	500	0	0	0
After-sale Support (*k*=5)	1	0	0	0

Table 5. Total scores and ranks of alternative ISMs

Alternatives	Total Score	Rank
ISM 1	65.5231	1
ISM 2	175.6959	7
ISM 3	315.2143	8
ISM 4	70.719	2
ISM 5	84.63109	3
ISM 6	111.7504	6
ISM 7	102.3962	5
ISM 8	86.42765	4

4. CONCLUSION

The use of the most suitable sewing machine has an utmost importance in the profitability and effectiveness of sewing operations. In this study, LPP was employed in order to solve the sewing machine selection problem faced by a textile company. A ranking of eight alternative industrial sewing machines was obtained based on the preferences of company managers. ISM 1 is proposed as the best sewing machine since it has the lowest total score.

Although LPP allows the decision maker to express his/her preferences using physically meaningful values it cannot consider the uncertainty and vagueness associated with decision maker's preferences. That is why development of a sewing machine selection approach based on fuzzy linear physical programming can be an interesting future research topic.

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