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The Effective Work Priority Decision Method Using TOPSIS and PROMETHEE for SMEs

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Abstract

Background/Objectives: Today, with the arrival of the Fourth Industrial Revolution, the company's production environment is rapidly changing. Customer requirements are becoming more diversified and product life cycles are shortening. In this paper, we propose a decision support system suitable for SMEs.

Methods/Statistical analysis: In this paper, we selected the priorities through the TOPSIS method and the PROMETHEE methodology, which are based empirical knowledge of field production managers, among the existing multi attribute decision making method and compared with the existing dispatching rules.

Findings: We compared the effort and time required to assign work priorities by reflecting the rapidly changing order environment of small and medium-sized manufacturing companies as scenarios. In particular, we analyzed the performance of each methodologies finding work priorities based on new orders or change of delivery dates. The result of simulation analysis on the deadline delays which SMEs consider the most important factor as follows. PROMETHEE was lowest as 268.78 min/month while TOPSIS was 421.39 min/month, the FIFO rule was 466.64 min/month, the SPT rule was 496.17 min/month, and the LPT rule was 602.07 min/month. As a result, the application of the PROTMETHEE reduces the manufacturing lead time by approximately 252.85 min/month on average, over the FIFO, SPT, and LPT rules used in existing companies. In addition, the average manufacturing lead time was reduced by about 100.24 min/month than the SPT, LPT, and FIFO rules.

Improvements/Applications: As a result, by using both PROMETHEE and TOPSIS, it is possible to reduce the tardiness time by about 176.54 min/month compared to the existing dispatching rules..

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1. Introduction

Today, as the 4th Industrial Revolution arrives, companies are diversifying into small-scale production systems for personalized products by diversifying customer demands and shortening the life cycle of products [1]. In this rapidly changing production environment, a smart factory system is required to make decisions quickly and accurately. In this paper, we propose a decision support system based on a multi-criteria decision-making methodology that enables small and medium-sized manufacturers to optimize production with minimal changes by continuously reflecting the

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experience of field managers in the rapidly changing production environment.

2. Driving principle

2.1. Multi attribute decision making(MAMD)

Multi-criteria decision-making is basically the process of selecting the best alternative for a number of conflicting criteria or attributes [2]. The multi-criteria decision-making methodologies are divided into three areas by Berton and Stewart [3].

First, it is a value measurement model such as AHP(analytical hierarchy process). The advantage of AHP is that it can consider both quantitative and qualitative criteria by decomposing complex problems into a hierarchy. But In the case of a large number of determinants, the process of entering and calculating values is very complicated because of the relative evaluation of factors and alternatives. [4].

Second, it means methods such as ELECTRE(elimination and choice expressing reality) and PROMETHEE(preference ranking organization method for enrichment evaluations) [5, 6]. ELECTRE was not found to be superior to B, but was created under the concept of outranking that the decision maker could take the risks of claiming an advantage [5]. PROMETHEE has the advantage of classifying alternatives that are difficult to compare into comparable alternatives based on the concept of ranking preference, reflecting the decision function's subjective preference function and preference thresholds [6, 7].

Third, it is a goal aspiration and reference level method such as TOPSIS (the technique for order of preference by similarity to ideal solution) [8]. The TOPSIS method has the rational logic of human beings that considers the best and worst alternatives at the same time. It is based on the concept of choosing an alternative that is closest to the PIS (positive ideal solution) and farthest from the NIS (negative ideal solution) [9, 10]. This TOPSIS methodology makes it easy to measure the performance of all alternatives from a multi-property point of view, and has the advantage of a simple calculation process and excellent applicability.

However, the TOPSIS method, like the PROMETHEE method, has a disadvantage in that weights of evaluation criteria must be determined in advance [11].

2.2. MCDA input/output effort and methodology selection

Figure 1 shows the input and output contents of the multi-criteria decision-making methodologies for prioritization and selection, and the effort consumption of the input data requirements [12]. Looking at this, the effort consumption of TOPSIS is much less than other methodologies, and the following is the PROMETHEE. Therefore, in this study, TOPSIS methodology and PROMETHEE methodology, which requires little effort for priority selection was selected to quickly derive work priorities in the harsh production situation of SMEs.

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Rank	Inputs	Effort input	MCDA method	Output
1	utility function	Very-High	MAUT	Complete ranking with scores
2	pairwise comparisions on a ratio sclae and interdependencies	↑	ANP	Complete ranking with scores
3	pairwise comparisons on an interval scale		MACHBETH	Complete ranking with scores
4	pairwise comparisons on a ratio scale		AHP	Complete ranking with scores
5	indifference, preferences and thresholds		ELECTRE	Partial and complete ranking(pairwise outranking degrees)
6	indifference, preferences and thresholds		PROMETHEE	Partial and complete ranking(pairwise preference degrees and scores)
7	ideal and anti-ideal option	↓ Very-Low	TOPSIS	Complete ranking with closeness score

Figure 1. Degree of MCDA I/O effort for prioritization and selection

2.3. Method of work priority selection

To select work priorities by applying the TOPSIS and PROMETHEE, weights are set by AHP's pairwise comparison for each evaluation criteria. AHP's pairwise comparison is used to reflect on-site production manager's empirical knowledge to determine weights of basic factors such as cost, late delivery cost, inventory management cost, confidence level, setup time, and defective rate.

2.3.1. Set Weight of Empirical Knowledge Base of Field Production Manager

First, the empirical weighting of the field production manager by AHP method is as follows. First, as in Figure 2, a pair-to-pair comparison is established for the evaluation criteria set by the field production manager, and a pair-to-pair comparison for the evaluation criteria is performed. At this time, if A and B evaluation criteria are the same in terms of importance, 1 point is given, 3 points as a little important, 5 points as more important, 7 points as very important, and 9 points as absolutely important. If A is a 9 point, B automatically evaluated as 1/9 times [12]. Third, input the matrixed values into the Expert choice program and output the empirical weights of the field production manager as shown in Figure 3. The weights of factor is Unit price: 0.067, Tardiness penalty cost: 0.526, Inventory cost: 0.065, Confidence level: 0.198, Setup time: 0.058, Failure rate: 0.086.

No	Attribute 1	Important ←									→ Important								Attribute 2
1	Unit price	9	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	9	Tardiness penalty Cost
2	Unit price	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Inventory Cost
3	Unit price	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Confidence Level
4	Unit price	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Set-up time
5	Unit price	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Failure rate
6	Tardiness penalty Cost	9	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Inventory Cost
7	Tardiness penalty Cost	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Confidence Level
8	Tardiness penalty Cost	9	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Setup time
9	Tardiness penalty Cost	9	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Failure rate
10	Inventory Cost	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Confidence Level
11	Inventory Cost	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Setup time
12	Inventory Cost	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Failure rate
13	Confidence Level	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Setup time
14	Confidence Level	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Failure rate
15	Setup time	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Failure rate

Figure 2. Pairwise comparison of evaluation criteria

Figure 3. Matrix of evaluation criteria

2.3.2. TOPSIS Method

The process of prioritizing the TOPSIS methodology is as follows:

Step 1. Convert non-numeric parts of evaluation criteria and alternatives to numbers.

Step 2. Normalize the values and build a matrix.

Step 3. Weight the criteria.

Step 4. The matrix is constructed by multiplying the normalized matrix with weights.

Step 5. Ideally determine the best and the bad alternatives.

Step 6. Calculate the positional distance (The distance from the best alternative, the distance from the worst alternative).

Step 7. Proceed with the similarity calculation.

Step 8. The final work priority is selected based on the calculated similarity value.

As such, the work priority selection algorithm of this study maintains an operating system to make effective decision-making in which production schedules are established based on the empirical knowledge of field production managers and minimizing system changes by utilizing production data collected from actual sites. Its algorithm driving platform is shown in Figure 4.

The TOPSIS driving procedure is as follows.

First, implement the work priority algorithm driving platform. Second, extract production data from the MDS. Third, select major work assignments and process ranges by product. Fourth, input production data related to product standard scale (unit price, tardiness penalty cost, inventory cost, confidence level, setup time,

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failure rate). Fifth, weight the empirical knowledge base of field production managers by reference scale. Sixth, normalize work and calculate similarity by reference scale. Seventh, decide work priority decision.

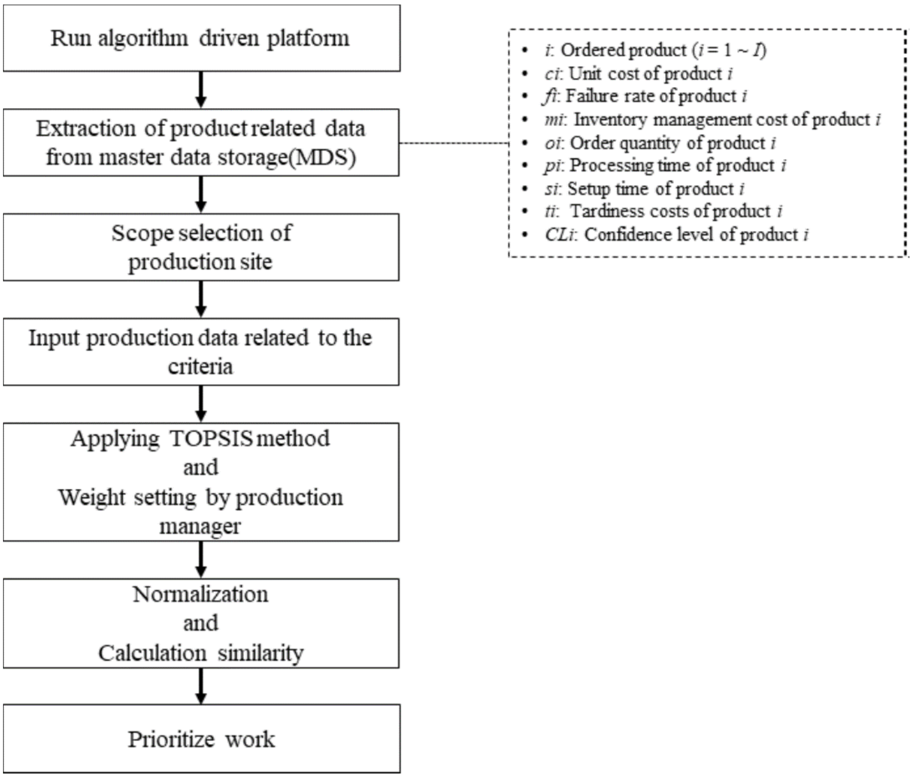

Figure 4. Driving platform of TOPSIS algorithm

2.3.3. PROMETHEE Method

Like the AHP method, the PROMETHEE prioritizes the overall alternatives through pairwise comparison of alternatives [12]. The assessment of the superiority of alternatives through the pairwise comparison between alternatives used in the PROMETHEE method uses six predefined functions and mainly uses the concept of preferential flow (entering flow) and preferred flow (entering flow). PROMETHEE, which derives the preference preferences of alternatives, defines the preference index π (a, b) used to calculate the preferred outflow and inflow as shown in Table 1. Table 2 shows the definition of the preferred flow rate, the preferred flow rate, and the net flow of preference. The preference function value Pj (a, b) is the value of the function that reflects the appraisers' preference for the difference between the evaluation scores of the two alternatives a and b. The preference functions for each evaluation criterion can be divided into usual type, quad type, linear preference type, level type, linear preference and indifference type, and normal distribution type (Gaussian type) [12]. In addition, as shown in Table 3, preference functions can be selected for each evaluation criterion. Which preference function is used can be selected through analysis and experience by accumulating a lot of data.

Table 1. Formula of PROMETHEE's ranking preference

Rank preference method of 'PROMETHEE'	$\pi(a,b) = \sum_{j=1}^{n} \omega_j P_j(a,b)$
	ω_j = Weight of criterion j
	$P_j(a,b)$ = Preference function value of criterion j

Table 2. Formula of leaving flow, entering flow and net flow

No.	Division	Formula
1	(Leaving flow: ϕ^+)	$\phi^+(a) = \frac{1}{m-1}\sum_{b \in A} \pi(a,b)$
2	(Entering flow: ϕ^-)	$\phi^-(a) = \frac{1}{m-1}\sum_{b \in A} \pi(a,b)$
3	(Net flow: $\phi(a)$)	$\phi(a) = \phi^+(a) - \phi^-(a)$

Table 3. Preference functions and preference threshold

Type	Ranking preference	Preference threshold
Usual	$H(x) = \begin{Bmatrix} 0 & if & x \le 0 \\ 1 & if & x > 0 \end{Bmatrix}$	
Quais	$H(x) = \begin{Bmatrix} 0 & if & x \le l \\ 1 & if & x > l \end{Bmatrix}$	$l > 0$
Linear preference	$H(x) = \begin{Bmatrix} x/m & if & x \le m \\ 1 & if & x \ge m \end{Bmatrix}$	$m > 0$
Level	$H(x) = \begin{Bmatrix} 0 \;\; if \;\; x \le s \\ 1/2 \;\; if \;\; x \le q + p \\ 1 \;\; if \;\; x > s + r \end{Bmatrix}$	$q > 0, p > 0$
Linear preference and indifference	$H(x) = \begin{Bmatrix} 0 \;\; if \;\; x \le s \\ x - s/r \;\; if \;\; s < x \le s + r \\ 1 \;\; if \;\; x > s + r \end{Bmatrix}$	$s > 0, r > 0$
Gaussian	$H(x) = \begin{Bmatrix} 0 \;\; if \;\; x \le 0 \\ 1 - e^{-x^2/2\sigma^2} \;\; if \;\; x \ge 0 \end{Bmatrix}$	$\sigma > 0$

PROMETHEE prioritization methods include PROMETHEE I and PROMETHEE II. The PROMETHEE I method is used to determine the priority of each alternative by comparing two alternatives with the preferred runoff and the preferred inflow. In this study, to compare priorities with the PROMETHEE method, we performed a pairwise comparison of the alternatives using excel, and in order of preference for evaluation criteria using open source software as shown in Figure 5.

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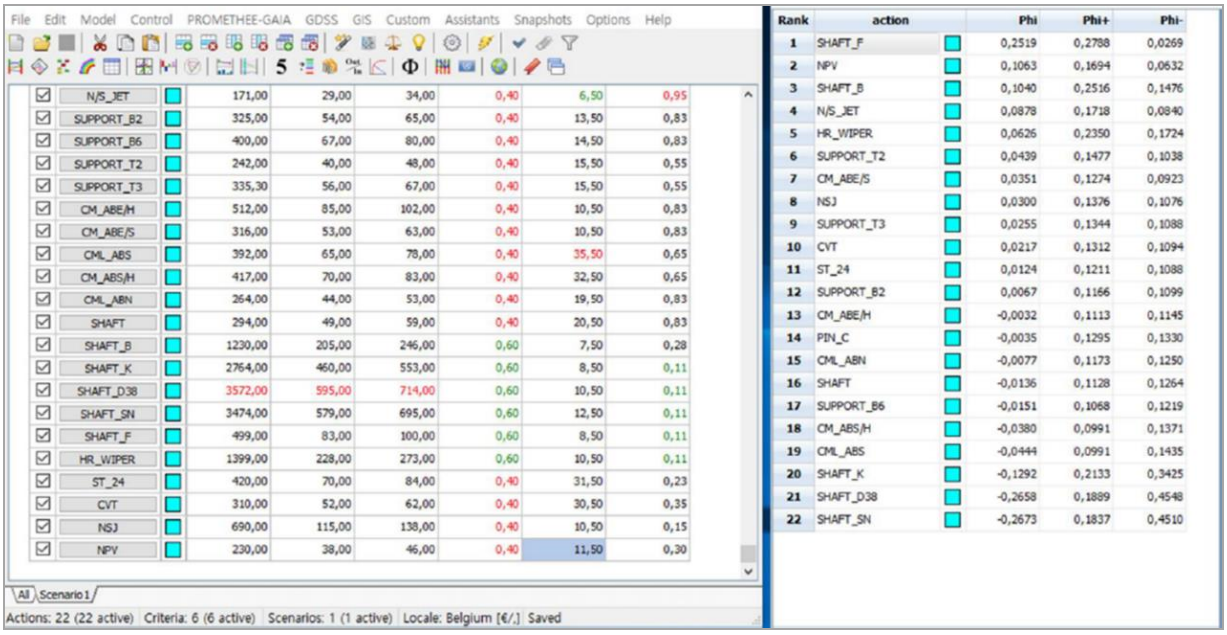

Figure 5. Priority rank calculating by Visual PROMETHEE

3. Comparison analysis

3.1. Set-up of analysis

The system aims to establish the most suitable work priority algorithm and efficient production schedule to produce the ordered products. In other words, it establishes an optimal production schedule that can minimize the cost and time required to efficiently allocate work to limited production resources and produce. The scenario for verifying this system was used based on the actual data of the case companies selected. First of all, the product composition received from the customer was set to 19 types, and each product quantity, unit cost for each ordered product, tardiness cost, inventory management cost, customer credit, work processing time, setup time, defect rate and process type information are shown in Table 4. The basic assumptions and symbols for the verification are shown in Table 5 and Table 6.

Order dates and delivery dates were set from January 01, 2019 to February 01, 2019, respectively. Design an AS-IS model using the dispatching rules, FIFO, SPT, and LPT rules, which are used by companies, and select prior assignment priorities for each of the assigned products, and set scheduling results according to the selected priorities. To derive In the TO-BE model, work priorities are selected through the TOPSIS and PROMETHEE, which reflect the empirical knowledge of field production managers, and the scheduling results are derived by applying the selected priorities to the system.

Table 4. Preference functions and preference threshold

No.	Product	Order qty	Unit Price	Tardiness penalty cost	Inventor y cost	Confiden ce level	Setup time	Failure
1	PIN_C	2400	125	21	25	0.4	32.5	0.95
2	N/S_JET	2600	171	29	34	0.4	6.5	0.95
3	SUPPORT_B2	2700	325	54	65	0.4	13.5	0.825
4	SUPPORT_B6	2900	400	67	80	0.4	14.5	0.825

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5	SUPPORT_T2	3000	242	40	48	0.4	15.5	0.55
6	SUPPORT_T3	3200	335.3	56	67	0.4	15.5	0.55
7	CM_ABE/H	1300	512	85	102	0.4	10.5	0.825
8	CM_ABE/S	1500	316	53	63	0.4	10.5	0.825
9	CML_ABS	1600	392	65	78	0.4	35.5	0.65
10	CM_ABS/H	600	417	70	83	0.4	32.5	0.65
11	CML_ABN	700	264	44	53	0.4	19.5	0.825
12	HR_WIPER	7500	294	49	59	0.4	20.5	0.8252
13	SHAFT	110	1230	205	246	0.6	7.5	0.275
14	SHAFT_B	150	2764	460	553	0.6	8.5	0.11
15	SHAFT_K	200	3572	595	714	0.6	10.5	0.11
16	SHAFT_SN	100	3474	579	695	0.6	12.5	0.11
17	SHAFT_D38	2500	499	83	100	0.6	8.5	0.11
18	SHAFT_F	150	1366	228	273	0.6	10.5	0.11
19	ST_24	300	420	70	84	0.4	31.5	0.23

Table 5. Assumption for analysis

No.	Assumption list
1	Each product is placed in a separate facility that is independent of each other and has a predecessor relationship.
2	Each plant can work on only one process for raw material input and processing and does not stop before the work is completed.
3	The working time of each process is different.
4	The order date and delivery date of each product are the same.
5	The start time of each work is different.
6	At the time of scheduling, the inventory of the product is set to '0'.
7	No urgent orders or product failures occur during scheduling.

Table 6. Description of symbols

Symbols	The details	Symbols	The details
i	Product number ($i = 1 \sim I$)	m_i	Inventory cost of product i
e	Equipment number($e = 1 \sim E$)	t_i	Tardiness penalty cost of product i
o_i	Order quantity of product i	c_i	Unit cost of product i
d_i	Delivery date of product i	CL_i	Confidence level of product i
s_i	Setup time of product i	P_i	Total processing time of product i
p_i	Processing time of product i	K_i	Total lead time of product i
n_i	Number of raw materials put into equipment e	S_i	Total set-up time of product i
f_i	Failure rate of product i	T_i	Total tardiness time of product i

3.2. Procedure of analysis

The simulation analysis procedure to verify the decision support system reflecting the empirical knowledge of the field production manager is shown in Figure 6.

Step 1: Enter standard information and status information for each product. That is, it generates work list information for each process flow based on ordered product information for each customer, and information on unit process, worker / equipment, work performance, raw

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materials, order date / delivery date, stock / stock etc.

Step 2: Set each work priority based on each methodology (SPT, LPT, FIFO, TOPSIS, PROMETHEE). In other words, SPT and LPT derive priorities based on processing time for each product, and FIFO derives priorities for each product using a random function. The TOPSIS and PROMETHEE derive priorities by assigning weights that reflect the empirical knowledge of field production managers through AHP's pairwise comparison.

Step 3: Perform the scheduling. Scheduling based on the priority scenario models was derived from the upper two-stage part to select a production schedule that requires the shortest total manufacturing lead time(Ki). However, if the total manufacturing lead time(Ki) is the same, additionally select a production schedule that minimizes the total tardiness time(Ti).

Step 4: Conduct a comprehensive productivity analysis of the schedule results. That is, the total manufacturing lead time(Ki) and the total tardiness time(Ti) are analyzed based on the scheduling result derived from the upper three steps.

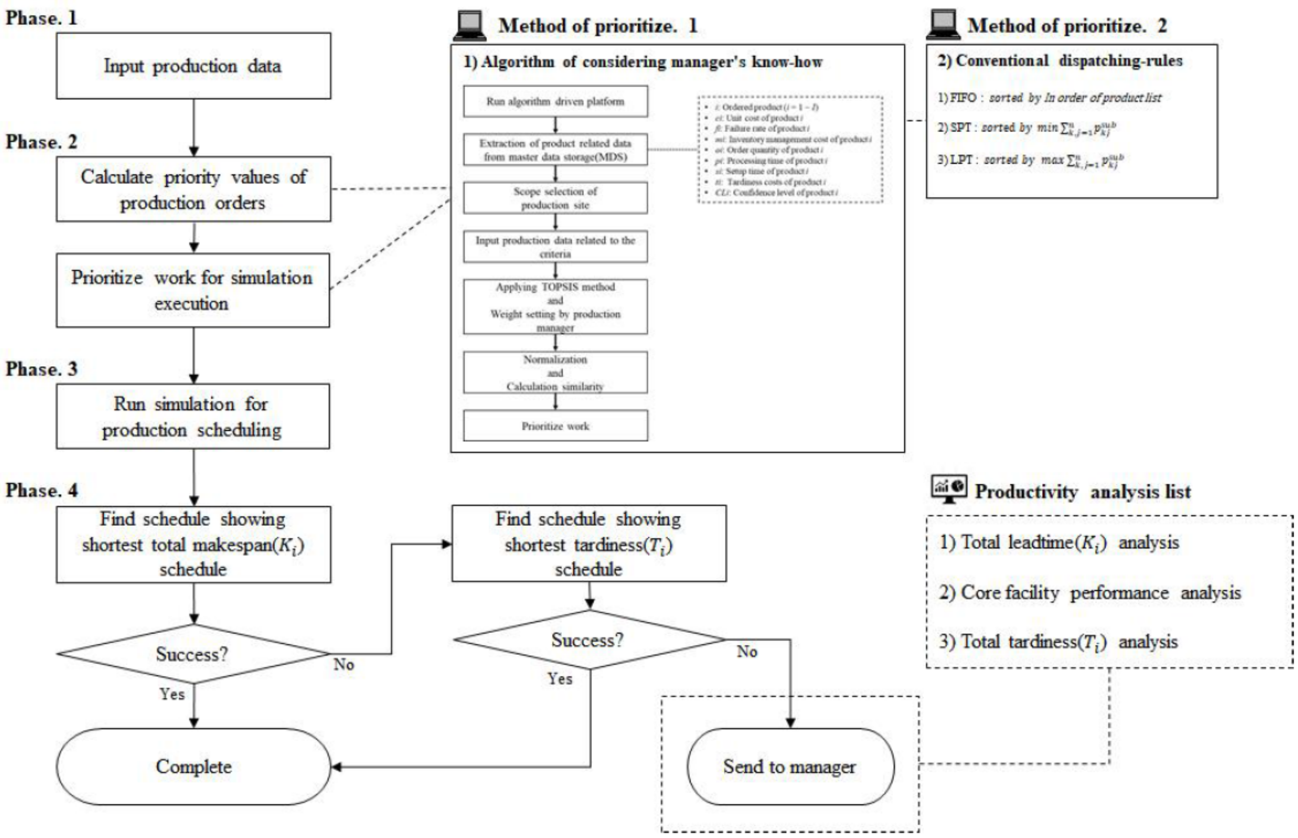

Figure 6. Procedure of analysis

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3.3. Results of analysis

In this study, the degree of effort and time of methodologies required to assign work priorities considering new orders or change of delivery dates was compared and analyzed. The criterion of the comparative analysis is set as the tardiness time which is considered the most important factor by SMEs. The results of analysis, PROMETHEE had the lowest lead delay of 268.78min/month, TOPSIS was analyzed as 421.39min/month, FIFO rule as 466.64min/month, SPT rule as 496.17min/month, and LPT rule as 602.07min/month (see Table 7). The application of the field production manager's empirical knowledge-based PROTMETHEE can reduce the manufacturing lead time on average by about 252.85min/month, compared to the FIFO, SPT, and LPT rules used in existing companies. In addition, the average manufacturing lead time was reduced by about 100.24min/month than the SPT, LPT, and FIFO rules. In the end, the PROMETHEE showed the best performance. However the effort consumption when using TOPSIS is much lower than that of PROMETHEE. Therefore, if there are many urgent orders or more standard attributes to consider, it can be used as an immediate response system by hybridizing with PROMETHEE.

Table 7. Comparative analysis of derived total tardiness time

Rank	Methods and rules	Total tardiness time (min)
1	PROMETHEE	268.78
2	TOPSIS	421.39
3	FIFO	466.64
4	SPT	496.17
5	LPT	602.07

4. Conclusion

Korean small and medium-sized manufacturing companies are feeling a lot of pressure to introduce new systems despite the sense of crisis caused by the Fourth Industrial Revolution, and not respond to the needs of various customers due to the lack of a basic management system. Therefore, we present the priority selection method through TOPSIS and PROMETHEE, which is the most easily used among the multi attribute decision making (MAMD) methodologies. Also, a comparative analysis on the existing dispatching rules was performed using scheduling simulation. As a result, the proposed methodology outperformed the existing dispatching rules in terms of tardiness and inventory quantity management. Further research is needed to develop and analyze specialized scheduling algorithms by industry.

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