Jiamruangjarus & Naenna, *Cogent Engineering* (2016), 3: 1158515
http://dx.doi.org/10.1080/23311916.2016.1158515

cogent engineering

PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

An integrated multi-criteria decision-making methodology for conveyor system selection

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Received: 23 October 2015
Accepted: 07 February 2016
First Published: 02 March 2016

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Reviewing editor:
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Abstract: Material handling equipment (MHE) is important for every industry because it has an effect on the productivity of manufacturing. Conveyor systems are presently one popular type of MHE. This paper presents an integration of the analytic network process (ANP) with the benefits, opportunities, costs and risk (BOCR) model in order to select the best conveyor system. The proposed model established a network with four merits, six strategies criteria, and twenty six sub-criteria with four alternatives (present, roller conveyor, chain conveyor, and monorail). The ANP is to determine the relative weights of an evaluative criteria and decision alternatives. Therefore, the final ranking of the alternatives are calculated by synthesizing the score of each alternative under BOCR. The results showed that the best alternative under all five methods is the chain conveyor. These research results can be easily applied, adapted and used to improve performance of selecting the conveyer system in small and medium enterprises through large industries.

Subjects: Industrial Design; Manufacturing & Processing; Operations Research; Production Systems

Keywords: material handling equipment; analytic network process (ANP); BOCR

1. Introduction

Although we are not particularly interested in the practice of material handling, in everyday life material handling equipment (MHE) can be found almost anywhere, especially in trade and industry. In fact, in modern life, it is not rare for materials handling to be used for such purposes as lifting, moving, storage and other activities. The study on metal processing industries has been a

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PUBLIC INTEREST STATEMENT

In this paper, we propose a multi-criteria decision-making model for conveyor system selection. Selection of the appropriate conveyor system is a very difficult task for manufacturing company. There are many conflicting quantitative and qualitative factors influencing the conveyor system selection decision. Multi-criteria decision-making model has been found to be useful approach to analyze these factors. This paper proposes an integrated multi-criteria decision-making model with benefits, opportunities, costs and risks (BOCR) to support decision-making in the problem of conveyor system selection. Analytic network process (ANP) with BOCR is utilized for assigning weights of criteria and is designed to select the most proper conveyor system alternative using the criteria weights attained by ANP.

discontinuous process; it was found that only five percent of total production time is spent working on a machine, and the other ninety-five percent is spent on waiting and movement (Srisom & Sriuthai, 2004). It was also found that in each industry, the cost of material handling will account for approximately 30–70% or more of the total cost of production, depending on the type of industry (Dongre & Mohite, 2015). The initial cost of manufacturing operation can be reduced by 15–30% by efficient management of material handling (Sule, 1994; Kulak, 2005; Sujono & Lashkari, 2007; Tuzkaya, Gülsün, Kahraman, & Özgen, 2010).

An investment analysis in choosing a material handling system (MHS) is extremely complex, and there are multiple solutions for particular situations (Swaminathan, Matson, & Mellichamp, 1992). The material handling selection problem is important (Chan, Ip, & Lau, 2001), and there are many factors concerned that should be considered. It may be significantly affected by constraints or other factors such as product size, the characteristics of the product that is to be handled, space and time required, etc. (Marcello, Gabbrielli, & Miconi, 2001). These main factors consist of MHE, manufacturing type, working area, product appearance, environment, functional equipment, material handling methods, and other factors. Many times, investors will only consider the benefits of investment and investment cost, which makes the mistake of considering the major two factors: the opportunities and risks arising from the investment.

This research focuses on the investment conveyor system. The complexity of conveyor equipment selection is a problem for many manufacturers (Fonseca, Uppal, & Greene, 2004). There are several factors and limitations involved in conveyor equipment selection. A conveyor system is a part of the mechanical handling equipment that is used to move materials from one location to another (Tompkins, White, Bozer, & Tanchoco, 2002). The types of conveyors can be categorized in several ways. For example, a belt conveyor can be used for bulk and unit loads, so it can be located overhead or on the floor. Bulk materials such as grain, dry chemicals and saw dust can be conveyed using a chute, belt, bucket or vibrating conveyors. Unit materials such as castings, machined parts, and materials can be placed on pallets and cartons or tote boxes, and can be conveyed using chute, belt, roller, wheel, or tow conveyors. Materials can be conveyed on belt, roller, wheel, vibrating, pneumatic or tow conveyors.

This paper describes a tool to support decision-making in the problem of conveyor system selection. For this problem, this paper used the analytic network process (ANP) with the benefits, opportunities, costs and risk (BOCR) as a development tool. The ANP, as one of widely used multiple criteria decision-making (MCDM) method, is often implemented in BOCR analysis to improve the performance of decision analysis (Chen, Lee, & Kang, 2010; Cho, Kim, & Heo, 2015; Erdogmus, Kapanoglu, & Koc, 2005; Jaafari, Najafi, & Melónc, 2015; Krishna Mohan, Reformat, & Pedrycz, 2013; Lee, Chang, & Lin, 2009; Malmir, Hamzehi, & Farsijani, 2013; Mili, 2014; Saatya & Sagir, 2015; Sakthivela, Ilangkumaranb, & Gaikwada, 2015; Tornjanski, Marinković, & Lalić, 2014; Ustun & Demirtas, 2008; Wang, Lee, Peng, & Wud, 2013; Wiratanaya, Darmawan, Kolopaking, & Windia, 2015; Wijnmalen, 2007; Yazgan, Boran, & Goztepe, 2010). The rest of this paper is organized as follows. Section 2 describes the MHS, the ANP and presents the five methods of BOCR. Section 3 describes the methodology and algorithm for the ANP model with BOCR. In Section 4, selected examples are presented to apply the model in real cases. The final section provides concluding remarks.

2. Literature review

2.1. Material handling system

Material handling is defined by American Society of Mechanical Engineers as the art and science involving the moving, packaging, and storing of substances in a form. Although the best solution to the problem of materials handling is no handling, or the simplest solution to the handling of materials being no movement no cost. Both solutions are hardly possible for a complete manufacturing process. A MHS is a system for improving the performance of a manufacturing system, such as reducing work-in-process (WIP) by delivering the right amount of materials, to the right place, at the right time, and at the lowest cost (Kulak, 2005).

In a manufacturing system, MHE is the most important part, and it plays an increasingly important role in the productivity of manufacturing. The selection of an MHE system is complex, and there is a considerable amount of capital investment required. As handling activities account for 30–40% of production costs (Tompkins & White, 1984), an appropriate MHE should be selected by aiming to reduce production costs and increase profit. For these reasons, researchers have to find solutions by using various methods such as expert systems, mathematical models, MCDM method, etc. For this study, the researcher has placed an emphasis on MCDM methods. Types of MHE have been divided into seven main groups: conveyors, overhead conveyors, cranes, industrial trucks, automated guided vehicles (AGVs), robots, and storage/retrieval systems.

The complexity of conveyor equipment selection is a problem for many manufacturers (Fonseca et al., 2004). There are several factors and limitations involved in conveyor equipment selection. A conveyor system is a part of mechanical handling equipment that is used to move materials from one location to another (Tompkins et al., 2002).

2.2. Analytic network process

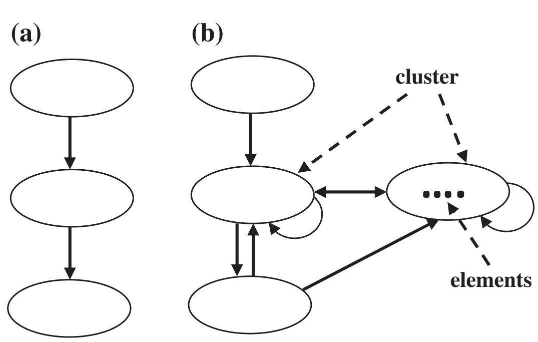
The ANP was introduced by T. L. Saaty, as a generalization of the analytic hierarchy process (AHP) (Saaty, 2004a). The ANP is an improved model of the AHP. The AHP was proposed in 1980 by Thomas L. Saaty as a decision-making method. The ANP permits mutual dependence and feedback among criteria, therefore the ANP is different from the AHP (Liang & Li, 2008).

The AHP is designed for solving the independence problem among alternatives or criteria problems, while the ANP is designed for solving the dependence problem among alternatives or criteria problems (Lee & Kim, 2000). Therefore, the AHP would not be appropriate for complex relationships, because the structure is linear from top-to-bottom. The ANP allows for complex interrelationships among clusters or elements, by replacing hierarchies with networks as shown in Figure 1.

- Step 1: Model construction and problem structuring: The problem should begin distinctly and decomposed into a rational system as a network. This network structure can be obtained through the opinion of decision-makers, through brainstorming or other appropriate methods (Chung, Lee, & Pearn, 2005).
- Step 2: Pairwise comparison matrices and priorities: At each cluster, all pairs of the decision elements are compared with respect to the importance of the elements toward their control criteria. The clusters are also compared pairwise themselves, with respect to their contribution to the purpose. An expert who acts as a decision-maker is asked to determine the relative importance of each criterion on a scale of 1 to 9 (Wijnmalen, 2007).

Figure 1. Structural difference between (a) hierarchy and (b) network.

Source: Chung et al. (2005).



Reversing the comparison between already compared elements, a reciprocal value is assigned to the reverse comparison; that is $a_{ij} = 1/a_{ij}$ (Lee et al., 2009) and then, a pairwise comparison matrix was developed and solved by the following equation (1):

$$A \times w = \lambda_{\max} \times w, \tag{1}$$

where A is the matrix of pairwise comparison, w is the eigenvector, and $\lambda_{\max}$ is the largest eigenvalue according to an approximation of w from several algorithms by Saaty (Lee et al., 2009).

- Step 3: Supermatrix formation: The supermatrix concept resembles the Markov chain process (Yazgan et al., 2010). The local priority vectors are entered into the appropriate column of a matrix, known as a supermatrix, by aiming to obtain global priorities in a system with interdependent influences. As a result, a supermatrix is actually a partitioned matrix, where each matrix segment represents a relationship between two nodes in a system (Wijnmalen, 2007). Let the clusters of a decision system be C_k, $k = 1, 2,..., N$, and each cluster k has n_k elements, denoted by $e_{k1}, e_{k2}, \dots, e_{kn_k}$. The value obtained in the previous steps are clustered and placed in the appropriate positions in a supermatrix, based on the influence flow from one cluster to another, or from a cluster to itself, as in a loop. A standard form for a supermatrix is as in formulate (2) (Yazgan et al., 2010):

$$W = \begin{array}{cc} & \begin{array}{c} e_{11}\ e_{12} \cdots e_{1m1} \cdots e_{k1} e_{k2} \cdots e_{kmk} \cdots e_{n1} e_{n2} \cdots e_{nmn} \end{array} \\ \begin{array}{cc} & e_{11} \\ c_1 & e_{12} \\ \vdots & \vdots \\ & e_{1m1} \\ & \vdots \\ & e_{k1} \\ & e_{k2} \\ c_k & \vdots \\ & e_{kmk} \\ \vdots & \vdots \\ & e_{n1} \\ c_n & e_{n2} \\ & \vdots \\ & e_{nmn} \end{array} & \begin{bmatrix} W_{11} & \cdots & W_{1k} & \cdots & W_{1n} \\ \vdots & & \vdots & \vdots & \vdots \\ W_{k1} & \cdots & W_{kk} & \cdots & W_{kn} \\ \vdots & & & \vdots & \\ W_{n1} & \cdots & W_{nk} & \cdots & W_{nn} \end{bmatrix} \end{array} \tag{2}$$

As an example, the representation of the supermatrix for a hierarchy with three levels (Yazgan et al., 2010):

$$W = \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & 0 & 0 \\ 0 & W_{32} & I \end{bmatrix}. \tag{3}$$

where W_{21} is a vector that represents the effect of the objective on the criteria, W_{32} is a matrix that represents the effect of the criteria on each of the alternatives, I is the identity matrix, and all of the zeros correspond to those elements that have no influence. For the previous example, if the criteria are interrelated among themselves, the hierarchy is replaced by a network as shown in Equation (2). The presence of the matrix element W_{22} of the supermatrix W_n can be represented by the interdependency that the supermatrix would present (Yazgan et al., 2010):

$$W_n = \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & I \end{bmatrix}. \tag{4}$$

If there is an interrelationship of elements within a cluster or between two clusters, then any zero value in the supermatrix can be replaced by a matrix. As there is usually interdependence among clusters in a network, the columns of a supermatrix may sum to more than one. However, the supermatrix must be modified so that each column of the matrix sums to a unified value. Saaty (Yazgan et al., 2010) has recommended the approach of determining the relative importance of the cluster as the controlling component (Wijnmalen, 2007). Raising a matrix to powers gives the long-term influences of the elements relative to each other. To obtain a convergence on the importance of weights, the weighted supermatrix is raised to the power of $2k + 1$, where k is an arbitrarily large number, and forms a new matrix that is called the limit supermatrix (Yazgan et al., 2010). The limit supermatrix form is similar to the weighted supermatrix, except that all of the columns of the limit supermatrix are the same. The normalizing of each cluster of this supermatrix can be reached with the final priorities of all elements in the matrix.

- Step 4: Selection of the best alternatives: The final priorities can be obtained by normalizing each alternative's column in the limit supermatrix.

The ANP is a technique which is similar to the AHP. The characteristic between criteria and subcriteria of the ANP is a network, while AHP is a hierarchy. In addition, the ANP is also similar to other techniques as well. For example, the multi-attribute utility technique (MUAT), cross-impact analysis and cost-consequences analysis (CCA), these are categorized as alternative selection analyses, as well as the AHP or the ANP. Saaty has proposed one of the general theories of the ANP (Saaty, 2004a), which is the BOCR or benefits, opportunities, costs, and risks in a decision-making process (Chen et al., 2010). The BOCR is a combination of the score of each alternative by five methods.

1. Additive: $P_i = bB_i + oO_i + c[(1/C_i)_{\text{Normalized}}] + r[(1/R_i)_{\text{Normalized}}]$ (5)

2. Probabilistic additive: $P_i = bB_i + oO_i + c(1 - C_i) + r(1 - R_i)$ (6)

3. Subtractive: $P_i = bB_i + oO_i - cC_i - rR_i$ (7)

4. Multiplicative priority powers: $P_i = B_i^b O_i^o [(1/C_i)_{\text{Normalized}}]^c [(1/R_i)_{\text{Normalized}}]^r$ (8)

5. Multiplicative: $P_i = B_i O_i / C_i R_i$ (9)

An example of recent research using BOCR is the Disney decision. Examining the construction of a new theme park in greater China, this research uses an integration of BOCRs models. It has an objective of searching for new market areas. An area for a new Disney park will require a minimal investment, mostly on returns through royalties, licensing and income streams. The final result for this project is Hong Kong as the first site to get into China, although Shanghai is a more costly option with a higher potential future market than Hong Kong. Another research paper on the topic is about the model of the buyer–supplier relationship. It has integrated the ANP and BOCR concepts. The result of the research provides advice to select the most suitable form of relationship between supplier and manufacturer.

3. Methodology and algorithm

The adoption of the BOCR concept, the ANP model with BOCR is suggested in this segment to select a solution to the conveyor system problem. The steps are shown as follows:

Step 1. Define the problem, set criteria, and set definition criteria by experts through brainstorming or other appropriate methods.

Step 2. Set a control network for the problem by specifying strategic criteria and the four merits, benefits, opportunities, costs, and risks (Saaty, 2004b, 2004c) as shown in Figure 2. The four merits in the control network are used to rate the B, O, C, and R.

Step 3. Create a questionnaire with a nine-point scale as outlined by Saaty, as a comparison in determining the pairwise strategic criteria.

Step 4. Use a five-step scale that can evaluate the importance of BOCRs for each strategic criterion. Values and wording of five-scale 0.42, 0.26, 0.16, 0.10, and 0.06, of very high, high, medium, low, and very low, respectively. (Erdogmus et al., 2005; Erdogmus, Aras, & Koc, 2006; Saaty, 2004b, 2004c). The panelist opinions are aggregated by the geometric mean method.

Step 5. Calculate the score of each strategic criterion from Step 4, and the respective strategic criteria from Step 3. The value of B, O, C, and R came from the normalized priorities of BOCRs, respectively.

Step 6. Set criteria and sub criteria according to the merit of each and organization for all four merits. Based on brainstorming or other appropriate methods, a network is constructed in the form as shown in Figure 3. The goal must be connected with the four merits, benefits (B), opportunities (O), costs (C), risks (R).

Step 7. Prepare a questionnaire established on a pairwise comparison of elements at each level. The questionnaire used in this section is the nine-point-scale questionnaire.

Step 8. After all experts have filled out the questionnaire, create an aggregate of opinions by the geometric mean method. After that, calculate the unweighted supermatrix, weighted supermatrix, and limit supermatrix for each merit.

Step 9. Calculate each alternative by using the five ways, additive, probabilistic additive, subtractive, multiplicative priority powers, and multiplicative.

Figure 2. The network of the decision problem (control network).

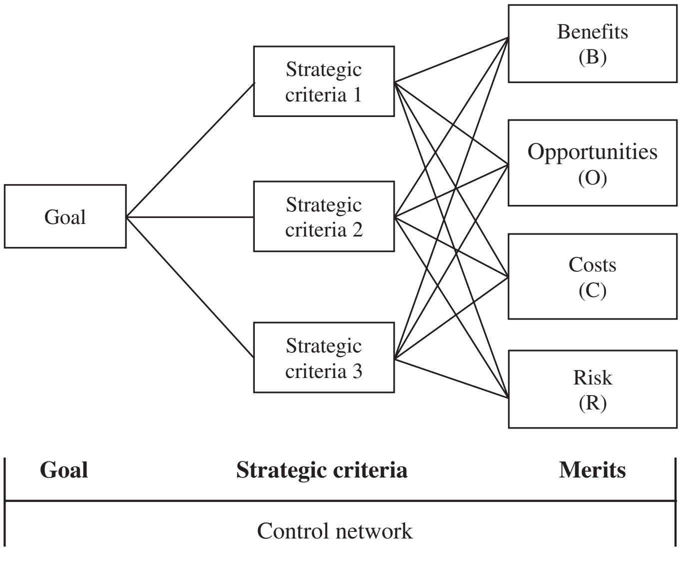
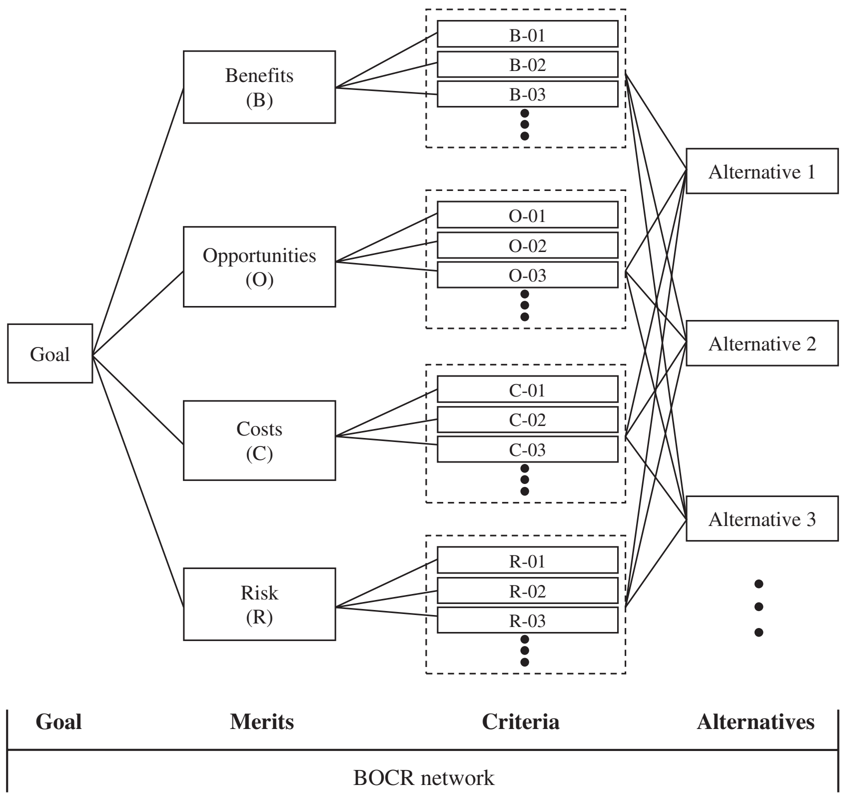


Figure 3. The network of the decision problem (BOCR network).



4. Experimental results

A committee should be formed composed of three experts, including a manager, senior manager from the company logistics department, and a manager from the design department from the conveyor system company.

In Figure 4, the strategic criteria for the conveyor selection system is shown. The company wants to select a conveyor system, and the strategic criteria are flexibility, manufacturing, future plans, productivity, safety, and quality. Flexibility is related with the quality of being adaptable or variable. Manufacturing is related with reputation and relationships. Future plans are related with capacity plans and process plans. Productivity is related with the quality of being productive or having the power to produce. Safety is related with safety device design at an ergonomics design level. Quality is related with fulfilling the customer's requirements and expectations, at all times. In the third level, there are four merits: benefits (B), opportunities (O), costs (C), risks (R). For example, an expert's opinion of a questionnaire with a nine-point scale is shown in Table 1. A proportion of 5:1 between flexibility and manufacturing implies that flexibility is five times more important than manufacturing.

The eigenvalue method is used for calculating eigenvector and eigenvalue. Calculating the consistency index (CI) and consistency ratio (CR) value is used for checking consistency of comparison (Saaty, 1980).

$$\text{Ws1} = \begin{matrix} \text{flexibility} \\ \text{manufacture} \\ \text{future plan} \\ \text{productivity} \\ \text{safety} \\ \text{quality} \end{matrix} \begin{bmatrix} 0.3169 \\ 0.0975 \\ 0.0723 \\ 0.1739 \\ 0.0973 \\ 0.2419 \end{bmatrix} \quad \text{and } \lambda_{max} = 6.3827 \tag{10}$$

Figure 4. Control network.

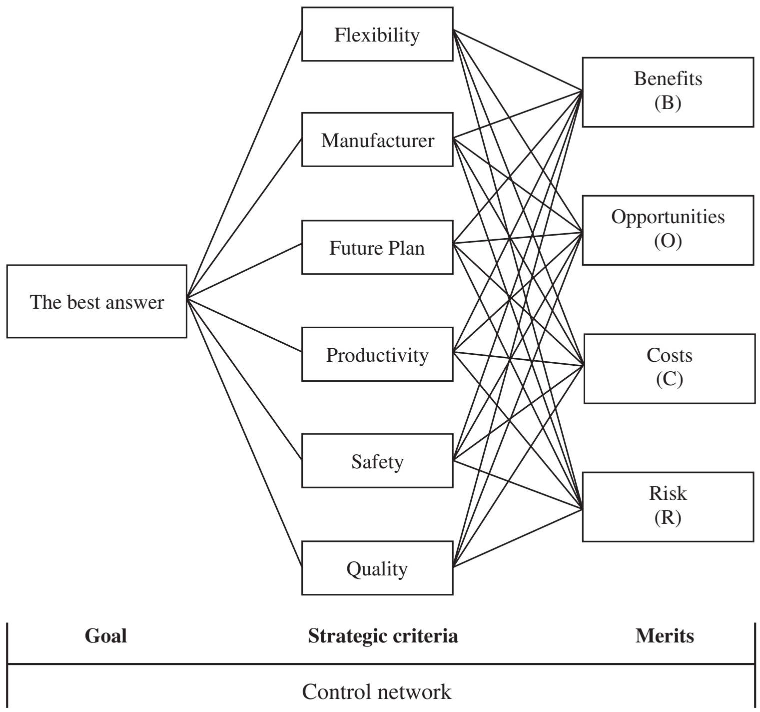


Table 1. Scale of relative importance

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it
2, 4, 6, 8	For compromise between the above values	When compromise is needed

Note: Saaty, 1980.

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{6.3827 - 6}{6 - 1} = 0.0765 \quad (11)$$

$$CR = \frac{CI}{RI} = \frac{0.0765}{1.25} = 0.0612 \quad (12)$$

If the value of CR is less than 0.1, the mean comparison is consistent (Ergu, Kou, Shi, & Shi, 2014). A combination of opinions from all experts is used as a geometric mean method. For example, the pairwise comparison between flexibility and manufacturing from all respondents are (5:1), (3:1), and (5:1). Therefore, putting the value in the geometric mean method is $(5 \times 3 \times 5)^{1/3} = 4.2172$. For the six strategic criteria calculated shown in Table 2, the synthesized priorities of strategic criteria are as follows:

$$\text{Ws} = \begin{matrix} \text{flexibility} \\ \text{manufacture} \\ \text{future plan} \\ \text{productivity} \\ \text{safety} \\ \text{quality} \end{matrix} \begin{bmatrix} 0.2934 \\ 0.1415 \\ 0.1025 \\ 0.1662 \\ 0.0928 \\ 0.2037 \end{bmatrix} \tag{13}$$

For BOCR, each expert will be asked to answer according to a five-step scale. According to Step 4 in the methodology and algorithm section, the values according to the five-scale were 0.42, 0.26, 0.16, 0.10, and 0.06, of very high, high, medium, low, and very low, respectively. The final value after brainstorming all the expert opinions is shown in Tables 3 and 4. The final criteria in the BOCR network came from experts through the Delphi method as shown in Figure 5. For example, calculations will show the network of benefits/used subnet as shown in Figure 6.

After calculating all of the comparisons, the unweighted supermatrix and the weighted supermatrix for benefits/used are formed as presented in Tables 5 and 6. And after that, they are transformed to the limit supermatrix. The final decision for used/benefits subnet is shown in the limit supermatrix, and the highest final score is alternative 4.

Table 2. Pairwise comparison

	Absolute		Very strong		Strong		Weak		Equal	Weak		Strong		Very strong		Absolute		
	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
In order to have the best selection for conveyor system.																		
Flexibility					x													Manufacture
Flexibility							x											Future plan
Flexibility							x											Productivity
Flexibility							x											Safety
Flexibility									x									Quality
Manufacture							x											Future plan
Manufacture											x							Productivity
Manufacture									x									Safety
Manufacture											x							Quality
Future plan											x							Productivity
Future plan									x									Safety
Future plan											x							Quality
Productivity									x									Safety
Productivity									x									Quality
Safety											x							Quality

Table 3. Comparison matrix for strategic criteria

	Flexibility	Manufacturer	Future plan	Productivity	Safety	Quality	Synthesized priorities
Flexibility	1	4.2172	2.0801	2.4662	2.0801	1.0000	0.2934
Manufacturer	0.2371	1	2.0801	1.0000	1.0000	1.0000	0.1415
Future plan	0.4807	0.4807	1	0.4807	1.4422	0.5503	0.1025
Productivity	0.4055	1.0000	2.0801	1	2.0801	1.0000	0.1662
Safety	0.4807	1.0000	0.6934	0.4807	1	0.3333	0.0928
Quality	1.0000	1.0000	1.8171	1.0000	3.0000	1	0.2037

Table 4. Priorities of BOCRs

	Flexibility (0.2934)	Manufacturer (0.1415)	Future plan (0.1025)	Productivity (0.1662)	Safety (0.0928)	Quality (0.2037)	Priorities for BOCR merits	Normalized priorities
Benefit	High	High	High	Very high	High	High	0.2866	0.2977 (b)
Opportunity	High	High	Medium	High	High	Very high	0.2823	0.2932 (o)
Cost	Low	High	High	Medium	Low	Low	0.1490	0.1547 (c)
Risk	High	High	Very high	Medium	Low	High	0.2449	0.2544 (r)

The alternative's final ranking is a combination of scores under the B, O, C, and R of each alternative by using the five methods for combining scores. The final ranking of the alternatives are as shown in Table 6. For example, alternative 1 (As-Is: Present) is calculated by the five methods.

Additive:

$$\begin{aligned} P_1 &= bB_1 + oO_1 + c\left[(1/C_1)_{\text{Normalized}}\right] + r\left[(1/R_1)_{\text{Normalized}}\right] \\ &= 0.2977 \times 0.1018 + 0.2932 \times 0.0999 + 0.1547 \times 0.5480 + 0.2544 \times 0.5618 \\ &= 0.2873 \end{aligned}$$

Probabilistic additive:

$$\begin{aligned} P_1 &= bB_1 + oO_1 + c(1 - C_1) + r(1 - R_1) \\ &= 0.2977 \times 0.1018 + 0.2932 \times 0.0999 + 0.1547 \times (1–0.0792) + 0.2544 \times (1–0.0747) \\ &= 0.4375 \end{aligned}$$

Subtractive:

$$\begin{aligned} P_1 &= bB_1 + oO_1 - cC_1 - rR_1 \\ &= 0.2977 \times 0.1018 + 0.2932 \times 0.0999 - 0.1547 \times 0.0792 - 0.2544 \times 0.0747 \\ &= 0.0283 \end{aligned}$$

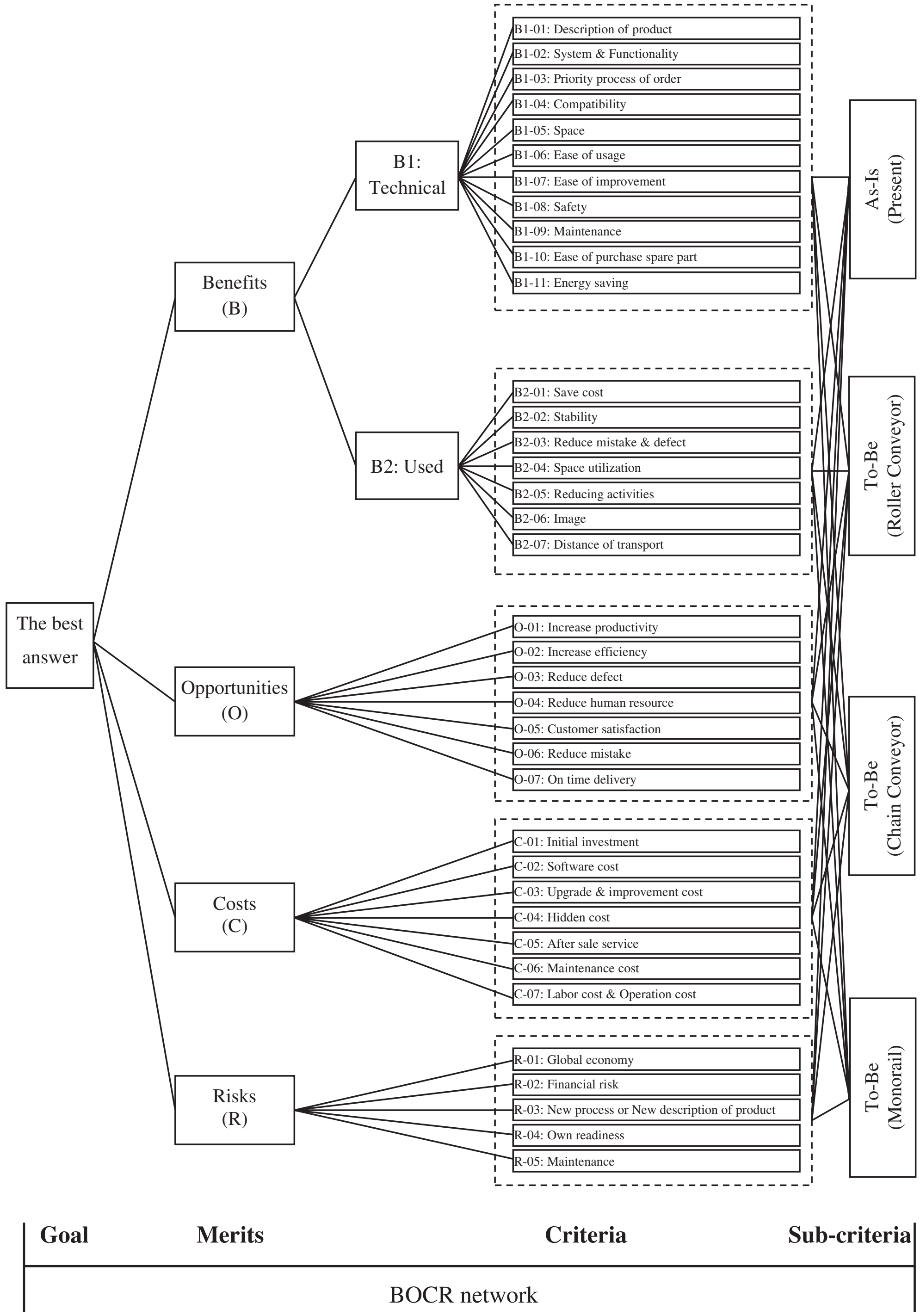
Multiplicative priority powers:

$$\begin{aligned} P1 &= B_1^b O_1^o [(1/C1)_{\text{Normalized}}]^c [(1/R1)_{\text{Normalized}}]^r \\ &= (0.1018^{0.2977})(0.0999^{0.2932})(0.5480^{0.1547})(0.5618^{0.2932}) \\ &= 0.2029 \end{aligned}$$

Multiplicative:

$$\begin{aligned} P_1 &= B_1 O_1 / C_1 R_1 \\ &= 0.1018 \times 0.0999/0.0792 \times 0.0747 \\ &= 1.7194 \end{aligned}$$

Figure 5. BOCR network.



Under the benefits and opportunities merits in Table 7, to-be: Monorail is the best with 0.3654, 0.3918, respectively. Nevertheless, under the costs and risks merits, as-is: Present has the best cost and the least risky alternative, with normalized reciprocals of 0.5480 and 0.5618, respectively.

The final calculation of alternatives uses the five methods under B, O, C, and R. The results of ranking the alternatives are shown in Table 8. From final result, first priority of the best alternative under all five methods is the chain conveyor. While roller conveyor always stay, respectively, as the third and the last

Figure 6. Clusters with element under used benefits.

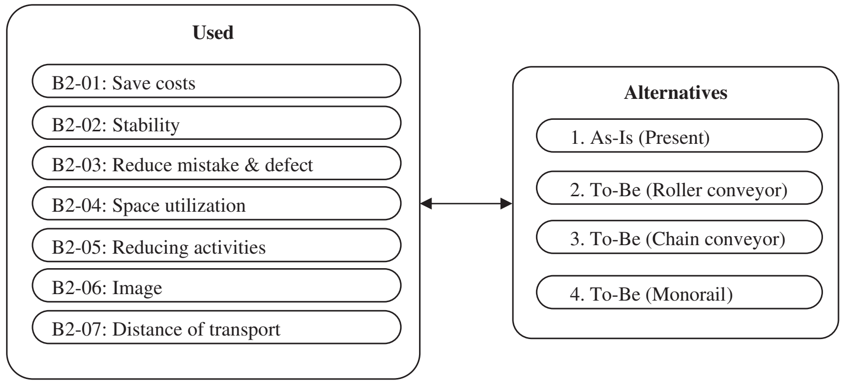


Table 5. Weighted supermatrix under benefits/used subnet

	Alternatives				Benefits/Used						
	As-Is: present (I)	To-be: roller Conveyor (II)	To-be: chain Conveyor (III)	To-be: monorail (IV)	Save costs (B2–01)	Stability (B2–02)	Reduce mistake & defect (B2–03)	Space utilization (B2–04)	Reducing activities (B2–05)	Image (B2–06)	Distance of transport (B2–07)
As-Is: present (I)	0	0	0	0	0.0935	0.0786	0.0844	0.0562	0.0973	0.0810	0.1081
To-be: roller conveyor (II)	0	0	0	0	0.2151	0.1876	0.2711	0.4412	0.0820	0.1540	0.3206
To-be: chain conveyor (III)	0	0	0	0	0.2149	0.3389	0.4063	0.2435	0.3266	0.3885	0.3104
To-be: monorail (IV)	0	0	0	0	0.4765	0.3949	0.2382	0.2591	0.4942	0.3765	0.2609
Save costs (B2–01)	0.2054	0.3318	0.2498	0.3039	0	0	0	0	0	0	0
Stability (B2–02)	0.1561	0.2205	0.2164	0.1738	0	0	0	0	0	0	0
Reduce mistake & defect (B2–03)	0.1224	0.0877	0.1399	0.1149	0	0	0	0	0	0	0
Space utilization (B2–04)	0.1390	0.1051	0.1580	0.1817	0	0	0	0	0	0	0
Reducing activities (B2–05)	0.0559	0.0539	0.0957	0.0561	0	0	0	0	0	0	0
Image (B2–06)	0.0853	0.0360	0.0611	0.0679	0	0	0	0	0	0	0
Distance of transport (B2–07)	0.2360	0.1651	0.0792	0.1018	0	0	0	0	0	0	0

system. Under probabilistic additive (0.4771), subtractive (0.0680), and the multiplicative priority powers (0.2326), chain conveyor is the first best, and monorail is the second. In addition, the ranking under multiplicative method is not the same as other, major reason is that the method does not take into account the priorities B, O, C, and R. Nevertheless, with the objective of selecting two systems, the first and second select chain conveyor and monorail, respectively, under all five methods.

Table 6. The Limit supermatrix under benefits/used subnet

	Alternatives				Benefits/Used						
	As-Is: present (I)	**To-be: roller Conveyor (II)**	**To-be: chain Conveyor (III)**	**To-be: monorail (IV)**	**Save costs (B2–01)**	**Stability (B2–02)**	**Reduce mistake & defect (B2–03)**	**Space utilization (B2–04)**	**Reducing activities (B2–05)**	**Image (B2–06)**	**Distance of transport (B2–07)**
As-Is: present (I)	0.0426	0.0426	0.0426	0.0426	0.0426	0.0426	0.0426	0.0426	0.0426	0.0426	0.0426
To-be: roller conveyor (II)	0.1254	0.1254	0.1254	0.1254	0.1254	0.1254	0.1254	0.1254	0.1254	0.1254	0.1254
To-be: chain conveyor (III)	0.1477	0.1477	0.1477	0.1477	0.1477	0.1477	0.1477	0.1477	0.1477	0.1477	0.1477
To-be: monorail (IV)	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843
Save costs (B2–01)	0.1433	0.1433	0.1433	0.1433	0.1433	0.1433	0.1433	0.1433	0.1433	0.1433	0.1433
Stability (B2–02)	0.0983	0.0983	0.0983	0.0983	0.0983	0.0983	0.0983	0.0983	0.0983	0.0983	0.0983
Reduce mistake & defect (B2–03)	0.0581	0.0581	0.0581	0.0581	0.0581	0.0581	0.0581	0.0581	0.0581	0.0581	0.0581
Space utilization (B2–04)	0.0759	0.0759	0.0759	0.0759	0.0759	0.0759	0.0759	0.0759	0.0759	0.0759	0.0759
Reducing activities (B2–05)	0.0336	0.0336	0.0336	0.0336	0.0336	0.0336	0.0336	0.0336	0.0336	0.0336	0.0336
Image (B2–06)	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297
Distance of transport (B2–07)	0.0612	0.0612	0.0612	0.0612	0.0612	0.0612	0.0612	0.0612	0.0612	0.0612	0.0612

Table 7. Priorities of alternatives under four merits

Merits	**Benefits (0.2977)**			**Opportunities (0.2932)**		
			Normalized			Normalized
Alternative						
As-Is: present			0.1018			0.0999
To-be: roller conveyor			0.2482			0.2258
To-be: chain conveyor			0.2846			0.2824
To-be: monorail			0.3654			0.3918
	Costs (0.1547)			Risks (0.2544)		
	Normalized	Reciprocal	Normalized reciprocal	Normalized	Reciprocal	Normalized reciprocal
Alternative						
As-Is: PRESENT	0.0792	12.6228	0.5480	0.0747	13.3890	0.5618
To-be: roller conveyor	0.2440	4.0985	0.1779	0.2549	3.9230	0.1646
To-be: chain conveyor	0.2528	3.9555	0.1717	0.2375	4.2112	0.1767
To-be: monorail	0.4240	2.3586	0.1024	0.4329	2.3098	0.0969

Table 8. Final synthesis of priorities of alternatives

Alternatives	Synthesizing methods									
	Additive		Probabilistic additive		Subtractive		Multiplication priority powers		Multiplicative	
	Priority	Rank	Priority	Rank	Priority	Rank	Priority	Rank	Priority	Rank
As-Is: present	0.2873	1	0.4375	4	0.0283	4	0.2029	4	1.7194	1
To-be: roller conveyor	0.2095	4	0.4466	3	0.0375	3	0.2065	3	0.9010	3
To-be: chain conveyor	0.2390	3	0.4771	1	0.0680	1	0.2326	1	1.3389	2
To-be: monorail	0.2642	2	0.4570	2	0.0479	2	0.2186	2	0.7801	4

5. Conclusions

In the industrialized world from past to present, one very important aspect to every industry is materials handling. For an investment analysis in choosing a MHS, the process is extremely complex and there are multiple solutions for any particular situation. Therefore, this paper differs from previous studies of the conveyor selection system problem by using decision-making techniques to select the best conveyor system for a company.

In this research, a model, which performs an analysis using the ANP with benefits-opportunities-costs-risks (BOCR), is used to evaluate conveyor system selection. The model in this paper can help perform a stable evaluation of the various types of conveyor systems. The multi-criteria decision-making techniques used by the ANP are the same as the AHP, but the ANP has been featured for its relationship between alternatives on the criteria. The suggested model not only considers the cost and benefit factors, similar to other decision-making investment models, but this paper also takes into account opportunity and risk factors. Therefore, the proposed model can be used to properly evaluate any conveyor system in any industry, to help select the best form of conveyor system.

This research suggests key factors which used for a decision to help consider and investment in material handling conveyor system. Moreover, this research provides the conveyor selection model that aimed to support decision-making of executive or plant manager who are interested for conveyor system investment analysis while this model is also useful as to increase reliability for manufacturers of conveyor and to encourage clients to be more participated in conveyor system selection.

The criteria in the model are not fixed, but may differ across the type of situation. Therefore, the criteria should be removed or added conditional upon the development of the model. This model can also be profitable for use in future research.

Funding
The authors received no direct funding for this research.

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Citation information
Cite this article as: An integrated multi-criteria decision-making methodology for conveyor system selection, Pairat Jiamruangjarus & Thanakorn Naenna, *Cogent Engineering* (2016), 3: 1158515.

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