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The Factors Affecting the Reverse Supply Chain and Circular Economy, Case Study: Mobarakeh Steel Company

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Abstract

Production companies currently face significant environmental concerns, which raised the circular economy (CE). The CE is an economic system that aims to eliminate wastes by reusing them. This study aims to investigate the factors affecting the reverse supply chain in order to implement the CE in Mobarakeh Steel Company of Isfahan. Structured interviews were conducted with 13 managers and experts of the company. Among the factors in the literature, 16 factors were specifically identified as relevant to the company. The Delphi method has been used in order to determine the importance and priority of the factors for the company. To analyze the data, the analytical-survey method was used, and in order to collect information, a combination of library and field research methods was applied. By using these methods, we selected 7 factors out of 16 that were very important for the company. They were environmental-oriented design, industrial ecology, redistribution, reuse, redesign, recycling, and reduction. We prioritized these factors using the fuzzy TOPSIS method based on 6 criteria: efficiency of steel resources, slag use, electricity consumption, water consumption, gas consumption, and SO_2 emissions. The result shows that "Industrial ecology" has the 1st and "Reuse" has the 7th priority. The relationships between these factors were identified using a panel of experts and then, plotted the relationships as an IDEF0 (Icam DEFinition for Function Modeling) model. This is the first attempt to configure the model of reverse supply chain factors in a steel company.

Keywords: Ni-P Coatings; Circular Economy, Reverse Supply Chain, Delphi, Fuzzy TOPSIS, Mobarakeh Steel Company.

JEL classification: Q01, L60, Q57,

1. Introduction

For more than two decades, sustainable development has emerged in the literature. It tries to reduce human interference in the environment while achieving development goals. In this regard, the circular economy (CE) was presented which is a subset of green and sustainable supply chain management practices[1)]. The CE is against linear economy. In the linear, materials after becoming a product, eventually become discarded. In the new concept, modification and determination of disposable materials is valueable due to their reuse ability. Moreover, the disposable materials return to the supply chain and thus, create sustainable economic growth[2)]. Fig. 1 symbolically compares linear and CE and Fig. 2 compares the supply chains.

The production and consumption practices that follow the "take-make-dispose" flow, have negatively impacted the environment over time. This has propelled

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the society to evaluate and seek sustainable development options, where CE emerged as a relevant concept. This embraced the accountability for reverse logistics of the end-of-life products, which is seen as a costly and complex effort to be managed [16]. Traditionally, industries have operated according to a linear "make-use-dispose" model, with end-of-life landfilling of the products[18]. Therefore, nowadays, providing novel consumption and production patterns is considered due to a sustainable model of development[19]. Within this context, the notion of the CE has been receiving increasing attention[20-21]. According to the European Commission (2015), in a CE, the value of materials and products is maintained for as long as possible; waste and resource use is reduced, and resources are kept within the economy when a product has reached the end of its life, through reuse and recycling processes[13]. CE, not only reduces the use of the environment as a waste disposal site, but also creates self-sustaining production systems in which materials are used repeatedly[1]. Moreover, in the field of supply chain management, we are witnessing the emergence of a concept called reverse supply chain (RSC). The most important principle of RSC is that many materials that are so-called unusable for the consumer are valuable and can be re-introduced into the supply chain with a little modification. While governments and the social systems are pushing the transition towards a CE through top-down legislation and directives, increased bottom-up efforts from industrial organizations are also essential [22]. As a result, the designing and planning of appropriate supply chains constitute a significant building block towards the implementation of CE and RSC practices[1]. In this regard, the following questions were raised.

What RSC configuration should be taken to achieve the goals of the CE in Mobarakeh Steel Company? What are the components of CE in the company? How is the order of the CE components in terms of importance for the company? So, this paper contributes to configure the factors of a model of the reverse supply chain in a steel company. The paper continues with a review of the literature, research method, results, and discussion.

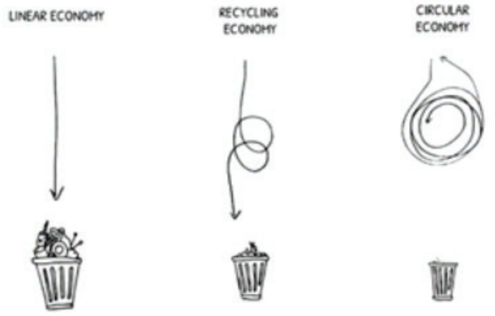
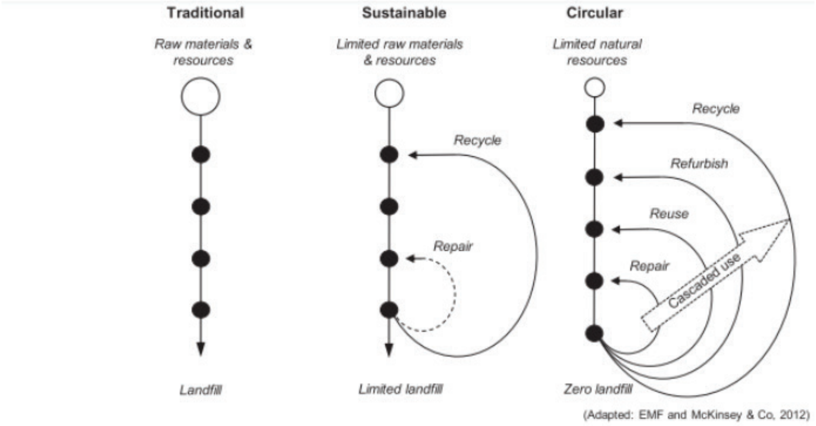


Fig. 1. Circular economy vs linear economy.[3]



(Adapted: EMF and McKinsey & Co, 2012)

	Traditional supply chains	Sustainable supply chains	Circular supply chains
Strategy	Component price	Cost of ownership	Leasing and service outcome
Structure	Linear and open	Partially closed	Closed, short and cascaded loops
Flow	Input-output	Mixed throughput	Biological and technical cycles
Focus	Efficiency	Customer effective	Collaborative value capture
Scale	High volume	High-medium volume	Medium-low volume
Scope	Global	Global and regional	Regional and local

Fig. 2. Traditional, sustainable and circular supply chains.[4]

1.1 Literature review

1.1.1 Definition of some relevant theories

- Circular economy (CE): This is an economic system, in which raw materials, components, and products lose their value as little as possible, renewable energy sources are used and systems thinking is at the core.

-Reverse logistics (RL): This stands for all operations related to the reuse of products and materials. RL can include all recycling, reclamation of raw materials, refurbishment, and reselling of items that have been restocked.

- Circular supply chain management (CSCM): this is the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems.

- Reverse supply chain (RSC), is an umbrella for a number of models, all of which are built to carry out five key processes: (1) product acquisition, which refers to obtaining the used product from the user; (2) reverse logistics or refurbishing, the process that enables the most economically attractive options (e.g. direct reuse, repair, remanufacture, recycle or disposal); (3) inspection and disposition, recycling and the assessment of the return condition to make the most profitable decision for reuse through the reduction of the product to its basic elements; (4) remanufacturing, returning the product to original specifications; and (5) marketing or reselling, which refers to creating secondary markets for the recovered product and remarketing them in order to create and exploit markets for refurbishing and distributing them.

-Sustainable development: this is an organizing principle for meeting human development goals while also sustaining the ability of natural systems to provide the natural resources and ecosystem services on which the economy and society depend.

1.1.2 review of the literature

Reverse supply chain (RSC) in the iron and steel industry refers to the active process of transporting scrap steel, scrap iron, and steel and sources of recyclable waste that can be returned to the beginning of the chain, after being used in the consumer market, through recycling. The field of the RSC can be divided into two parts, which are internal and external RSC. The internal RSC refers to the recycling process to return various iron and steel scraps from the current process to previous processes. The external RSC includes the reuse of non-steel solid scrap materials or by-products of the iron and steel industry that can be converted as raw materials in other industries. The reverse steel supply chain system has been created with the vision of high energy industries5). Davis (2007), collected data and information on steel production, estimated product life value, scrap steel production, and other data and built an annual scrap steel emission model in the UK and concluded that up to 30% of them are recyclable from waste6). Suthikarnnarunai (2009), studied the RSC as well as the supply chain in the Thai steel industry and concluded that the principles of supply chain management, labor and exchange rates, etc. affect the cost of the RSC in the iron and steel industry7). Xiuyu (2012), emphasized that there are many problems in the implementation of the RSC in the iron and steel industry8). For example, recyclable orders in the market were confusing, public-sector support was insufficient, recovery system control was weak, and the number of recycling companies was small. Edward et al. (2011), created a database of steel plant wastes and, concluded that there were approximately ninety types of wastes that were of great use-value in the entire casting process of iron and steel production9). Biagio et al. (2013), argued that some sort of waste recycling contract should have been established between the steel industry and its customers in the RSC of the iron and steel industry10). Zhou Yanfi (2013), used the PEST analysis method to examine the challenges and problems related to the construction of RSC systems in the iron and steel industry in terms of political, economic, social, and technical aspects11). Julianelli et al. (2020), developed a taxonomy for critical success factors (CSFs) of the reverse logistics capable of creating value for the company and its supply chain, from the perspective of the CE technical cycle16). They provided a framework that represents the relationship between the CSFs and reverse logistics in the context of the circular supply chain16). The proposed taxonomy embraced five CSFs, Material Planning and Management, Life Cycle Assessment, Industrial Sustainability, Information and Communication Technology, and Promoters and Relationship16). Charef et al. (2021), identified the factors impacting CE adoption17). A total of 64 factors were identified and placed into three interconnected categories, organizational, political and procedural, and technical factors. The relationships between the 64 factors and five entities, including stakeholders, asset lifecycle, material circularity, regulations, and facilitating technologies were analyzed. They clarified the impacts of the CE approach on five entities17). The steel industry is the core of industrial growth, and it has an indispensable role in the development of countries23). Steel is a highly recyclable product, meaning that it can be reused infinitely, increasing the significance of its reverse logistics23). Reverse logistics is an important business process in the iron and steel industry for the collection, recycling, and reuse of scrapped metals23). Focusing on the contradiction between the strong potential and the backward practice status of recycling scrapped steel, a decision framework was established in an attempt to help steel companies choose the best RL modes and effectively use the resource of scrapped steel23). Recognizing that companies are facing intense market, political, and social pressures to improve their reverse logistic practices, a comprehensive framework was proposed that encompasses six dimensions, economic, social, environmental, government policy, internal management practices, and external market competition23). By working with major Chinese iron and steel companies, key decision factors were identified along these dimensions23). The results indicated that policymaking has an outsiz impact on incentivizing companies to invest in reverse logistic systems23). It was found that external market and economic factors provide important feedback for shaping government policies24). The CE is widely known as a possible solution to address sustainable development in the manufacturing sector. The adoption status of CE in the steel industry of Thailand was investigated24). It was indicated that some of the participants' organizations had already implemented the CE24). The implementation success of CE was moderate-high24). The CE was found to be implemented mainly at the departmental level, rather than across the entire organization24). The main drivers of CE implementation were internal motivations, including environmental awareness, long-term sustainable development, and cost savings from material circularity24). Furthermore, reducing the environmental impact on external stakeholders was the main CE external driver24). A lack of proper training and knowledge, too much effort required, and a lack of support from top management were the main barriers to implementing the CE25).

The review of the research background shows that although the concept of RSC is known in Iran, the concept of CE has been discussed in only a few articles, none of which has been published in steel journals 12-15). In addition, it is clear that in Iran, no study has been done on the relationships, effects, and overlaps of the CE and supply chain. Also, most of the studies in the world regarding the CE in the steel industry have focused on the issue of recycling, especially scrap iron recycling, and none of the factors of the CE have been addressed in a macro model. Therefore, it seems that the research reported in this article is done for the first time in the Iranian steel industry. Moreover, this research has not been done in Mobarakeh Steel Company so far.

1.2. Problem definition

Creating a CE requires fundamental changes in the value chain from product design and production process to new business models and consumption patterns. So, it seems that the RSC can be used to achieve the goals of a CE. In response to this need, a study was conducted at Mobarakeh Steel Company, which seeks to determine and prioritize the factors affecting the RSC, in order to implement the CE in the company. Research questions are, what are the most important factors in the realization of the CE in Mobarakeh Steel Company? How important are they from the perspective of the company experts? Finally, how do these factors relate to each other?

2. Materials and methods

The first step in this research is to identify the factors related to CE. The initial factors related to CE were extracted from the research literature and the final factors in Mobarakeh Steel Company were extracted using the Delphi method by referring to experts. Then these factors were ranked in the CE of the industry. In this regard, a questionnaire has been designed and provided to the managers of Mobarakeh Steel Company based on the TOPSIS method. The criteria used to rank the factors of CE were extracted from library studies. These criteria are related to the iron and steel industry, and their list was finalized by consultation with the experts of Mobarakeh Steel Company. Then, the relationship between the factors was determined using the standard IDEF0 model and the expert panel method.

The statistical population of this research were the managers of Mobarakeh Steel Company. Due to the nature and purpose of this research, managers of finance, procurement, supply and production were willing to cooperate. The process was such that after studying, reviewing, and using the opinion of consultants, Delphi questions were formulated. After that, by snowball method, or direct invitation of the selected managers to participate in the Delphi process, the fuzzy TOPSIS questionnaire was completed (by the panel of experts). Although some practitioners suggested 6-9 expert members of the panel, Cochran (1977), offered a statistical formula that suggested 12 – 13 out of 70 relevant managers26). The formula is:

n= ((z^2 p(1-p))/e^2)/((1+(z^2 p(1-p))/(e^2 N))) formula (1)

where N is population size (70 managers), e is margin of error (3%), z is confidence level (95%), and p is percentage value (0.5).

Therefore, the sampling methods in this study are qualitative.

To analyze the data, in this research, the analytical-survey method was used and a combination of library and field research methods was used.

2.1. Analysis of research data

In this research, three methods have been used to analyze the data: Delphi, fuzzy TOPSIS, and expert panel method.

2.1.1. Descriptive analysis

According to the formula (1), 13 managers and senior experts (out of 70) of Mobarakeh Steel Company from the departments of Finance, Technology, Operation and Purchasing have participated in this research. Of those, 4 have served between 5 and 15 years, 4 have more than 25 years and 5 have 15 to 25 years of service in the steel company.

3. Results and discussion

3.1. Identification of factors related to circular economy using Delphi method

Members were first asked to name the factors of the CE that they thought could be examined at Mobarakeh Steel Company. They were also asked to comment on removing, modifying, or adding new factors. In the second round, while observing anonymity, the mean, mode, and standard deviation of the scores of CE factors were reported to the members. In this round of Delphi, 16 factors, derived from the results of the first round, were put to the vote of Delphi members. These factors were the main factors according to the members' ideas. Table 1. shows the results.

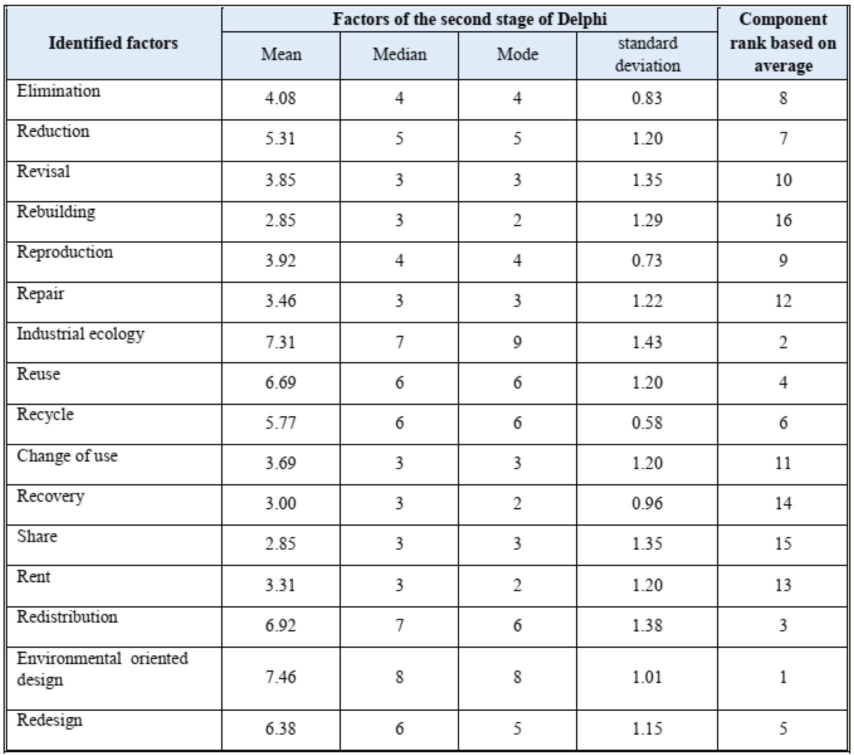
After extracting the results of this round, the mean, median, mode, and standard deviation of each factor were calculated. Table 2 shows the results.

Table 1. Factors of CE in the first round of Delphi.

Proposed factors of circular economy	
1	(Refuse) Elimination
2	(Redesign)
3	(Rethink) Revisal
4	(Reduce) Reduction
5	(Reuse)
6	(Repair) Repair
7	(Refurbish) Rebuilding
8	(Remanufacture) Reproduction
9	(Repurpose) Change of use
10	(Recycle)
11	(Recover) Recovery
12	(sharing) share
13	(Redistributed Manufacturing) Redistribution
14	(Rent)
15	(Environmentally Based Design[1]) Environmental oriented design
16	(Industrial Ecology)

Source: the research finding

Table 2. Results of the second stage of Delphi.



Identified factors	Factors of the second stage of Delphi				Component rank based on average
	Mean	Median	Mode	standard deviation	
Elimination	4.08	4	4	0.83	8
Reduction	5.31	5	5	1.20	7
Revisal	3.85	3	3	1.35	10
Rebuilding	2.85	3	2	1.29	16
Reproduction	3.92	4	4	0.73	9
Repair	3.46	3	3	1.22	12
Industrial ecology	7.31	7	9	1.43	2
Reuse	6.69	6	6	1.20	4
Recycle	5.77	6	6	0.58	6
Change of use	3.69	3	3	1.20	11
Recovery	3.00	3	2	0.96	14
Share	2.85	3	3	1.35	15
Rent	3.31	3	2	1.20	13
Redistribution	6.92	7	6	1.38	3
Environmental oriented design	7.46	8	8	1.01	1
Redesign	6.38	6	5	1.15	5

Source: the research finding

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[1] EBD

Then, based on the average score of each factor, the existing factors were ranked. Table 3. shows the results.

At this stage, in order to select the most important factors, agreed upon by the experts who are Delphi members, the criterion of breaking point in the "distribution chart" was used. For this purpose, the factors were shown in descending order of points on the horizontal axis (X) and the average score of each factor on the vertical axis (Y), so that by moving to the right, the average of the factors is reduced. To select the appropriate number of factors, a point was used at which the curved line decreases sharply. In Fig. 3, which relates to the mean distribution of the factors of the CE, agreed upon by the Delphi members, the point at which the curve decreases sharply (the breaking point) is related to the seventh factor. So, the factors after the seventh factor will be removed from the study, and only the first seven factors, namely environmental design, industrial ecology, redistribution, reuse, redesign, recycling, and reduction, were selected as the most important factors.

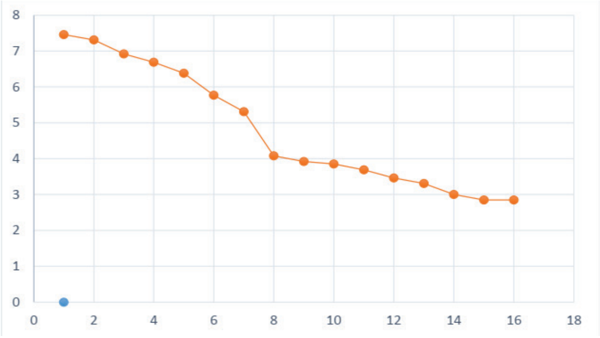


Fig. 3. Distribution of the average factors proposed by Delphi experts in the distribution diagram.

3.2. Prioritize options using fuzzy TOPSIS technique based on expert opinions

Table 4. shows fuzzy numbers and verbal expressions that are used in this research.

Table 3. Ranking of factors of CE based on the average opinions of experts in Delphi.

Average	The factor	rank
7.46	Environmental oriented design	1
7.31	Industrial ecology	2
6.92	Redistribution	3
6.69	Reuse	4
6.38	Redesign	5
5.77	Recycle	6
5.31	Reduction	7
4.08	Elimination (refuse)	8
3.92	Reproduction	9
3.85	Revisal	10
3.69	Change of Use	11
3.46	Repair	12
3.31	Rent	13
3.00	Recovery	14
2.85	Share	15
2.85	Rebuilding	16

Source: the research finding

Table 4. Fuzzy numbers and verbal expressions.

Fuzzy number	Number	verbal expression
(0,0.05,0.15)	1	Too little
(0.1,0.2,0.3)	2	Low
(0.2,0.35,0.5)	3	Relatively low
(0.3,0.5,0.7)	4	medium
(0.5,0.65,0.8)	5	Relatively high
(0.7,0.8,0.9)	6	Much
(0.85,0.95,1)	7	very much

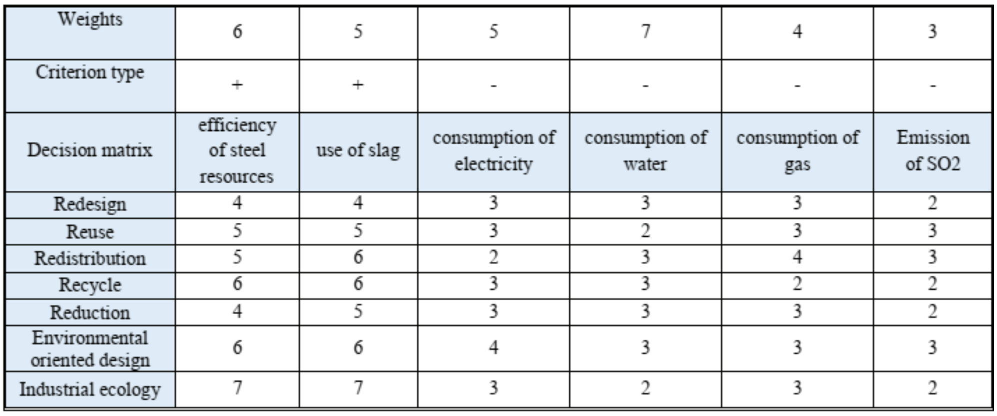
Source: the research finding

In the following, we will discuss the findings of the fuzzy TOPSIS technique.

Step 1, is to form a decision-making matrix for evaluating the options. For the TOPSIS method,9 experts collaborated, and we have a decision matrix for each one to evaluate. The weight of the criteria was selected by a survey of experts that get numbers between 1 to 7. In table 5., for example, the scores of one of the experts has been reported.

Using Table 4. and converting numbers to fuzzy numbers, a fuzzy decision matrix is created for each expert. For example, the expert fuzzy decision matrix 6 is shown in Table 6. Table 7. shows the fuzzy mean matrix of the experts.

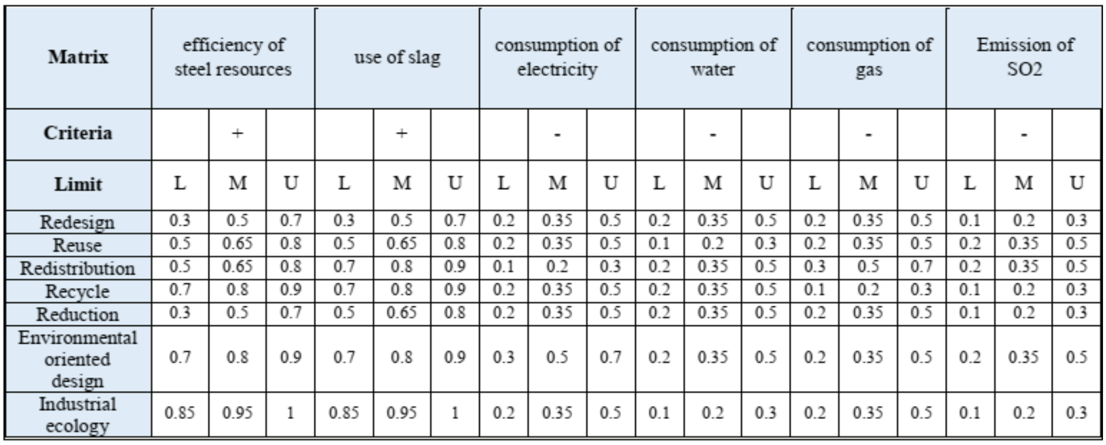
Table 5. Options Evaluation Scores (The expert number 6 Decision Matrix).



Weights	6	5	5	7	4	3
Criterion type	+	+	-	-	-	-
Decision matrix	efficiency of steel resources	use of slag	consumption of electricity	consumption of water	consumption of gas	Emission of SO2
Redesign	4	4	3	3	3	2
Reuse	5	5	3	2	3	3
Redistribution	5	6	2	3	4	3
Recycle	6	6	3	3	2	2
Reduction	4	5	3	3	3	2
Environmental oriented design	6	6	4	3	3	3
Industrial ecology	7	7	3	2	3	2

Source: the research finding

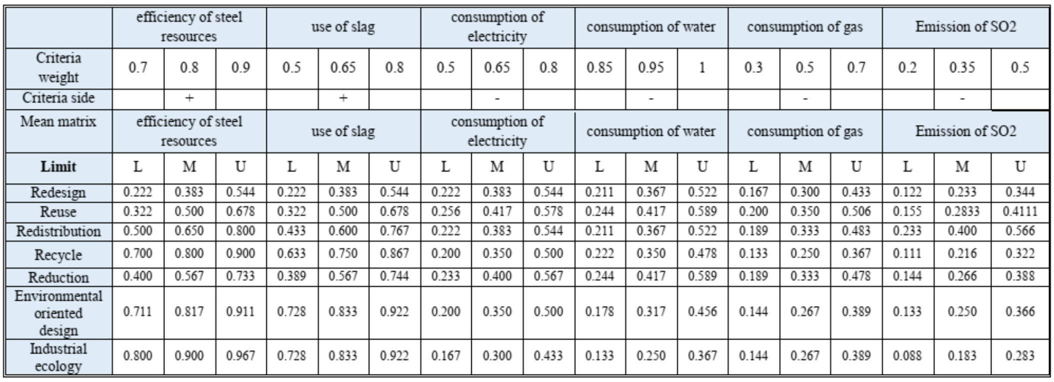
Table 6. Fuzzy scores of Evaluation Options (The expert number 6 Matrix).



Matrix	efficiency of steel resources			use of slag			consumption of electricity			consumption of water			consumption of gas			Emission of SO2		
Criteria		+			+			-			-			-			-	
Limit	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
Redesign	0.3	0.5	0.7	0.3	0.5	0.7	0.2	0.35	0.5	0.2	0.35	0.5	0.2	0.35	0.5	0.1	0.2	0.3
Reuse	0.5	0.65	0.8	0.5	0.65	0.8	0.2	0.35	0.5	0.1	0.2	0.3	0.2	0.35	0.5	0.2	0.35	0.5
Redistribution	0.5	0.65	0.8	0.7	0.8	0.9	0.1	0.2	0.3	0.2	0.35	0.5	0.3	0.5	0.7	0.2	0.35	0.5
Recycle	0.7	0.8	0.9	0.7	0.8	0.9	0.2	0.35	0.5	0.2	0.35	0.5	0.1	0.2	0.3	0.1	0.2	0.3
Reduction	0.3	0.5	0.7	0.5	0.65	0.8	0.2	0.35	0.5	0.2	0.35	0.5	0.2	0.35	0.5	0.1	0.2	0.3
Environmental oriented design	0.7	0.8	0.9	0.7	0.8	0.9	0.3	0.5	0.7	0.2	0.35	0.5	0.2	0.35	0.5	0.2	0.35	0.5
Industrial ecology	0.85	0.95	1	0.85	0.95	1	0.2	0.35	0.5	0.1	0.2	0.3	0.2	0.35	0.5	0.1	0.2	0.3

Source: the research finding.

Table 7. Expert fuzzy mean matrix



	efficiency of steel resources			use of slag			consumption of electricity			consumption of water			consumption of gas			Emission of SO2		
Criteria weight	0.7	0.8	0.9	0.5	0.65	0.8	0.5	0.65	0.8	0.85	0.95	1	0.3	0.5	0.7	0.2	0.35	0.5
Criteria side		+			+			-			-			-			-	
Mean matrix	efficiency of steel resources			use of slag			consumption of electricity			consumption of water			consumption of gas			Emission of SO2		
Limit	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
Redesign	0.222	0.383	0.544	0.222	0.383	0.544	0.222	0.383	0.544	0.211	0.367	0.522	0.167	0.300	0.433	0.122	0.233	0.344
Reuse	0.322	0.500	0.678	0.322	0.500	0.678	0.256	0.417	0.578	0.244	0.417	0.589	0.200	0.350	0.506	0.155	0.2833	0.4111
Redistribution	0.500	0.650	0.800	0.433	0.600	0.767	0.222	0.383	0.544	0.211	0.367	0.522	0.189	0.333	0.483	0.233	0.400	0.566
Recycle	0.700	0.800	0.900	0.633	0.750	0.867	0.200	0.350	0.500	0.222	0.350	0.478	0.133	0.250	0.367	0.111	0.216	0.322
Reduction	0.400	0.567	0.733	0.389	0.567	0.744	0.233	0.400	0.567	0.244	0.417	0.589	0.189	0.333	0.478	0.144	0.266	0.388
Environmental oriented design	0.711	0.817	0.911	0.728	0.833	0.922	0.200	0.350	0.500	0.178	0.317	0.456	0.144	0.267	0.389	0.133	0.250	0.366
Industrial ecology	0.800	0.900	0.967	0.728	0.833	0.922	0.167	0.300	0.433	0.133	0.250	0.367	0.144	0.267	0.389	0.088	0.183	0.283

Source: the research finding.

Step 2, converts the fuzzy decision evaluation matrix into a fuzzy non-scale matrix (Equ. 1).

$$\widetilde{R} = [\widetilde{r}_{ij}]_{m\times n} \quad i = 1,2,\ldots,m \;\; j = 1,2,\ldots,n \qquad \text{Eq. (1)}$$

m: Number of options; n: Number of experts

If the fuzzy numbers are (a, b, c), which is a scaleless (normalized) matrix, we get:

$$\widetilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \qquad \text{Eq. (2)}$$

In this equation c_j^* is the maximum value of c for the expert j among all the options. Equation 3 states this:

$$c_j^* = \max_i c_{ij} \qquad \text{Eq. (3)}$$

The results are shown in Table 8.

Step 3, creates a fuzzy weightless scale ($\widetilde{V}$):

$$\widetilde{v}_{ij} = \widetilde{r}_{ij} \otimes \widetilde{w}_j \qquad i = 1,2,\ldots,m \quad j = 1,2,\ldots,n \qquad \text{Eq. (4)}$$

In this equation, $\widetilde{r_{ij}}$ is a scaleless matrix that is obtained from step 2 and $\widetilde{w_j}$ is a fuzzy matrix of weighted factors.

The weight of the criteria was obtained based on a survey of experts, and average weight was assigned to each of the criteria. Table 9. shows the fuzzy weightless scale matrix.

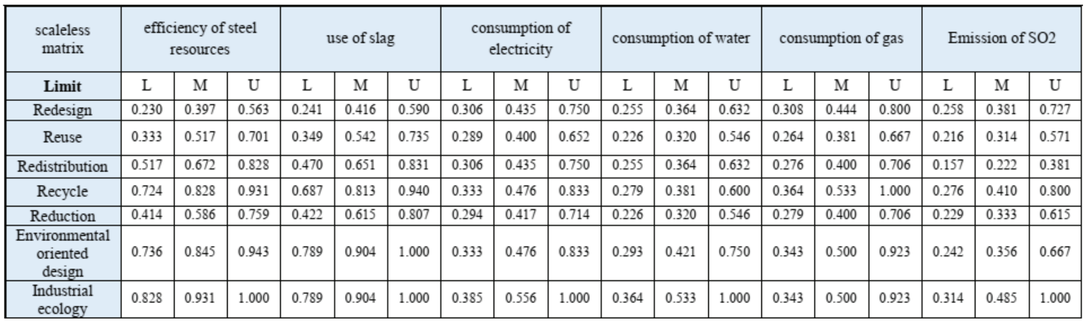
Step 4, determine the fuzzy ideal A + and the counter fuzzy ideal A- for the factors:

In this step, the positive ideal equals the largest element and the negative ideal equals the smallest element of the corresponding column. Equations 5 and 6 are used to obtain negative and positive ideals (see Table 10.).

$$A^* = (\hat{v}_1^*, \hat{v}_2^*, \ldots, \hat{v}_n^*) \; where \; \hat{v}_j^* = \left(\hat{C}_j^*, \hat{C}_j^*, \hat{C}_j^*\right) \qquad \text{Eq. (5)}$$

$$A^- = (\hat{v}_1^-, \hat{v}_2^-, \ldots, \hat{v}_n^-) \; where \; \hat{v}_j^- = \left(\hat{a}_j^-, \hat{a}_j^-, \hat{a}_j^-\right) \; and \; \hat{a}_j^- = min_i\{\hat{a}_{ij}\} \qquad \text{Eq. (6)}$$

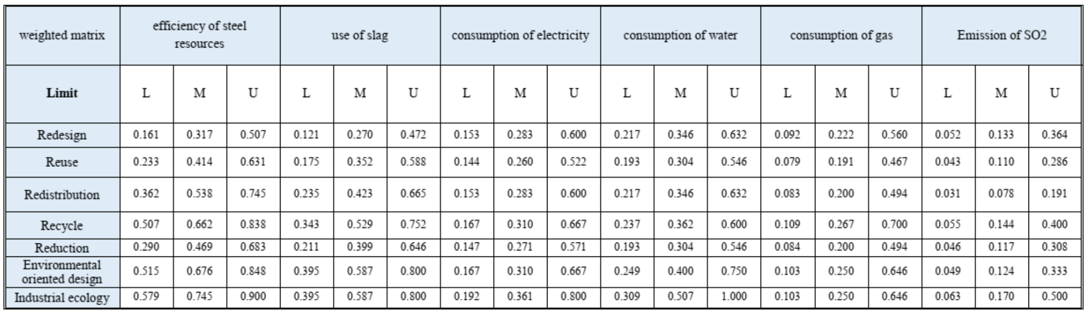
Table 8. The scaleless matrix.



scaleless matrix	efficiency of steel resources			use of slag			consumption of electricity			consumption of water			consumption of gas			Emission of SO2		
Limit	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
Redesign	0.230	0.397	0.563	0.241	0.416	0.590	0.306	0.435	0.750	0.255	0.364	0.632	0.308	0.444	0.800	0.258	0.381	0.727
Reuse	0.333	0.517	0.701	0.349	0.542	0.735	0.289	0.400	0.652	0.226	0.320	0.546	0.264	0.381	0.667	0.216	0.314	0.571
Redistribution	0.517	0.672	0.828	0.470	0.651	0.831	0.306	0.435	0.750	0.255	0.364	0.632	0.276	0.400	0.706	0.157	0.222	0.381
Recycle	0.724	0.828	0.931	0.687	0.813	0.940	0.333	0.476	0.833	0.279	0.381	0.600	0.364	0.533	1.000	0.276	0.410	0.800
Reduction	0.414	0.586	0.759	0.422	0.615	0.807	0.294	0.417	0.714	0.226	0.320	0.546	0.279	0.400	0.706	0.229	0.333	0.615
Environmental oriented design	0.736	0.845	0.943	0.789	0.904	1.000	0.333	0.476	0.833	0.293	0.421	0.750	0.343	0.500	0.923	0.242	0.356	0.667
Industrial ecology	0.828	0.931	1.000	0.789	0.904	1.000	0.385	0.556	1.000	0.364	0.533	1.000	0.343	0.500	0.923	0.314	0.485	1.000

Source: the research finding.

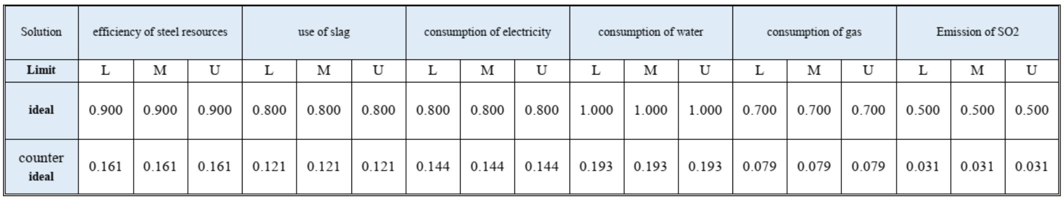
Table 9. Fuzzy weighted scaleless matrix.



weighted matrix	efficiency of steel resources			use of slag			consumption of electricity			consumption of water			consumption of gas			Emission of SO2		
Limit	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
Redesign	0.161	0.317	0.507	0.121	0.270	0.472	0.153	0.283	0.600	0.217	0.346	0.632	0.092	0.222	0.560	0.052	0.133	0.364
Reuse	0.233	0.414	0.631	0.175	0.352	0.588	0.144	0.260	0.522	0.193	0.304	0.546	0.079	0.191	0.467	0.043	0.110	0.286
Redistribution	0.362	0.538	0.745	0.235	0.423	0.665	0.153	0.283	0.600	0.217	0.346	0.632	0.083	0.200	0.494	0.031	0.078	0.191
Recycle	0.507	0.662	0.838	0.343	0.529	0.752	0.167	0.310	0.667	0.237	0.362	0.600	0.109	0.267	0.700	0.055	0.144	0.400
Reduction	0.290	0.469	0.683	0.211	0.399	0.646	0.147	0.271	0.571	0.193	0.304	0.546	0.084	0.200	0.494	0.046	0.117	0.308
Environmental oriented design	0.515	0.676	0.848	0.395	0.587	0.800	0.167	0.310	0.667	0.249	0.400	0.750	0.103	0.250	0.646	0.049	0.124	0.333
Industrial ecology	0.579	0.745	0.900	0.395	0.587	0.800	0.192	0.361	0.800	0.309	0.507	1.000	0.103	0.250	0.646	0.063	0.170	0.500

Source: the research finding.

Table 10. Fuzzy ideal and counter fuzzy ideal.



Solution	efficiency of steel resources			use of slag			consumption of electricity			consumption of water			consumption of gas			Emission of SO2		
Limit	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
ideal	0.900	0.900	0.900	0.800	0.800	0.800	0.800	0.800	0.800	1.000	1.000	1.000	0.700	0.700	0.700	0.500	0.500	0.500
counter **ideal**	0.161	0.161	0.161	0.121	0.121	0.121	0.144	0.144	0.144	0.193	0.193	0.193	0.079	0.079	0.079	0.031	0.031	0.031

Source: the research finding.

Step 5, calculates sum of the distances of the options from fuzzy ideal to counter fuzzy ideal:

If $\tilde{A}$ and $\tilde{B}$ are two fuzzy numbers as follows, then the distance between these two fuzzy numbers is obtained by Equation 7.

$$\widetilde{A} = (a_1, a_2, a_3)$$

$$\widetilde{B} = (b_1, b_2, b_3)$$

$$D(\widetilde{A}, \widetilde{B}) = \sqrt{\frac{1}{3}[(a_2 - a_1)^2 + (b_2 - b_1)^2 + (c_2 - c_1)^2]} \qquad \text{Eq. (7)}$$

According to the above explanations on how to calculate the distance between two fuzzy numbers, we get the distance of each component from the ideal and the counter ideal (equations 8 , 9):

$$d_i^* = \sum_{j=1}^{n} d(\widetilde{v}_{ij} - \widetilde{v}_{ij}^*) \qquad i = 1,2,\ldots,m \qquad \text{Eq. (8)}$$

$$d_i^- = \sum_{j=1}^{n} d(\widetilde{v}_{ij} - \widetilde{v}_{ij}^-) \qquad i = 1,2,\ldots,m \qquad \text{Eq. (9)}$$

Table11. calculates the distance of each option to the ideal solution.

Table12. shows the distance between the options and the counter-ideal.

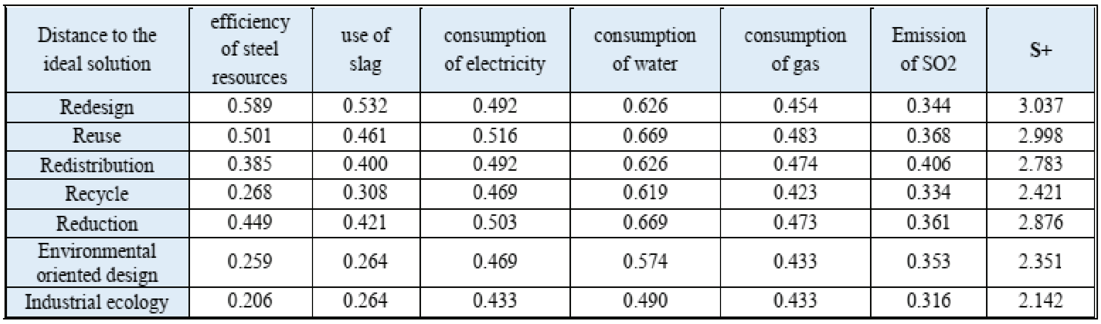
Step 6, calculates the Relative Proximity of the i^th^ option from the Ideal solution as follows:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \qquad i = 1,2,\ldots,m \qquad \text{Eq. (10)}$$

Table13. shows the relative similarity or closeness.

Step 7, ranks the options in descending order. Any option with a larger similarity index (CC) is a better choice. Table14. shows the final ranking.

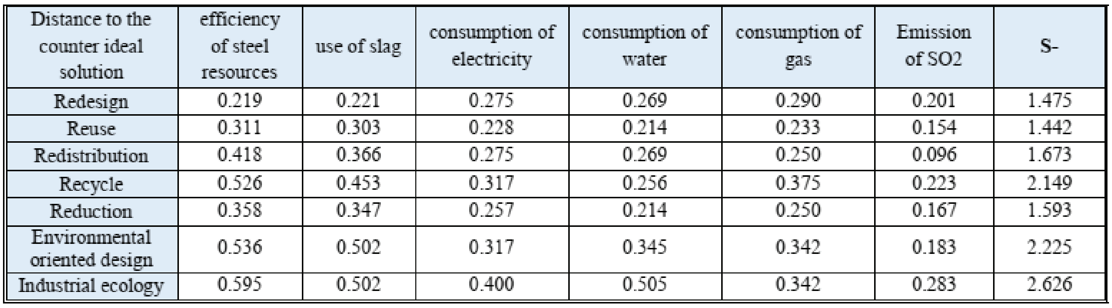
Table 11. Distance to the ideal solution.



Distance to the ideal solution	efficiency of steel resources	use of slag	consumption of electricity	consumption of water	consumption of gas	Emission of SO2	S+
Redesign	0.589	0.532	0.492	0.626	0.454	0.344	3.037
Reuse	0.501	0.461	0.516	0.669	0.483	0.368	2.998
Redistribution	0.385	0.400	0.492	0.626	0.474	0.406	2.783
Recycle	0.268	0.308	0.469	0.619	0.423	0.334	2.421
Reduction	0.449	0.421	0.503	0.669	0.473	0.361	2.876
Environmental oriented design	0.259	0.264	0.469	0.574	0.433	0.353	2.351
Industrial ecology	0.206	0.264	0.433	0.490	0.433	0.316	2.142

Source: the research finding.

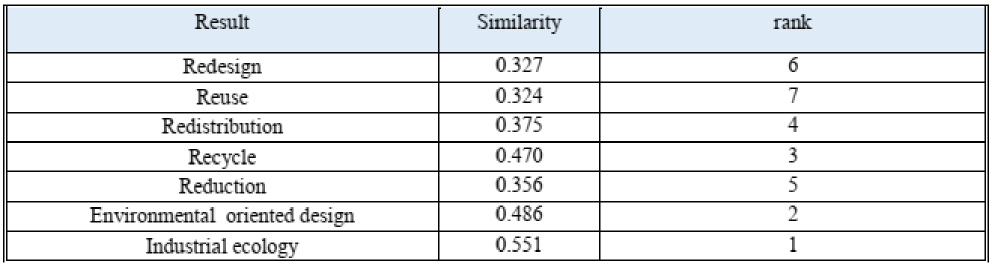
Table 12. Distance to the counter ideal solution.



Distance to the counter ideal solution	efficiency of steel resources	use of slag	consumption of electricity	consumption of water	consumption of gas	Emission of SO2	S-
Redesign	0.219	0.221	0.275	0.269	0.290	0.201	1.475
Reuse	0.311	0.303	0.228	0.214	0.233	0.154	1.442
Redistribution	0.418	0.366	0.275	0.269	0.250	0.096	1.673
Recycle	0.526	0.453	0.317	0.256	0.375	0.223	2.149
Reduction	0.358	0.347	0.257	0.214	0.250	0.167	1.593
Environmental oriented design	0.536	0.502	0.317	0.345	0.342	0.183	2.225
Industrial ecology	0.595	0.502	0.400	0.505	0.342	0.283	2.626

Source: the research finding.

Table 13. Relative similarity or closeness.



Result	Similarity	rank
Redesign	0.327	6
Reuse	0.324	7
Redistribution	0.375	4
Recycle	0.470	3
Reduction	0.356	5
Environmental oriented design	0.486	2
Industrial ecology	0.551	1

Source: the research finding.

Table 14. Final ranking of options.

Result	S+	S-	Similarity	Rank
Industrial ecology	2.142	2.626	0.551	1
Environmental oriented design	2.351	2.225	0.486	2
Recycle	2.421	2.149	0.470	3
Redistribution	2.783	1.673	0.375	4
Reduction	2.876	1.593	0.356	5
Redesign	3.037	1.475	0.327	6
Reuse	2.998	1.442	0.324	7

Source: the research finding.

Finally, the results of ranking the options with the fuzzy TOPSIS technique indicate that the “Industrial ecology “ and “environmental oriented design” have higher priority than the others.

4.Conclusion

Our study was conducted at Mobarakeh Steel Company, which seeked to determine and prioritize the factors affecting the RSC, in order to implement the CE in the company. Research questions answed in this paper were, what are the most important factors of the CE in Mobarakeh Steel Company? How important are they from the perspective of the company experts? How do these factors relate to each other?

The initial factors related to the CE were extracted from the research literature. Which were elimination (Refuse), redesign, revisal (Rethink), reduction, reuse, repair, rebuild (Refurbish), reproduction (Remanufacture), change of use (Repurpose), recycle, recovery, sharing, redistribution (Redistributed Manufacturing), rent, environmental oriented design (Environmentally Based Design), and Industrial Ecology.

The final factors for the company were extracted using the Delphi method and the expert’s experiences. By this method, only the first seven important factors, namely environmental design, industrial ecology, redistribution, reuse, redesign, recycling, and reduction, were selected as the agreed factors.

Then these factors were ranked in the CE of the industry using the TOPSIS method. The criteria used to rank the factors were extracted from library studies. These criteria are related to the iron and steel industry, and their list was finalized in consultation with the experts of the Steel Company. The final list consists of six criteria namely, efficiency of steel resources, slag use, electricity consumption, water consumption, gas consumption, and SO2 emissions. The priority order that was obtained is 1. Industrial ecology, 2. Environmental design, 3. Recycling, 4. Redistribution, 5. Reduction, 6. Redesign and 7. Reuse. Then, using the “Panel of Experts” method, the relationship of these factors in the RSC to achieve a CE was determined. For this purpose, the standard model IDEF0 was used. IDEF0, is an auxiliary tool for identifying, determining the interaction between processes, and mapping them. In this model, the process is shown in the center of a rectangle, inputs enter from the left, the mechanisms come from the bottom, and the controls are added from the top as arrows, and the outputs exit from the left (have a look at fig. 4).

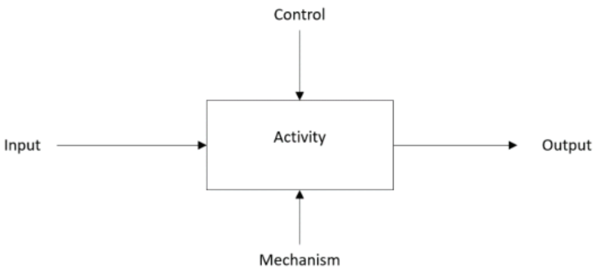


Fig. 4. A general IDEF0 model.

Using IDEF0 model, the identified factors by the panel of experts were examined and their relationships were determined. The following diagram (Fig. 5) shows the factors affecting the RSC in Mobarakeh Steel Company according to IDEF0 model.

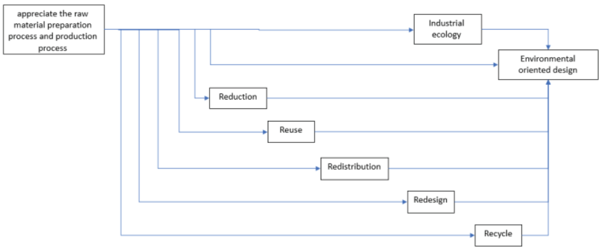


Fig. 5. IDEF0 Model of RSC Factors in Mobarakeh Steel Company.

In this model, first of all, the “appreciation of the production and raw material preparation processes” is needed as an input for the “Industrial ecology”. Then, based on the opinion provided by the panel of experts, the output of the “Industrial Ecology” is used as a control for the "Environmental Design". Other enumerated factors have also been used as mechanisms for the "environmental design". Thus, the results of this research indicate that, first of all, the activity "industrial ecology" should be determined. Then the output of this activity, as a control (control factor) and the output of the other factors of CE (recycling, redesign, etc.) as mechanisms, should enter the "environmental design".

In comparison with other researches, we determined more factors. For instance, Gu et al. (2021) defined collection, recycling, and reusing of scrapped metals in the iron and steel industry[24]. However, they focused on broad criteria such as economic, social, environmental, government policy, internal management practices, and external market competition, while our focus is on the technical criteria such as steel resources, slag use, electricity consumption, water consumption, gas consumption, and SO_2 emissions. Moreover, our paper is the first attempt to configure the model of RSC factors in a steel company.

For further research, we suggest that the relationships between the factors in figure 5 are investigated.

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