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Development of network-ranking modeling in planning effective efficiency of multi-stage production industries value chain: A case study of textile industry

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In order to manage the organization, in n-stage production industries it is important to know whether it is better that, in any of the n-stages of production, a semi-manufactured good is directly sold in the market or it is allowed that completely manufactured good is sent to market at the end of chain. Which of them will have effective efficiency and more profit? Also, it is of great importance for the macro-level planners, in order to strengthen the internal productions against imports and also to gradually create a brand and empower it to gain sustainable competitive advantage in any stage of goods exports. Presented model, formulated through linear programming, can evaluate and assess the strategy of pure profit management by efficiency based on each of production stages work stations (White Box). In fact, a network-ranking model is considered for multi-stage series processes using collective performance analysis to p-stage processes. The ideal decision unit could reach the efficiency of 1 due since it consists of production stations whose efficiencies are 1. With this decision unit, a set of improvement strategies for all 10 understudy production stations can be suggested. It can be claimed that the suggested strategies are based on reality. When two or more networks have the same efficiency, they can be ranked by means of this ideal decision unit.

Keywords: Value chain; Data envelopment analysis (DEA); Ideal decision making unit; Network- Ranking models; Linear Programming

INTRODUCTION

Value chain is usually defined as a network of units that interrelate in different forms. Supplying the demands and organizational sources optimally is among the most important reasons for formation of value chain so that by the management section would be able to guarantee the organization survival, to reach the area of benefit, and gradually create the growth in profits. To achieve this goal, making use of DEA is of paramount importance [14].

In traditional DEA the decision units are taken into consideration as a black box (Charnes et al. [5]) in a way that internal structures of units are often ignored and the performance of a decision unit is determined merely in terms of its inputs and outputs [4].

In many cases it is possible decision units have network structures. Network structures are common in process industries. In the previously conducted studies some attempts have been made to calculate the efficiency based on a network viewpoint. In some of them the relative efficiency of decision unit stages has been calculated by a non-linear model, cf. Liang et al. [15].

A set of examples might be mentioned in terms of production in industry and even services centers in which each system is formed of some sub systems and these sub systems has different inputs and outputs. During this process it might happen that in the intermediate stages the decision unit enters directly from outside into the intermediate stages or gets out it, cf. Kao&Hwang [13]. The advantage of this view point is, in fact, a meticulous exact look at decision units. It, in fact, makes it possible for the decision maker to make a more appropriate decision because in this type of analysis, the efficiency of decision units and different stages are compared with similar units and stages in other comparable units and their relative efficiency is offered as well. To put it clearly, in this analysis, the Achilles heel of units will be identified [18]. Moreover, by using this type of analysis it will be possible to suggest some strategies to improve the units in a way that by considering their inputs and outputs we can suggest effective strategies to increase their efficiency [19].

In order to reach the intended pattern, in these improvement strategies we can offer the suitable amount of input and output [18]. Another advantage of the model is that the efficiency of each unit is formed from the sum efficiency of stages or its forming sections. Thus, the sum of their efficiency, like the traditional models, will be between $\mathbf{0} \leq \boldsymbol{E} \leq \mathbf{1}$. Different applications can be mentioned for this approach [13].

The models offered after the classic ones made tremendous attempts to remove the weaknesses of the previous models. For example, the Andersen and Petersen efficient units ranking can be mentioned. This model ranks the efficient units. In other words,

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by removing the restrictions related to decision unit, it ranks the units whose efficiencies were 1 in the classic models. While this strategy applies in most of cases, in cases where units have a zero input this model encounters an unanswerable question [1].

In a similar vein, different attempts have been made to cover the weaknesses of zero inputs. For example, Chen's articles [3] and Cook et al. research article [9] can be mentioned. Besides, Lee &Zhu [16] offered a new strategy for zero inputs. In their proposed model, titled super-efficiency models tried to rank the efficient units with zero input. Although these approaches could effectively deal with the weakness of classic models in ranking, but other weaknesses and criticisms were still present.

Another approach that tried to cover all the criticisms was the ideal decision making unit. It tries to create an ideal unit to make a pattern for all units ranging from efficient or inefficient ones. This approach especially tried to deal with the inefficiency of efficient units. An important question is available concerning inefficiency of efficient units: why efficient units are good patterns for other units but they themselves lack any improvement pattern? In other words, why should not offer patterns and strategies for patterns and their improvements [2]? In fact, in these models, the efficient units are like machines that merely smooth the path for improvement of other units and move them toward efficiency but no strategy is offered by traditional DEA approaches to improve these efficient units [20]. From another perspective, it sometimes happened in reality that even patterns could not satisfy the managers and shareholders. That is, sometimes the efficient units failed to reach the real determined goals. It means that though efficient units had a relative efficiency 1 in comparison to other units, they could not be regarded as successful patterns that have always achieved the goals and wishes of managers, shareholders, and elites. Thus, in order to take into consideration the opinions of managers and elites about the efficient units, the approach of creating an ideal decision making unit was proposed by Jahanshahloo et al. [11]. Although it was a good response to proposed criticisms about the classic models, but it caused a set of new criticisms. That how and based on what criteria this ideal unit should be created so that it is neither strict nor easy was one of new criticisms. Furthermore, Human interferences were also another weakness and criticism.

On the other hands, in the real world, most of the companies that make use of these types of models for improvement purposes face some problems. They argue that the strategies offered by ideal virtual units to reach the efficiency frontier are not feasible in reality. That is why; it was a dream for these companies to reach an ideal unit for inefficient units. Given this justification that if these goals, views, and wishes were achievable, the current decision units had achieved them, Jahanshahloo et al. [12].

Stewart [17] in his article examined the ideals using the **“**Chebyshev scalarizing function**”**. According to the model suggested by him, if these ideals are within the feasible space, they are drawn on the border of feasible space. Some criticisms are made to this model as well. For example, the ideals made by humans for this model are in fact a weak point for it. Moreover, the existence of ideals within the feasible space is meaningless and although it has defined a set of ideals and strategies for current patterns, their being virtual is still open to discussion. Additionally, these models cannot rank the units and only offer improvement strategies and patterns for the units. It should also be pointed out that in the mentioned study some ideals are introduced that are within the recent feasible space meaning that some ideals are sometimes defined for the decision units that those units have reached more achievements than that and now those ideals consider less accomplishments. This is, in itself, a serious criticism to this model in the sense that how could it be that an ideal is within the recent feasible space.

Accordingly, in the present paper a network model was designed in a way that not only has the ranking capability of units, but also offers some improvement strategies for them and patterns which, in turn, makes it possible for the decision unit to reach more achievements than the present ones. This model, in fact, evaluates different scenarios based on duty-oriented management and also the units and stations in each production stage (internal evaluation). It, then, leads to more achievements than present possible space based on separate stages and finally highlights the production for management decision makings at the end of different stages.

MODELING

This model is formulated through linear programming in a way that can evaluate and assess the strategy of pure profit management by efficiency that is based on each of production stages work stations (white box). In fact, network models are taken into account for multi-stage series processes using collective performance analysis to p-stage process.

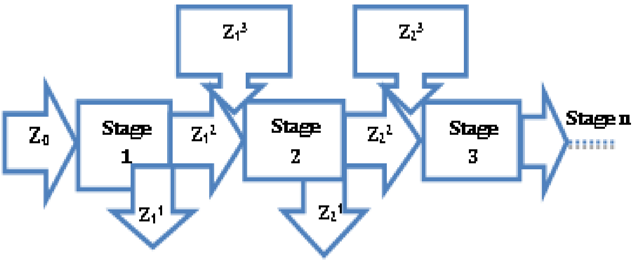

Fig. 1. Network Model.

According to figure 1, the input vector of stage 1 is represented by Z_0. The output vectors from p stage (P=1,2,…,p) are of two types: Z_P^1 and Z_P^2 . In figure 1, Z_P^1indicates the output that has moved out of decision unit in p stage and thus does not entered into next stage as an input. $Z_P^2$is the output that has moved out from the p stage and enters into the P+1 stage as an input. The new inputs shown with Z_P^3 are those that directly from the capacitor enter the P+1 stage (P=2,3,..,p).

MODEL FORMULATION

1. Z_{pr}^{j1} the r component that (r=1,2,…,R$_p$)is the output vector of R$_p$ dimension of DMU_j that exits p stage and does not enter the subsequent stage as input.

2. Z_{pk}^{j2} the k component that (k=1,2,…,S$_p$) is the output vector of S$_p$dimension of DMU_j that exits from the p stage and goes into the p+1 stage as input.

3. Z_{pi}^{j3} the i component (i=0,1,2,…,i$_p$) of input vector I$_p$ dimension of DMU_j in the p+1 stage that enters into the process.

The following coefficients are taken into account for the above-mentioned factors:

U_{pr} : is the coefficient component of output Z_{pr}^{j1}that exits from stage p.

η_{px}: is the coefficient component of output Z_{pk}^{j2}in stage p and also the multiple of the same component that goes into stage p+1 as input.

V_{pi} :is the coefficient component of input Z_{pi}^{j3} that moves into stage p+1. Thus, when p=2,3,…, the ratio of DMU_j efficiency is as follow:

$$, (1)\theta_p = \frac{(\sum_{r=1}^{R_p} U_{pr} Z_{pr}^{j1} + \sum_{k=1}^{S_p} \eta_{pk} Z_{pk}^{j2})}{(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} Z_{p-1k}^{j2} + \sum_{i=1}^{I_p} V_{p-1i} Z_{p-1i}^{j3})}$$

It should be noted that there is no output that is entered into the first stage. The efficiency for the first stage that is p=1 for DMU_j is as follow:

$$, (2)\theta_1 = \frac{(\sum_{r=1}^{R_1} U_{1r} Z_{1r}^{j1} + \sum_{k=1}^{S_1} \eta_{1k} Z_{1k}^{j2})}{\sum_{i=1}^{I_0} V_{0i} Z_{0i}^{j}}$$

Z_{oi} are the only inputs that enter the first stage and the input vector is shown by Z_o . The claim is that the whole efficiency of the network is obtained by the component P convex linear combination.

Note that the weights of W_p are offered for showing the relative importance of each stage to the whole network. An approach of determining W_p is the total amount of sources that is allocated to each p stage and reveals that stage relative importance. Specifically, the sum of above-cited fractions denominator indicates the total consumption of network in figure 1 and W_p in it represents the ratio of consumed input in the p stage.

$$W_1 = \frac{\sum_{i=1}^{I_0} V_{0i} Z_{0i}^{j}}{\sum_{i=1}^{I_0} V_{0i} Z_{0i}^{j} + \sum_{p=2}^{P}(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} Z_{p-1k}^{j2} + \sum_{i=1}^{I_p} V_{p-1i} Z_{p-1i}^{j3})}, \quad (3)$$

Therefore, the total efficiency is calculated as follows:

$$W_p = \frac{(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} Z_{p-1k}^{j2} + \sum_{i=1}^{I_p} V_{p-1i} Z_{p-1i}^{j3})}{\sum_{i=1}^{I_0} V_{0i} Z_{0i}^{j} + \sum_{p=2}^{P}(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} Z_{p-1k}^{j2} + \sum_{i=1}^{I_p} V_{p-1i} Z_{p-1i}^{j3})} \quad (4)$$

Also, θ is showing the relative efficiency of each stage.

$$\theta = \frac{\sum_{p=1}^{P}(\sum_{r=1}^{R_p} U_{pr} Z_{pr}^{j1} + \sum_{k=1}^{S_p} \eta_{pk} Z_{pk}^{j2})}{\sum_{i=1}^{I_0} V_{0i} Z_{0i}^{j} + \sum_{p=2}^{P}(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} Z_{p-1k}^{j2} + \sum_{i=1}^{I_p} V_{p-1i} Z_{p-1i}^{j3})}, \quad (5)$$

Now for optimization of the total efficiency of θ - a multi-stage process dependent on restrictions that $\theta_p$should not be more than 1- the non-linear models are changed into linear ones using Charnes & Cooper. Again, it should be noted that W_p is not fixed.

In Charnes and Cooper's model, there are three ways to increase the output/input fraction:

1. While the fraction denominator is fixed, its numerator increases

2. While the fraction numerator is fixed, its denominator decreases

3. While the fraction numerator increases, its denominator decreases.

Charnes et al. [5] consider the fraction denominator of θ a fixed number that is generally 1 and try to increase the fraction numerator in the objective function. That is:

$$max = \sum_{p=1}^{P}(\sum_{r=1}^{R_p} U_{pr} Z_{pr}^{01} + \sum_{k=1}^{S_p} \eta_{pk} Z_{pk}^{02}), \quad (6)$$

$$s.t:$$

$$\sum_{i=1}^{I_0} V_{0i} Z_{0i}^{0} + \sum_{p=2}^{P}(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} Z_{p-1k}^{02} + \sum_{i=1}^{I_p} V_{p-1} Z_{p-1i}^{03}) = 1, \quad (7)$$

$$(\sum_{r=1}^{R_1} U_{1r} Z_{1r}^{j1} + \sum_{k=1}^{S_1} \eta_{1k} Z_{1k}^{j2}) \le \sum_{i=1}^{I_0} V_{0i} Z_{0i}^{j}, \quad (8)$$

$$\left(\sum_{r=1}^{R_1} U_{pr} Z_{pr}^{j1} + \sum_{k=1}^{S_p} \eta_{pk} Z_{pk}^{j2}\right) \leq \left(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} Z_{p-1k}^{j2} + \sum_{i=1}^{I_p} V_{p-1i} Z_{p-1i}^{j3}\right) \quad (9)$$

$$U_{pr}, \eta_{pk}, V_{pi}, V_{oi} > 0$$

*The first restriction (relation 7) is the inputs in the fraction denominator of θ.

** The second restriction (relation 8) is related to W_1 amount that cannot be more than 1 and for the whole efficiency not to be over 1, the stages' weights are considered less than or equal to 1. That is, by considering the fraction of θ_1, this restriction is resulted.

*** The third restriction (relation 9) is related to W_p resulted from considering θ_p less than or equal to 1.

CASE STUDY

Due to the fact that the case study is the textile Industry Value Chain, we do the evaluation process of this industry, described by empirical-scientific experts (elites) like figure 2, based on an innovative model of network data envelopment analysis. Furthermore, because the defined value chain comprises four stages of spinning, weaving, dyeing and finishing, and clothe production (men clothe) and each stage consists of a set of different working stations, we just study the dyeing and finishing unit that, according to figure 3, entails seven different stations with 10 types of production(various production scenarios). The model, in fact, evaluates the different scenarios on the basis of task-oriented management and in terms of the units or working stations within each stage of production process (introvert evaluation).

As it is clear the fabric dyeing and finishing process involves seven working stations in which the output of each station is the input of next station. At the beginning of this network and from outside of the network, serge raw fabric network is injected into the network. This fabric enters the perez fires Station after being **Inspected** and darned. Then after being perez fired, it enters the next station that is crabbing. The output of this station moves into the **cleanup** station and its output would be washed fabric. Then this washed fabric enters into the fifth station that is carbonized station. In the next stage, the carbonized fabric goes into the dyeing station for

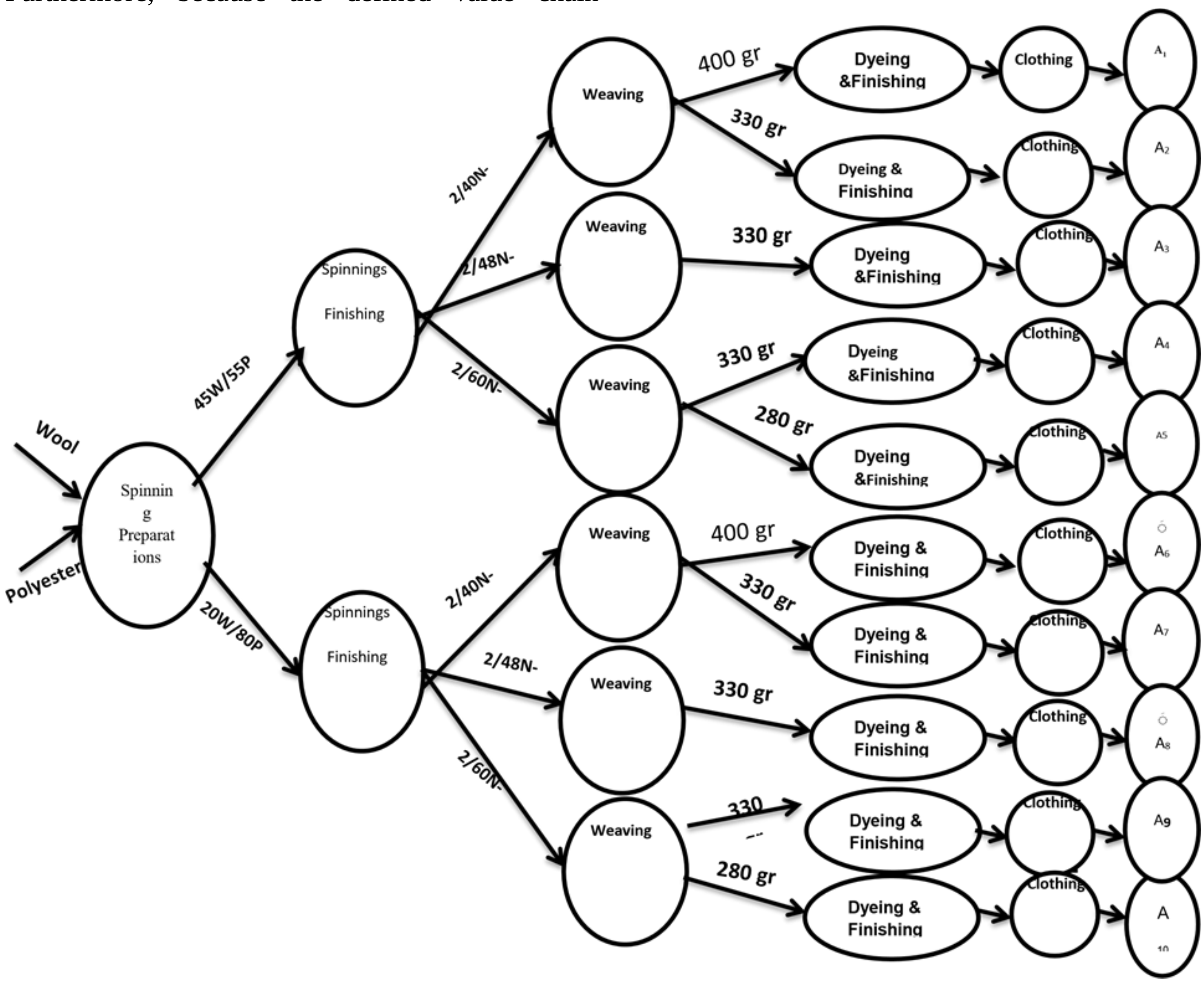

Fig. 2. Multiple scenarios/ Flowchart of production line (From A_1 to A_{10})

the purpose of designing and finally, the fabric enters into the seventh stage for the purpose of ironing and **packaging**. At the end of this network the finished fabric gets out of network. Table 1 shows this network figures for the 10 stations.

Now given the figures in Table 1 and also with regard to model 1, we deal with the evaluation of the 10 production stations. Table 2 represents the efficiency of each of these production stations and the weight of each station in the whole efficiency evaluation is also determined. In this table, θ_i represents the efficiency of each station that because this network consists of seven stations, i is between 1 to 7 (i= 1,2,…,7). Moreover, W_i indicates the weight of each of the stations efficiency. It should be noted that θ represents the whole efficiency of each of 10 working stations resulted from multiplying the efficiency weight of each station to the efficiency of the same station.

As Table 2 reveals, none of the dyeing and finishing production line could reach efficiency 1 and the reason is that there was no network that could reach efficiency 1 in all production stations. Though the number 2 production line could reach efficiency 1 in six of working stations, its whole efficiency was not 1 because it could not reach this efficiency in the sixth station.

This section deals with the ideal decision unit creation. Although this unit is virtual meaning that such a network did not really exist in the evaluation process, it is however real too in that it consists of real units. In the following section the way these units were created are described by Tables 3 and 4.

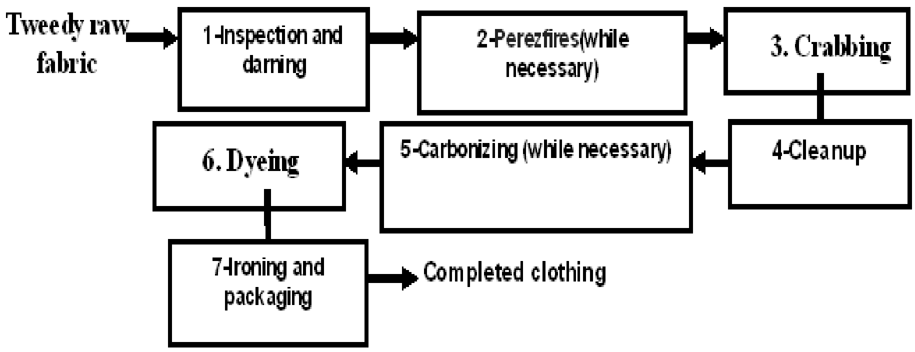

Fig. 3. Working stations of dyeing and finishing stage of fabric production (Men clothes).

Table 1. Input and output figures for the third production stage (Finishing and Dyeing)

Scenarios	1-Inspection and darning		2-Perez firing		3-crabbing		4-Washing		5-Carbonizing		6-Dyeing		7-Ironing and packaging	
	Input	Output	Input	Output	Input	Output	Input	Output	Input	Output	Input	Output	Input	Output
	Serge Raw Fabric	Controlled Fabric	Controlled Fabric	Perez fired Fabric	Perez fired Fabric	Crabbed Fabric	Crabbed Fabric	Washed Fabric	Washed Fabric	Carbo-nized Fabric	Carboniz ed Fabric	Washed Fabric	Dyed Fabric	Finished Fabric
A_1	10.5	10.725	10.725	10.95	10.95	11.355	11.355	11.715	11.715	12.075	12.075	14.775	14.775	15
A_2	8.6	8.785	8.785	8.97	8.97	9.303	9.303	9.599	9.599	9.895	9.895	12.115	12.115	12.3
A_3	11.2	11.44	11.44	11.68	11.68	12.112	12.112	12.496	12.496	12.88	12.88	15.76	15.76	16
A_4	12.2	12.46	12.46	12.72	12.72	13.188	13.188	13.604	13.604	14.02	14.02	17.14	17.14	17.4
A_5	10.5	10.72	10.72	10.94	10.94	11.336	11.336	11.688	11.688	12.04	12.04	14.68	14.68	14.9
A_6	3.8	3.88	3.88	3.96	3.96	4.104	4.104	4.232	4.232	4.36	4.36	5.32	5.32	5.4
A_7	3.1	3.165	3.165	3.23	3.23	3.347	3.347	3.451	3.451	3.555	3.555	4.335	4.335	4.4
A_8	4	4.08	4.08	4.16	4.16	4.304	4.304	4.432	4.432	4.56	4.56	5.52	5.52	5.6
A_9	4.4	4.49	4.49	4.58	4.58	4.742	4.742	4.886	4.886	5.03	5.03	6.11	6.11	6.2
A_{10}	3.8	3.88	3.88	3.96	3.96	4.104	4.104	4.232	4.232	4.36	4.36	5.32	5.32	5.4

Table 2. The efficiency of production network stations in dyeing and finishing stage of value chain production

		θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	w_1	w_2	w_3	w_4	w_5	w_6	w_7
A_1	0.98091	0.9999187	0.999220	0.9998675	0.9998899	0.9998905	0.807057	0.9999587	0.149	0.131	0.14	0.191	0.113	0.098	0.178
A_2	0.97267	1	1	1	1	1	0.8075588	1	0.138	0.168	0.128	0.127	0.164	0.142	0.133
A_3	0.98091	0.9999187	0.999220	0.9998675	0.9998899	0.9998905	0.807057	0.9999587	0.118	0.17	0.134	0.119	0.148	0.168	0.143
A_4	0.973668	0.9998044	0.999812	0.9996806	0.997346	0.9997504	0.8063557	0.9999004	0.14	0.21	0.137	0.084	0.133	0.134	0.162
A_5	0.971697	0.9994525	0.999474	0.9991069	0.9992575	0.9993014	0.8041988	0.9997203	0.076	0.193	0.148	0.134	0.175	0.142	0.132
A_6	0.973445	0.9995507	0.999569	0.9992671	0.9993908	0.9994269	0.8048019	0.9997708	0.13	0.138	0.146	0.176	0.129	0.134	0.147
A_7	0.953147	0.9994676	0.999489	0.9991314	0.9992779	0.9993206	0.8042912	0.9997281	0.142	0.138	0.159	0.1	0.167	0.145	0.149
A_8	0.959795	0.9077456	0.998579	0.9975814	0.9979862	0.9981028	0.8352576	0.9992341	0.139	0.159	0.137	0.127	0.142	0.159	0.137
A_9	0.998000	0.989652	0.999006	0.9983102	0.998594	0.9986762	1	0.9994678	0.108	0.176	0.143	0.133	0.155	0.148	0.137
A_{10}	0.973445	0.9995507	0.999569	0.9992671	0.9993908	0.9994269	0.8048019	0.9997708	0.13	0.138	0.146	0.176	0.129	0.134	0.147

Table 3.

Scenarios	1-Inspection and darning		2-Perez firing		3-crabbing		4-Washing		5-Carbonizing		6-Dyeing		7-Ironing and packaging	
	Input	Output	Input	Output	Input	Output	Input	Output	Input	Output	Input	Output	Input	Output
	Serge Raw Fabric	Controlled Fabric	Controlled Fabric	Perez fired Fabric	Perez fired Fabric	Crabbed Fabric	Crabbed Fabric	Washed Fabric	Washed Fabric	Carbonized Fabric	Carbonized Fabric	Washed Fabric	Dyed Fabric	Finished Fabric
A_9											5.03	6.11		
A_2	8.6	8.785	8.785	8.97	8.97	9.303	9.303	9.599	9.599	9.895			12.115	12.3

Table 4.

Scenarios	1-Inspection and darning		2-Perez firing		3-crabbing		4-Washing		5-Carbonizing		6-Dyeing		7-Ironing and packaging	
	Input	Output	Input	Output	Input	Output	Input	Output	Input	Output	Input	Output	Input	Output
	Serge Raw Fabric	Controlled Fabric	Controlled Fabric	Perez fired Fabric	Perez fired Fabric	Crabbed Fabric	Crabbed Fabric	Washed Fabric	Washed Fabric	Carbonized Fabric	Carbonized Fabric	Washed Fabric	Dyed Fabric	Finished Fabric
Ideal DMU	8.6	8.785	8.785	8.97	8.97	9.303	9.303	9.599	9.599	9.895	5.03	6.11	12.115	12.3

CONCLUSION

Based on the information in Table 2 obtained from Lingo software, the ideal scenario is created from combination of two A_2 and A_9 in Table 4 (More achievements from the present possible space) and as it is obvious, the ideal decision unit could reach the efficiency of 1 due to the fact that it consists of production stations whose efficiencies are 1. Additionally, by means of this decision unit it would be possible to suggest a set of improvement strategies for all 10 understudy production stations. These strategies are on the basis of this ideal decision unit. Thus, it can be claimed that the suggested strategies are based on reality. Furthermore, in the case where there of two or more networks having the same efficiency, they can be ranked by means of this ideal decision unit. This conclusion indicates a set of differences compared to other value chain models as follows:

1. Achievements more than the institution present possible space

2. This model was designed based on DEA model (network-ranking) to reach pure benefit management strategy through effective efficiency

3. This model designs the pure benefit management strategy in stage and integrative ways. Therefore, In the analysis and managerial decisions it will be possible to determine whether a part of produced items up to a specific stage should be sold directly as a Semi manufactured item or let the remaining stages be done to make more added value.

4. In designing this model, n types of factory (in the case study, four types of weaving, spinning, finishing, dyeing, and clothing production) which often work separately, are taken into consideration both separately and integrated.

5. It has the capability of evaluation and measurement in meticulous ways (different working stations of each stage) and also evaluation and measurement of efficiency between different production stages (process-based perspective).

SUGGESTIONS FOR FURTHER RESEARCH

1. The same process can also be carried out in ideal decision unit production of parallel network models.

2. Experts and elites' standpoints in the form of goal programming can be used while creating an ideal decision unit.

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