Publishing House
AKAPIT

COMPUTER METHODS IN MATERIALS SCIENCE
Informatyka w Technologii Materiałów

Vol. 15, 2015, No. 1

DIFFERENTIAL EVOLUTION FOR SUSTAINABLE SUPPLIER SELECTION IN PULP AND PAPER INDUSTRY: A DEA BASED APPROACH

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Abstract

Management of sustainable (ecologically green) supply chain is a vital concern for any industry around the world. The pulp and paper industry in INDIA is facing tremendous challenges like tumbling demands due to ecological concern, gloomy trend in technology advancement, and fierce worldwide competition. This highly competitive operating environment is of much concern and hence attention is focused towards the direction of climatic changes and additional ecological concerns. These concerns are voiced by activists, researchers, and the common man, which has compelled the industries to take suitable actions for sustainability. This paper aims to examine the challenges of sustainable supplier selection (SSS) and proposes a Differential Evolution (DE) based approach for selecting sustainable suppliers for a hypothetical north Indian pulp and paper industry's supply chain management (SCM).

Key words: sustainable supplier selection, supply chain management, differential evaluation, data envelopment analysis, pulp and paper industry

1. INTRODUCTION

Nowadays, sustainable development has become a topic of discussion among almost all the segments of our society and is getting a favourable response from different units like manufacturing (Jayal et al., 2010), business development (Floridi et al., 2011), tourism (Luthe & Schuckert, 2011) and agriculture (Paoletti et al., 2011).

In SCM both academics and general practitioner contemplate the sustainable concerns in their workings. The significance of Sustainable SCM has emerged as a result of the present-days commercial conditions of worldwide competition, globalization of supply chains, small product life cycles, immediate modifications in technologies, the need to deliver greater levels of consumer service, and the continual

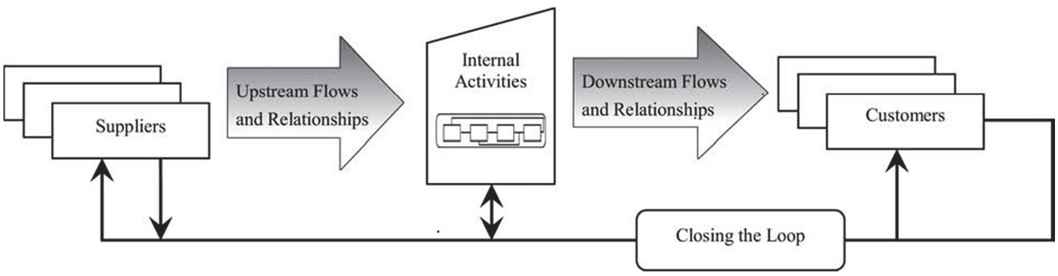

Fig. 1. Sustainable supply chain with stages and relationships field (Sarkis, 2012).

ISSN 1641-8581

force to decrease prices, increase asset use while taking care of environment concerns. Figure 1 presents a flow diagram of sustainable supply chain with stages and relationships field.

In view of the growing awareness concerning sustainability in the pulp and paper industries, the SSS would be the vital element in the process of managing a sustainable supply chain. The nature of this decision usually is difficult and is many times unstructured. Now, it is the duty of the purchasing managers to identify most suitable clusters of sustainable suppliers for their product. Optimization practices might serve as useful tools for these types of decision-making problems.

During last few years, DE has arisen as a dominating tool used for solving a variety of problems arising in numerous fields. Proposed by Storn and Price (1995), a population set based evolutionary algorithm was applied successfully to wide-ranging issues (Plagianakos et al., 2008; Wang & Jang, 2000; Joshi & Sanderson, 1999; Ilonen et al., 2003; Ali et al., 2011).

The proposed approach is an extension of method proposed by Jauhar et al. (2014a), which focuses on developing suitable supplier clusters. In Jauhar et al. (2014a) the authors presented an approach for SSS problem where the input criteria are lead time, price and quality of the delivered goods and the output criteria are service quality and CO_2 emission of the product and services. After successfully applying this approach with traditional output criteria for SSS, we further apply this approach for value-added SSS in pulp and paper industry. In this study we have taken reusability as output criteria with CO_2 emission; because now a day's material recovery through parts reuse and material recycling has become an important business strategy in pulp and paper industry (Mazhar et al., 2005).

Materials can have an impact on the environment in a range of different ways and at different times during their life cycles. For example, the extraction, transportation and manufacturing of raw material consume energy and produces carbon. However, when a material is reused or recycled the wider environmental impact of the material is significantly reduced (http://www.ukgbc.org/content/materials).

The paper manufacturers are striving for new approaches and methods to embrace the extended cycle for supplied products. They need economically competitive as well as environmentally friendly end of life material recovery options that help to transform the classical cradle-to-grave economy into a cycle economy.

The main difference between the earlier paper of the authors (Jauhar et al., 2014a) and this paper is that, in the previous paper the authors have considered the traditional output criteria for supplier selection and have considered a model accordingly. While in this paper, the authors have discussed the problem considering the aspect of global sustainability, for this the authors have also considered the impact of reusability and CO_2 emission. The output criteria are changed accordingly and modified model is considered in addition to the model considered in Jauhar et al. (2014a). Further, in this paper the study, including literature review, is done in more detail.

This paper is organized in eight sections. Subsequent to the introduction in section 1, the sustainable SCM in pulp and paper industry, sustainable supplier selection and methodology are briefed in 2, 3 and 4 sections respectively. Section 5 describes the mathematical model formulation with DEA used in this article. Section 6 describes the DE algorithm for SSS and a case on pulp and paper industry is discussed in section 7. Finally, discussion with conclusion of the current research is given in last section.

2. PULP AND PAPER INDUSTRY SSCM

The paper products manufacturing companies has a significant and complicated role in the worldwide carbon cycle. Pulp and paper are massive consumers of energy. In fact, the world's fifth-leading consumer of energy is the pulp and paper industry.

The World Resources Institute, a body of experts, placed the industry's CO_2 emissions at around 500m tons worldwide in 2005 (Martel et al., 2005). Rather, European companies are reasonably green. The Confederation of European Paper Industries (CEPI), a trade association, states his associates' emissions were 46m tons in 2011.Greenhouse gas (GHG) emissions from the pulp and paper source group are most of the part of CO_2 with lesser quantity of CH_4 as well as N_2O (Philpott & Everett, 2001).

Indian pulp and paper industries produces a great amount of paper as well as cellulose based fibre products. Bulletin papers, copy papers, different kinds of tissue, bottle sticky label, cigarette papers plus coffee filter are just a small number of patterns of the products frequently used in our daily life.

At present in India, there are 759 pulp and paper industries with an installed capacity of 12.7 million tons producing around 10.11 million tons/annum of paper/paper board and newsprint out of the total world production of around 402 million tons. The Indian pulp and paper industries structure consists of small, medium and large-sized paper mills having production capacities ranging from 10 to 1,150 tons per day (Chakraborty & Roy, 2014).

The industry employs wood, agro residues and recycled/waste paper as the major raw material for manufacturing different varieties of paper, paper board and newsprint. In 2000, the share in production of paper from wood-based raw materials, agro residues and recycled/waste paper had been 39, 31 and 30 %, respectively (Kulkarni, 2013).

Pulp and paper industries in India continue to face challenges with forest (wood)-based raw materials. The projected demand for paper by 2025 is 24 million tonnes leading to an estimated shortfall of 12 million tons of wood (Kulkarni, 2013).

There is a huge amount of activity involved in the chain behind these products; such a system of actions is acknowledged as supply chain in management as well as operation research works (https://www.cirrelt.ca/DocumentsTravail/2006/DT-2006-AM-3.pdf).

These industries are categorized by a huge and extremely incorporated supply chain. The entire supply chain starts in the procurement network, carry on through production network, distribution network and finishes by sales network. In this age, concern is usually for the sectors effect on external network of pulp and paper supply chain organization and its emissions of CO_2. Figure 2 presents an easy illustration of the wood based pulp and paper industry supply chain organization with corresponding main SCM level.

3. SSS IN PULP AND PAPER INDUSTRY

Supplier selection is a significant part of SCM. Supplier selection and evaluation forms an integral part of a supply chain. A wrong choice or decision may lead to unpleasant circumstances and in worst case may even lead to the deterioration of the entire supply chain's financial and operational position. The supplier selection practices are comprehensively studied in the literature with multi-criteria decision making models (MCDM). Different researchers have studied the works in the past relating the sup-

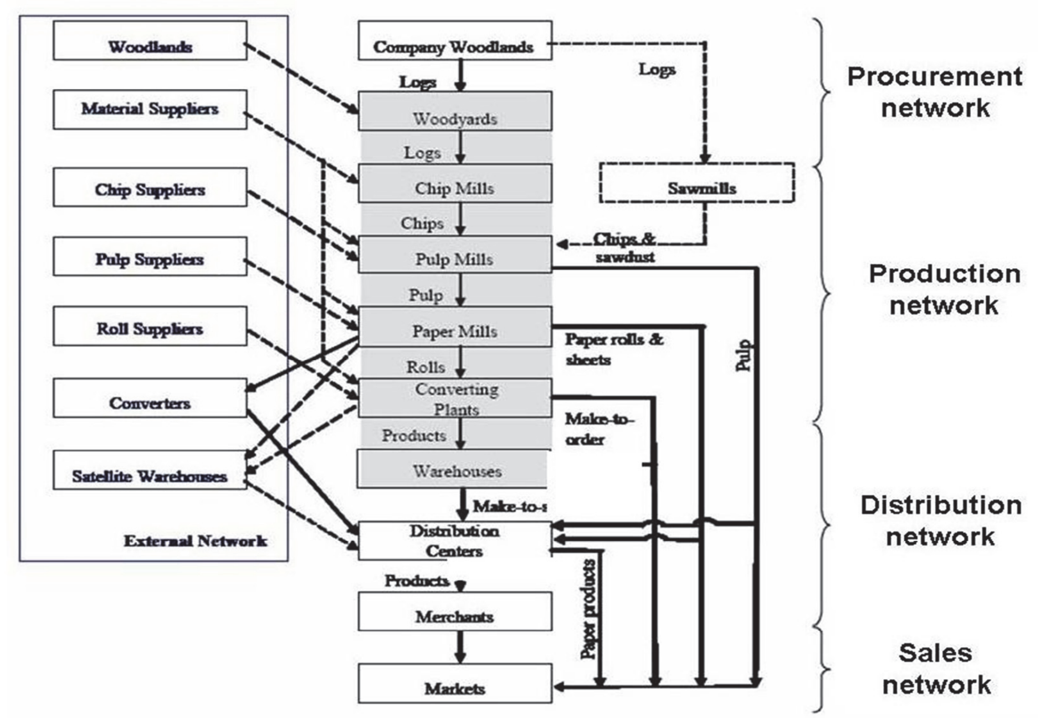

Fig. 2. The pulp and paper supply chain organization (Martel et al., 2005).

Indian business organizations are gradually identifying that the effective management of sustainable supply chains is a primary driver of value creation as well as environmental performance. Industries in the pulp and paper area have now started to identify the immense scope and potential future prospects that exist for sustainability in SCM.

plier evaluation and selection problem (Agarwal et al., 2011; Weber et al., 1991; Degraeve et al., 1991; Boer et al., 2000; Holt, 1998; Aamer & Sawhney, 2004; Ho et al., 2010; Tahriri et al., 2008; Cheraghi et al., 2011; Jauhar & Pant, 2013; Jauhar et al., 2013; Jauhar et al., 2014b).

Now days, a growing environmental consciousness has favoured the rise of the new sustainable supply chain paradigm; as a result, similarly in the suppliers selection issues, sustainable criteria have been integrated. Traditionally, only the management aspects like lead time, quality, price, late deliveries, rate of rejected parts and service quality of the supply chain were considered for selecting a potential supplier. However, with the growing environmental issues researchers are also paying attention to factors like greenhouse effect, reusability, carbon-di-oxide (CO_2) emission etc. The resulting problem is called '*Sustainable supplier selection* (*SSS*)', where a balance is maintained between the management and environment concerns.

Recently, Klassen and Vachon (2003) examined the role of suppliers in plant level ecological enrichments in the Canadian printing industry in addition to describing the significance of cooperation for supplier investments in environmental friendly technologies. To select the potential suppliers, two focuses comprise significance: one is the degree of the selection criteria, and the other is the suppliers' sustainable performance, these two focuses need to be verified with the appropriate decision makers (Buyukozkan & Çifçi, 2011).

Towards accomplishing a sustainable supply chain, entire associates in the chain from raw material suppliers to topmost administrators must have natural liking in relation to sustainability. Even now, comprehensive SCM study is yet to be accomplished on how corporations can contain suppliers in sustainable management practices and involve them into sustainable activities.

4. METHODOLOGY

To measure and analyse the relative efficiency of pulp and paper industries suppliers, we follow a four step methodology:

1) Design a criteria containing input and output criteria.
2) Select a problem.
3) Formulate the mathematical model of the SSS problem with the help of DEA.
4) Apply DE on mathematical model.

The present model can be carried out for any quantity of suppliers and there is no limitation, by using this model, the company can obtain a recommended combination of efficient suppliers.

5. MATHEMATICAL MODEL FORMULATION WITH DEA

DEA based method is used for determining the efficiencies of Decision-Making Units (DMUs) on the basis of multiple inputs and outputs (Dimitris et al., 2009). DMU can comprise of business firms, divisions of huge groups such as institution of higher education, schools, hospitals, power plants, police stations, tax offices, prisons, a set of organizations (Ramanathan, 2003; Wen & Chi, 2010; Dobos & Vorosmarty, 2012; Kumar et al., 2011). The DMU described in this research work using input as well as output criteria is as follows.

The performance of DMU is estimated in DEA by the concept of efficiency or productivity, which the proportion of weights sum of outputs (*o*/*p*) to the weights sum of (*i*/*p*) inputs (Srinivas, 2000) given by equation:

$$Efficiency = \frac{Weighted\ sum\ of\ o/p}{Weighted\ sum\ of\ i/p} \tag{1}$$

The two basic DEA models are the CCR (Charnes, Cooper and Rhodes) model (Charnes et al., 1978) and the BCC (Banker, Charnes and Cooper) model (Banker et al., 1984), these two models may be distinguished on the basis of returns to scale assumed. The former assumes constant returns-to-scale whereas the latter assumes variable returns-to-scale (Dimitris et al., 2009). In the current study we use CCR model which is well-defined further down: suppose that there are N DMUs and each unit have I input and O outputs then the efficiency of m^{th} unit is achieved by resolving the below model given by Charnes et al. (1978):

$$\text{Max } E_m = \frac{\sum_{k=1}^{O} w_k Output_{k,m}}{\sum_{l=1}^{i} z_l Input_{l,m}}$$
$$0 \le \frac{\sum_{k=1}^{O} w_k Output_{k,n}}{\sum_{l=1}^{i} z_l Input_{l,n}} \le 1 \quad n = 1, 2, \ldots, m \ldots N$$
$$w_k, z_l \ge 0 \qquad \forall k, l \tag{2}$$

where:
E_m is the efficiency of the m^{th} DMU, k=1 to O, l =1 to I and n =1 to N.; $Output_{k,m}$ is the k^{th} output of the m^{th} DMU and w_k is weight of output $Output_{k,m}$; $Input_{l,m}$ is the l^{th} input of m^{th} DMU and z_l is the weight

of $Input_{l,m}$; $Output_{k,n}$ and $Input_{l,n}$ are the k^{th} output and l^{th} input, respectively of the n^{th} DMU, where n=1, 2, …m...N.

The fractional equation (2) can be converted in a linear equation (3) presented below. To calculate the efficiency score for each DMU we run the above program N times. A DMU is considered efficient if the efficiency score is 1 otherwise it is considered inefficient.

$$\text{Max } E_m \sum_{k=1}^{O} w_k Output_{k,m}$$
$$s.t.$$
$$\sum_{l=1}^{I} z_l Input_{l,m} = 1 \tag{3}$$
$$\sum_{k=1}^{O} w_k Output_{k,n} - \sum_{l=1}^{I} z_l Input_{l,n} \le 0 \quad \forall n$$
$$w_k, z_l \ge 0 \quad \forall k, l$$

6. DE ALGORITHM

DE algorithm is a type of evolutionary algorithm, most effectively used in optimization problems.

A buyer (decision maker) can effect an assessment (supplier evaluation) with the ability to choose weight system. For this purpose with the help of program implemented in DEV C++, we generate uniform random numbers (between 0 to 1) using the inbuilt function *rand*() in DEV C++,the fitness value is taken as the average fitness value in 30 runs and the program is terminated when Max-Iteration is reached, to assist the selection of the weights for input as well as output criteria in a manner to permit the control of the result for the sustainable supplier evaluation and assessment practice.

6.1. Experimental settings

The parameter settings for DE are given in table 1.

Table 1. *Parameter setting for DE.*

Pop size (NP)	100
Scale Factor (F)	0.5
Crossover rate (Cr)	0.9
Max iteration	3000
DE Scheme used	DE/rand/1/bin
Constraint handling	Pareto Ranking method (Ray et al., 2000)

Pop size refers to the population size taken. Scale factor (F) and Crossover rate (Cr) are the control parameters of DE defined by the user. Max iteration refer to the maximum number of iterations which are performed. Pareto ranking method is used for solving constrained optimization problems. This method makes use of three criteria to select a candidate:

a) if two solutions are feasible then select the one giving the better fitness function value,
b) if one solution is feasible and one is infeasible then select the one which is feasible,
c) if two solutions are infeasible, select the one having smaller constraint violation.

7. CASE ON SUSTAINABLE SUPPLIER SELECTION

The case study presented in this paper stands a hypothetical data (Jauhar et al., 2013) for pulp and paper industry in Northern India (X Company).The Raw Material is assumed to be agro based. Around 150 Indian pulp and paper industries use agro residues like bagasse, wheat and rice straw etc. and produces 2.2 million tonnes of material which is 20% of total production. After verifying a group of criteria in a view point of sustainable merits, some criteria including lead time, quality, price, reusability and CO_2 emissions of the delivered products are derived for SSS problem.

7.1. Designing a criteria

In current study we split the criteria in two manners: the input and output criteria (shown in figure 3). The input criteria are the traditional supplier selection criteria, such as lead time, price and quality of the delivered goods. The output criteria are the reusability and CO_2 emission of the product and services.

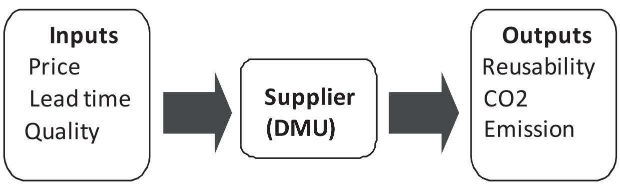

Fig. 3. *Input and output criteria for sustainable supplier selection.*

We assume that the reusability and CO_2 emission are the output of the examined model. Reusability concept is taken from Mazhar et al. (2005) and for CO_2 Emissions, *LOCOG* Guidelines on Carbon

Emissions of Products and Services – Version 1 (http://www.london2012.com/documents/locog-publications/locog-guidelines-on-carbon-emissions-of-products-and-services.pdf) is considered.

Table 2. *Data for numerical example.*

Criteria	Management criteria (Inputs)			Environmental criteria (Outputs)	
Suppliers	Lead time (L) (Day)	Quality (Q) (%)	Price (P) (Rs.)	Reusability (R) (%)	CO_2 Emissions (CE) (g)
1	2	80	107	70	30
2	1	70	161	50	10
3	3	90	269	60	15
4	4	65	270	30	12
5	2	55	260	40	18
6	5	70	201	50	20
7	3	85	111	66	14
8	2	95	300	35	28
9	1	67	197	60	16
10	4	72	157	44	28
11	5	51	170	41	14
12	3	58	106	49	10
13	2	72	255	32	25
14	4	60	117	40	29
15	5	63	245	22	5
16	3	90	299	10	9
17	1	87	101	42	15
18	2	82	206	70	18

7.2. Selection of a problem

The data is shown in table 2 with the supplier's database covering management (input) as well as environmental (output) criteria of an item provided in the shipment of company.

7.3. Mathematical model

Based on the basis of the above data the DEA model of K[th] DMU with the help of equation (3) will be as follows:

$$\begin{aligned}
& Max\ \ SQ_m + CE_n \\
& s.t. \qquad\qquad (4) \\
& z_1L_m + z_2Q_m + z_3P_m = 1 \\
& w_1SQ_n + w_2CE_n - (z_1L_m + z_2Q_m + z_3P_m) \le 0 \\
& \forall\ n = 1,\ldots m,\ldots 18
\end{aligned}$$

7.4. Applying DE on mathematical model

After applying DE on sustainable supplier selection problem, in table 3 average efficiency and weights results of all DMUs are given. In table 4 results of all DMUs are given and figure 4 shows the histogram of all suppliers with their efficiency score.

Table 3. *Average efficiency and weights in 30 runs.*

Suppliers	Value of input and output weight					Efficiency
	Z_1	Z_2	Z_3	W_1	W_2	
1	0.100129	0.00204427	0.00594674	0.0124772	0.00422648	1
2	0.9899	0	0	0.0166683	0.08283017	0.833417
3	0	0.0111122	0.18753e-016	0.0124103	0.3355601	0.744619
4	0	0.0153862	0	0.0165195	0.00248747	0.525436
5	0	0.0181836	0	0.011392	0.0219116	0.850091
6	0	0.0142871	0.19188e-020	0.0153397	0.00230969	0.81318
7	0	0.71429e-018	0.00900991	0.0137737	0.5848801	0.909066
8	0.442549	0.00121055	0	0	0.0327347	0.916572
9	0.989	0	0	0.00337086	0.0498655	1
10	0.0794687	0.00947534	0.71282e-009	0.42912008	0.0305688	0.855927
11	0	0.0196098	0.0887e-019	0.0210538	0.0031707	0.907594
12	0	0.0167855	0.000250394	0.0195676	0.29418018	0.958812
13	0.0944849	0.0112657	0	0.36807018	0.0363442	0.908605
14	0.0069216	0.0121538	0.00207852	0.00215503	0.0315172	1
15	0	0.0158746	0.68761e-019	0.0177283	0.14697017	0.390023
16	0.0728352	0.00868438	0.75703e-019	0	0.0280174	0.252156
17	0.963	0	0	0	0.0625062	0.937594
18	0	0.0117559	0.000175325	0.0137047	0.01723014	0.959331

***Table 4.** Suppliers efficiency.*

Supplier	Efficiency	Ranking
1	1	1
2	0.833417	13
3	0.744619	15
4	0.525436	16
5	0.850091	12
6	0.81318	14
7	0.909066	8
8	0.916572	7
9	1	1
10	0.855927	11
11	0.907594	10
12	0.958812	5
13	0.908605	9
14	1	1
15	0.390023	17
16	0.252156	18
17	0.937594	6
18	0.959331	4
Average	0.820134	

From table 4 we can see that for suppliers 1, 9 and 14, the efficiency score is 1 so these supplier are assumed to be 100% efficient while efficiency score for all other supplier is less than 1 indicating that these suppliers are not as efficient and among these, supplier no. 16 is probably the most inefficient in comparison to all other suppliers.

***Fig. 4.** Histogram of all suppliers with their efficiency score.*

8. DISCUSSION AND CONCLUSION

For performance assessment of the suppliers, three inputs and two outputs, as described in section 7.1, are taken and the results are shown in table 3. The research of efficient SSS practice can acquire a desirable cluster of competent sustainable suppliers 1, 9 and 14 using DE algorithm. The investigation shows that out of 18 suppliers, only 3 suppliers, namely, 1, 9 and 14 are most efficient. All the remaining suppliers are relatively less efficient as they have the efficiency scores less than one.

The average efficiency score using DE algorithm is 0.820134. Five suppliers 3, 4, 6, 15 and 16 scored lower than the average efficiency score. The lowest efficiency score (0.252156) is calculated for the 16. So the overall performance of 16th supplier is very poor.

For the current research conducted in 18 suppliers, the results are:

1) For suppliers 1, 9 and 14, the efficiency score is 1 so these suppliers are assumed to be 100% sustainable efficient.
2) Supplier 16 is probably most inefficient in comparison to all other suppliers.
3) Suppliers 1, 9 and 14 would be the most suitable set of suppliers (or key suppliers).
4) By using this DE algorithm, the business firms can acquire desirable clusters of competent sustainable suppliers.
5) Combination of suppliers 1, 9 and 14 would be the desirable clusters of competent sustainable suppliers set meanwhile the business firms requiring single-item sustainable suppliers.

In this study, we presented an approach to solve the multiple-criteria SSS problem with the application of DE, for data envelopment analysis (DEA) based mathematical model, and validated this approach with the help of a case taken from north Indian pulp and paper industry. Present study shows DE algorithm as a tool for selecting the optimal sustainable suppliers. Numerical results validate the efficiency of DE for dealing with such problems.

The key offerings of this research are précised as below:

1) SSS in SCM: to date, there are a small number of researches seeing sustainable concern in the supplier selection practice.
2) The selection criteria on the basis of sustainable concern are collected by means of the literature after that these are put in to the mathematical model for the SSS practice.
3) The present model can be used for analyzing any number of suppliers and criteria in the great size business firms.
4) In spite of the fact that lots of efforts have been made for the supplier selection, taking into consideration sustainable concern for this problem remains a demanding task.

5) In this study, the goal was the application of DE algorithm to the efficient SSS in the SCM.
6) A case on pulp and paper industry validates the application of the present approach.

Future research may explore the practice of the DE for finding a solution to more difficult problem with additional sustainable input and output criteria. Sensitivity analysis can also be used for the measuring the influence of each criteria for efficient sustainable suppliers. It is the hope of authors that the results of the DE and DEA model presented in this paper will stimulate further researches in the use of DE for sustainable supplier's evaluation and selection.

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ALGORYTM EWOLUCJI RÓŻNICOWEJ DLA ZRÓWNOWAŻONEGO WYBORU DOSTAWCÓW W PRZEMYŚLE CELULOZOWYM I PAPIERNICZYM: PODEJŚCIE OPARTE NA DEA

Streszczenie

Zarządzanie zrównoważonym (ekologicznie zielonym) łańcuchem dostaw jest istotnym problemem dla każdej branży przemysłowej na całym świecie. Przemysł celulozowo–papierniczy w Indiach stoi przed wielkim wyzwaniem związanym z dbałością o ekologię, pozostającą w sprzeczności z postępem technologicznym, i ostrą konkurencją na świecie. Konkurencja i rynek wymuszają troskę o środowisko w aspekcie zmian klimatycznych i innych problemów ekologicznych. Swoje obawy zgłaszają działacze, naukowcy, a także zwykli ludzie, zmuszając przemysł do podejmowania właściwych działań na rzecz zrównoważonego rozwoju. W pracy badano problem zrównoważonego wyboru dostawców (SSS). Zaproponowano zastosowanie algorytmu ewolucji różnicowej (DE) do rozwiązania postawionego zagadnienia SSS dla przykładowego przemysłu celulozowo-papierniczego na północy Indii, jako elementu zarządzania łańcuchem dostawców (SCM).

Received: October 1, 2014
Received in a revised form: November 17, 2014
Accepted: December 18, 2014