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Uncertain model of industrial clusters for the optimal arrangement of co-operation networks under sustainable and dynamic conditions

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Abstract. Industrial clusters are one of the most current development models. The aggregation of firms in a geographical area has many advantages, such as cost reduction, better supply, and knowledge emission with linkage together. The linkage result will be created in the networks. Industrial clusters without co-operation networking will not be developed. That must be noticed due to severe changes in business environment parameters. Therefore, this paper develops an uncertain mathematical model under sustainable and dynamic conditions. The model contains four objectives, namely profit, transportation cost, employment, and environment appraisal of the cluster. The goal of this research is to find the best/optimal solution for firms' arrangements with/within networks that maximize the profit, employment, and environment score and minimize the transportation cost. The assignment patterns show horizontal and vertical cooperation with/within networks. The efficiency of model clustering in sub-clusters is followed by the neighbor clustering efficiency and the one's clustering efficiency methods.

1. Introduction

Industrial clusters in the last four decades have been one of the current and useful models of economic development. A study about clusters shows a vast range of quality and quantity research. The economics of aggregate base, like industrial cluster models, because of many benefits and advantages, was developed all over the world from developing countries to developed countries. Nowadays, international organizations, the United Nations Industrial Development Organization (UNIDO), the International Labor Organization (ILO), and small and medium industries departments of countries are planning action plans to develop their industries that have been aggregated in a geographical region and industrial/business same category and maybe have linkages with together. One of the comprehensive general industry development models is the industrial cluster. With the survey about the industrial and business patterns of the world, it was found that comprehensive patterns have been dominated by Mi-

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cro, Small, and Medium-sized Enterprises (MSMEs). The World Bank reported in 2010 that more than 123 countries with 125 million formal MSMEs have been registered, including 89 million emerging markets. Therefore, it is proven that clusters are wide, current, and general economic phenomena. Many developed and developing countries have formed 95% MSME firms on average.

The industrial cluster is a suitable industrial and economic structure for MSME firms to address many industrial clusters' problems. Cluster theory and its application in cluster-based economic development have been pioneers of economic development theories and methods during the past three decades. The cluster viewpoint proposes that enterprises are an area of a geographically defined cluster that benefits from being an area of that cluster and that these benefits result in the development of the economic outcome for the district. A firm's proximity to an area creates more benefits because of decreased input costs and supply. Agglomeration and co-location of firms caused the flow of knowledge and information within them. Common benefits for firms include an increased willingness to participate in co-operation. The results of such actions increase productivity and competitiveness.

Therefore, the clusters are considerable and important for understanding and sustainable improving economic and industry growth. Policymakers and industry planners need to learn about effective actions and methods to make optimum decisions. According to this attention, cluster-based planning is a modern development method for governments. So, understanding dynamic and functional industrial clusters is necessary for strategic planning.

In today's world, decision-makers follow a variety of objectives of development concepts change continuously and cover more economic and social dimensions. Some objectives in the region's economy include increasing and improving income and benefits, employment, export, technical men and knowledge spillover, skills, research and development, innovation, technology, various markets, vertical and horizontal corporation, relationships, trust-building, social responsibility, welfare, environment considers and green products and decreasing and improvement costs, transports, energy consumption, poverty, waste, and air/soil/water pollutions. Achievement of objectives and advantages of cluster development and analysis of clusters are important steps. The cluster analysis has been classified into quality and quantity methods. According to the literature review, all of the industrial cluster survey fields emphasize quality and conceptual analysis. Otherwise, the quantity analysis survey covered statistical methods, and only a few surveys have been seen with mathematical and optimization models. So, this field of knowledge has a big research gap, and this study has tried to develop an optimization model with the mathematical approach. The industrial new concept's emphasis on the increase in the same firm's linkages and co-corporate empowerment, the linkages of firms together, and other stockholders in clusters creates phenomena that are named networks. Network building in clusters develops the process as a core activity that helps cluster sustainability, and many experts believe that without networking, cluster development cannot be completed. The general objective of networking is to gain more benefits for network members relative to when every member works alone. When firms work to gather within a network to determine a mission, the synergy will rise.

The main problem in network building is how to create an optimal/near-optimal/best network. What arrangement of firms can be optimal and suitable for assignments within networks? What is the optimal solution for an industrial cluster model under uncertain conditions?

This research tries to reply to questions by a mathematical model versus qualitative and experimental methods. The main benefit of networking in the model is to optimize sustainable economic goals. This is a novel method for network planners and decision-makers about networking in industrial and business clusters. This solving method includes member firms within networks, the amount of vertical and horizontal co-operation networks, a relationship among firms with/within networks, co-operation planning of production, and joint actions as advantages of joint actions that will be more of the alone act that is named synergy. Nowadays, this subject is the core of the development plans literature of clusters, and it is very widely used and practical. Moreover, the provided mathematical model in this study ensures the achievement of an optimal network with sustainability concerns.

The rest of the paper has been organized as follows: Background including concepts and problem definition, literature review, problem mathematical modeling, solution method with case study, conclusion, and future studies.

2. Background

2.1. Industrial cluster

Porter was the first person to come up with the idea of industrial clusters in 1990; however, then different definitions of an industrial cluster were provided. Industrial clusters are generally defined as a group of producer and commercial firms and non-profit organizations in which competitive performance is the key element of a member of a group. What makes an integrated cluster is the interaction of member firms. Competitive enterprises would create competitive clusters, and economic attractions will eventually close the clusters. Dimensions of space and time are the most important factors of the cluster policy that influence the decision on the cluster programs. On the other hand, the original data and substances might impose limitations on the definition of the clusters. In the following, there will be various definitions of the cluster provided by scholars. First, a group of enterprises has strong vertical ties and is located in a region that is geographically close to each other [1,2]. In the second and more comprehensive definition of Porter, a cluster is a geographic concentration of related enterprises and other firms in a special field [2].

In the broadcast sense, a cluster is regarded as the spatial concentration of economic activities. Opportunities related to the efficiency of mass are the factors drawing the attention of politicians to the clusters that originate from external economic costs, low transaction costs, and collective action. Therefore, the spatial gathering of the enterprises that do not communicate with each other cannot increase the efficiency of mass. Therefore, a cluster is a set of relatively large economic firms located in a particular region and has a specific technical background in which firms do a thriving business. The local and geographical concentration of firms is called a cluster. This would lead to external savings and the recruitment of distant markets, and also specialized services in the fields of technical, financial, and management will emerge. A cluster is a set of enterprises and organizations located in a geographical district where inner dependence causes an in-group relationship of products and services. Some of these enterprises, like suppliers of resources and raw materials and applicants for goods and services linked together, have complementary and similar products on a resource, process, or product [1,3]. A cluster is a group of enterprises focused on a geographical region facing common threats and opportunities providing related or complementary products [1]. This would lead to related businesses and emerging specialized services in the fields of technical, management, and finance [1]. The industrial cluster is a set of homogenous industries developed with economic objectives in geographical regions for specific advantages and consistent social capital like technology and skills. The main characteristics of the industrial cluster are as follows [4]:

1. Concentration on a geographical region;
2. Business and the industrial interrelationship between member firms;
3. Vertical relationship in clusters;
4. Existence of non-commercial organizations along with commercial firms in a cluster;
5. Cooperate among firms and do common and popular activities;
6. Member competency;
7. Being in the same field of firms in one branch or specific industrial branch (value chain formation);
8. Common threats and opportunities for firms in a cluster;
9. Emerging specialized technical, management and financial services in the cluster;
10. Dependence on an economic geographical specific region;
11. Synergy of competence and cooperation in the cluster;
12. Mass efficiency of external economic savings.

A cluster is a set of enterprises, organizations, enterprises, and institutions that are active in an industrial field that can synergize their capabilities [1]. The industrial cluster is generally formed on a local or urban geographical scale and has clear and various features [4]. Potentially, competitive industries tend to be a cluster in the economy ordered by data, skills, and infrastructures. The cluster concept has been used as an operational structure several times [4]. Recently, a mono-objective mathematical model has been developed based on knowledge diffusion within the cluster [5].

Table 1 [4,6,7] and Table 2 [8] show different types of clusters and a comparison of a network type in the cluster. The network activity types in MSMEs and industries are classified as management, the exchange of resources, and the production of collective goods in an experimental study in German SME networks. They developed the concept of the organized network in co-operation and joint actions with 4000 networks for various industries [9]. The last literature review about industrial clusters has found the network is one of the 10 top subjects in 25 top journals that publish on the cluster topic [10]. Therefore, the networks and relationships between industries, firms, clusters, and entities are a research gap and a novel and applicable field. The objective functions of the proposed model cover sustainable economic development aspects although Dezfoulian's model has studied another aspect, which is knowledge transfer among members. Also, Sarafrazi's model [29] was studied about deterministic conditions by considering the aspects of sustainable economic development.

Based on Tables 1 to 3, the main pillar of the clusters is a relationship among the system components, which is the networking. Relationship levels are different and create various networks. Table 2 categorizes the networks into three types (i.e., inter-firm, public, and regional). The first and fundamental level in the

Table 1. Types of clusters.

Cluster type				
Cluster/index	**Enterprises size**	**Product**	**Knowledge**	**Skill**
Business cluster	Micro/small	Product/service	Low/medium	Low/medium
Industrial cluster	Small/medium/large	Product	Medium/high	Medium/high
Technology cluster	Small/medium/large	Product/service	High/very high	High
Green cluster	Small/medium/large	Product	Medium/high	Medium
Pure agglomeration	Micro/small/medium/large	Product/service	Low/medium	Low/medium
Industrial complex	Medium/large	Product	Medium/high	Medium
Networks	Micro/small/medium	Product/service	Low/medium/high	Low/medium

Table 2. Comparison of the network type in the cluster.

Network/ characteristics	Inter-firm networks	Public and other institutional networks	Regional networks
Players	Businesses, especially MSMEs	Municipalities, educational and research institutes	Businesses, governmental offices, intermediary institutions, social groups
Motives/Aims	Improving competitiveness	Increased efficiency through the division of responsibilities	Sustainable solutions, regional solutions
Areas of cooperation (examples)	Supply, innovation, disposal, waste, sales, gain, ordering, law, finance	Transport, tourism, culture and education, utilities, and waste disposal, business development and management, administration	Regional planning, marketing, linkages, knowledge transfer,
Course of cooperation	Horizontal/vertical/ lateral	Horizontal	Cross-section/ lateral
Adjustment system and control	Trust, basic agreements, contracts	Agreements, contracts	Trust, agreements

cluster atmosphere is the inter-firm networks created based on relationships and cooperation between firms and main players. Therefore, in the literature, the clusters and the final expected of the cluster development programs are networking and network reinforcement. The networks form from co-operation and joint actions. The main flow in the clusters is the process of organized goods/services. The firms within networks share their facilities and resources to complete organized goods.

The vertical network is arranged based on production methods, engineering, and process sequence, like cutting, machinery, pressing, coloring, and packing. The horizontal network is arranged based on parallel operations and supporting activities like joint-buying, joint-marketing, joint-transportation, and joint-testing. These activities complete the main output. The lateral network is arranged based on machinery capacity exchange for higher demands.

By studying the literature from 1890 by Marshall [11] to now, the general aspect, all concepts, and definitions, the clusters are an agglomeration of similar units in a geographical region. Otherwise, the general goal of cluster development is to develop relationships and linkages that will lead to greater benefits. These more benefits are called synergy. In Table 3, these concepts and definitions are listed and developed by

Table 3. Literature review of cluster models and concepts.

Researcher	Year	Cluster definitions/concepts	Objectives	Model	Horizon/status
Marshall [11]	1890	"Clusters as external economies created by labor market pooling and the benefits of moving people across firms, supplier specialization, knowledge spillovers"	Economic knowledge	Conceptual	Static/certainty
Krugman [12]	1991	"New economic geography: Clusters as co-location decisions of firms due to increasing returns to scale, lower costs of moving goods across space, etc."	Economic	Qualitative	Static/certainty
Saxenian [13]	1994	"Clusters as social and institutional phenomena: Technological change, organizations, social networks, and other non-market relationships in which markets are embedded: Organization within and between businesses, the relationship between firms"	Economic social	Qualitative/ conceptual	Static/certainty/ network
Porter [7]	1998	"Geographic concentrations of interconnected companies and institutions in a particular field, linked by commonalities and complementarities. Clusters include linked industries and other entities (suppliers), distribution channels and customers (demand), related institutions (research organization, universities, training entities, etc."	Economic social	Conceptual	Static/certainty/ network
Simmie and Sennett [14]	1999	"An innovative cluster as a large number of interconnected industrial and/or service companies having a high degree of collaboration, typically through a supply chain, and operating under the same market conditions"	Economic social	Conceptual	Static/certainty/ network
Roelandt and Den Hertog [15]	1999	"Industrial clusters can be characterized as networks of producers of strongly interdependent firms (including specialized suppliers) linked each other in a value-adding production chain"	Economic social	Qualitative/ conceptual	Static/certainty/ network

Table 3. Literature review of cluster models and concepts (continued).

Researcher	Year	Cluster definitions/concepts	Objectives	Model	Horizon/status
Hill and Brennan [16]	2000	"Industrial cluster as a geographic concentration of competitive firms or establishments in the same industry that either has close buy-sell relationships with other industries in the region or shares a specialized labor pool that provides firms with a competitive advantage over the same industry in other places"	Economic social	Qualitative/ conceptual	Static/certainty
Van den Berg et al. [17]	2001	"The popular term cluster is most closely related to the local or regional dimension of networks. Most definitions share the notion of clusters as localized networks of specialized organizations, whose production processes are closely linked through the exchange of goods, services and/or knowledge"	Economic social knowledge	Qualitative/ conceptual	Static/certainty /network
Ketels [18]	2003	"Clusters are groups of companies and institutions co-located in a specific geographic region and linked by interdependencies in providing a related group of products and/or services"	Economic social knowledge	Conceptual	Static/certainty/ network
OECD [19]	2001	"Clusters, local concentrations of horizontally or vertically linked firms that specialize in related lines of business together with supporting organizations"	Economic social	Conceptual	Static/certainty/ network
Rosenfeld [20]	2005	"Clusters are simply geographic concentrations of interrelated companies and institutions of sufficient scale to generate externalities"	Economic social	Qualitative/ conceptual	Static/certainty/ network
Cortright [21]	2006	"An industry cluster is a group of firms and related economic actors and institutions, that are located near one, another and that draw productive advantage from their mutual proximity and connections"	Economic social	Qualitative/ conceptual	Static/certainty/ network

Table 3. Literature review of cluster models and concepts (continued).

Researcher	Year	Cluster definitions/concepts	Objectives	Model	Horizon/status
Schilling [22]	2008	Technology Sets (clusters) are a collection of companies that are located in a region and liked to the same technology, and the possible relationship between technology buyers, suppliers, and completion of the research collaboration between them	Knowledge social	Conceptual	Static/certainty/ network
Glaeser and Gottlieb [23]	2009	"People cluster in cities to be close to something. At their heart, agglomeration economies are simply reductions in transport costs for goods, people, and ideas"	Economic	Qualitative/ conceptual	Static/certainty
Wolman and Hincapie [24]	2010	"Firms in a region producing similar or related products, utilizing similar processes or engaging in similar functions (headquarters; R&D), the regional suppliers and customers of these firms, specialized labor skills (occupations) possessed by workers in the region employed by these firms, public and public-private programs that provide services to cluster around members (e.g., customized training by community colleges), and institutions (e.g., universities, community colleges, industry and trade associations, public and private sector organizations) whose presence or interaction, to the extent it exists (i.e., the extent of interaction is an empirical question), results in cost-savings to firms and/or knowledge spillovers that produce cost savings and/or product or process innovations"	Economic social	Qualitative/ conceptual	Static/certainty/ network
UNIDO [25]	2003	"Clusters as agglomerations of interconnected companies and associated institutions. Firms in a cluster produce similar or related goods or services and are supported by a range of dedicated institutions	Economic social	Conceptual	Static/certainty/ network

Table 3. Literature review of cluster models and concepts (continued).

Researcher	Year	Cluster definitions/concepts	Objectives	Model	Horizon/status
UNIDO [25]	2003	located in spatial proximity, such as business associations or training and business development service (BDS) providers. Networks can be established between firms within clusters but also exist outside clusters and can be horizontal and vertical. Horizontal networks are built between firms that target the same market. Vertical networks are alliances between firms belonging to different stages of the same value chain"	Economic social	Conceptual	Static/certainty/ network
Del-Angizan [4]	2011	"Technology clusters combine from universities, technology parks, research centers, and companies with superior technology, human resources, and physical infrastructure and institutional and human capital that in a certain geographic area with centralized management and specific legal structure connection with a consumer market to produce knowledge base goods and services"	Knowledge social	Conceptual	Static/certainty
Sheffi [26]	2012	"A number of strengths linked to logistics clusters. Moreover, logistics clusters provide opportunities to train and develop a skilled workforce internally. Furthermore, logistics services serve diverse industries and as a result, are more resilient to the recession shocks"	Economic social	Conceptual	Static/certainty/ network
Delgado et al. [27]	2016	"Clusters are geographic concentrations of industries related by knowledge, skills, inputs, demand, and/or other linkages"	Economic social	Qualitative/ conceptual	Static/certainty/ network
Dezfoulian et al. [5]	2017	"Knowledge transfer in intra -organizational and inter -organizational levels can be carried out. The inter-organizational knowledge transfer can be done horizontally and vertically"	Knowledge social	Mathematical mono-objective with a variable of 4 indices	Static/certainty/ network

Table 3. Literature review of cluster models and concepts (continued).

Researcher	Year	Cluster definitions/concepts	Objectives	Model	Horizon/status
Lu et al. [28]	2018	"The cluster is a human nature that being to be clustered in a certain region for business. The relation of the clusters with together will be constructed by firms/members inside some clusters"	Economic social environment	Conceptual/ review	Static/certainty/ network
Sarafrazi et al. [29]	2019	"The clusters are a set of similar firms and various entities that agglomerated in a geographical zone and connected by co-operation linkages within networks under sustainable economic conditions"	Economic social environment	Mathematical multi-objective with a variable of 5 indices	Dynamic certainty/network
This study	2021	"The clusters have located in dynamic and uncertainty conditions with many changes in a new era"	Economic social environment	Mathematical multi-objective with a variable of 5 indices/sensitivity analysis for demand/ firms random select	Dynamic uncertainty/ efficiency methods/ new proposed method for network composition

researchers in the last three decades. In all of these existing concepts, a general sense is an agglomeration and linkage. These two words (i.e., agglomeration and linkage) create the network. Therefore, the research is based on original concepts and goals that contribute to optimizing the model for co-operation optimal networks. The best arrangement of components and linkages between them are fundamental elements of the networks that developed in this research.

2.2. Industrial cluster sustainability

The main philosophy of the industrial clusters is regional economic development under sustainable conditions. Today, industrial policymakers try to achieve new development objectives in addition to basic objectives. Firstly, fundamental objectives are increasing benefit, income, economic, and enterprise quantity growth. Secondly, other objectives are increasing quality, employment, and environmental considerations, and decreases in transportation and pollution types. So, there are three main considerations in the sustainable development concept, including economic, social, and environmental considerations, as shown in Figure 1. Therefore, these objectives try to achieve wider and general development that includes a win-win-win concept for stockholder chains. The first win covers the optimal benefit for the market section, including customer(s)/consumer(s); the second win covers the optimal benefit for the product section, including producer(s)/supplier(s); and finally, the third win covers optimal benefit for social and environment section include protection of earth and human. Any-

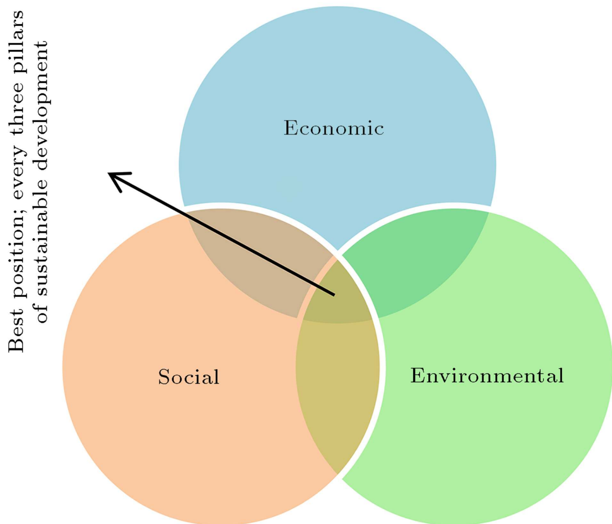

Figure 1. Diagram of sustainability development considerations [19].

way, the researchers have developed many uncertainty multi-objective models for supply chain sustainable problems. The uncertainty includes fuzziness and randomness [30,31].

2.3. Cell manufacturing system

The cellular phenomenon is a simplification action that helps in better understanding and operation in complex systems. Group Technology (GT) is a philosophy related to production systems. The cell-oriented method of clustering parts and machines is similar in processing and operations in a family. Assigning similar parts into a cell is called the Cellular Manufacturing System (CMS). The group of similar parts are part families and are processed by machines set into cells. Cellular design improves the production process, and has many other advantages. One of the useful utilizations of GT is the CMS, which intends to organize large and varied categories or batches into small and medium categories of part types produced in the flow shop system [32-36]. The main advantages of cellular manufacturing have been published in the literature as simplification and reduction in material inner transportation, decreasing semi-make and Work-In-Process (WIP) inventories, reduction in setup time, enhancement in flexibility, better production control, and shorter lead time [37–39]. In today's competitive market and fluctuating environments, systems must be developed using more efficient economic models. One of the CMS branches is a Virtual Cellular Manufacturing System (VCMS), which is based on "a highly flexible manufacturing concept designed to improve the performance of classical CMS and job shop manufacturing environments by creating a virtual grouping of the resources temporarily in the production planning and control system" [40,41]. In this case, machines cannot move physically within and between cells and change the cell's boundary logically. Rearrangements of facility and machines in a CMS cover additional costs, including machine movement costs, machine uninstall/install costs, setup costs, and production stop costs. However, in VCMS, because of the lack of machine movement, there are no such costs. Generally, a CMS is better for large companies with high technology; however, a VCMS improves this limitation for MSME companies with a lower cost.

2.4. Problem definition

The main approach to the industrial cluster's development is argued about the move from an unstable to a stable situation. Therefore, industrial planners and developers try to use improvement tools. In developing the process, cluster development agents and development organizations are intended to classify cluster members to efficiency and smaller sub-clusters that are co-located to subsets of main set firms in one region. This action is named networking in the concepts of cluster development. The networks of the cluster were formed to satisfy stockholders' objectives and develop economic and social advantages. Generally, the network's pattern or membrane of firms in sub-clusters is done by quality methods that are not very exact and have to try and error. Therefore, the lack of quantitative analysis methods and mathematical optimization is an important research gap in this field. The research gap focuses on modeling under uncertain conditions in planning and cooperation networking. Therefore, this research is an extension of fuzzy in the multi-objective programming proposed by the previous model. The research addresses optimal solutions for solving industrial cluster patterns with a variety of objectives. Because the problem has been extended, the model design has been considered several objectives, and it is important to notice industrial, economic, social, and environmental considerations. There are lots of objectives to solve industrial problems. However, a multi-objective approach is more useful and valuable compared to other objectives and single-objective problems. So, the industrial cluster problem model is designed with four objectives, including the maximization of a sub-cluster or cluster benefit, maximization of employment, minimization of material transport cost, and finally, maximization of green appraisal, respectively. This is a novel model and method for network planners and decision-makers about networking in industrial and business clusters under uncertainty and dynamic conditions. Nowadays, this subject is the core of the development plans literature of clusters, and it is very widely used and practical. As illustrated in a comparison table for the literature review, this study focuses on two aspects of horizontal and vertical collaboration in industrial clusters. To achieve the possibility of horizontal collaboration, we suggest a clustering algorithm; however, a mathematical model is presented to construct the vertical collaboration network. The mentioned novelties have been added to the end of the "Literature review" section.

In this study, the industrial cluster model has been designed for a multi-objective optimization problem. Four main objectives cover development sustainability concepts. To meet and cover the sustainable development approach, four goals, namely, economic, financial, social, and environmental, were identified [31,42]. These goals are described as follows:

1. Profit is an important economic goal that will grow clusters and firms and also will increase the motivation for development and cooperation;
2. Transportation costs are another important economic goal that needs to be decreased by optimal planning. This goal will have an impact on the economic and environmental aspects by reducing

fuel consumption and environmental pollution and also indirectly will have a positive social impact on the quality of life;

3. The employment goal is social and is considered in this study;
4. The environmental goal is important and necessary to protect the environment in terms of soil, water, air, and waste.

We consider the above-mentioned objectives to ensure that the designed industrial clusters network is sustainable.

The first objective is the maximization of a firm's benefit [7], which increases business power and continuous motivation and is the main objective. This objective is related to economic consideration. The second objective is the maximization of employment in a region [7]. This objective is related to social and economic considerations. The third objective is the minimization of the cost of material handling and transportation [7,11,43]. On the other hand, this objective is related to economic considerations on the other hand, decreasing carbon pollution, and environmental consideration. The fourth objective is the maximization of green appraisal [44]. This objective is related to environmental considerations and green production principles.

The research procedure of industrial clusters for co-operation networks is as follows:

-Step 1. First clustering:

1. Select the industrial cluster with f firms and enterprises and the MSME structure;

2. Determine the most important of variables for clustering with a full covering of objectives for the cluster development context. One hundred eleven variables are in the current research;

3. Clustering of firms with Wards/K-means methods and dividing them into C sub-clusters to decrease the problem dimensions with maximum similarity of firms to each other;

4. Validate clustering results and sub-clusters.

-Step 2. Mathematical modeling with sustainable development objectives:

5. Input one of the sub-clusters to a multi-objective model with uncertainty conditions in demand and firms' capacity;

6. Input data;

7. Select Lp-metric/ϵ-constraint methods;

8. Solve the model with GAMS software;

9. Repeat the model solving and setting parameters and so determine the efficiency of assignments;

10. Construct a new network from two clusters by random selection of firms and then solve a new network based on the developed models;

11. Construct the networks and linkages with/within firms of the network(s) members.

3. Mathematical model

3.1. Multi-objective optimization

A mono-objective optimization algorithm is terminated upon obtaining an optimal solution, yet it is unlikely to find a single solution for a multi-objective problem, and due to the contradictory objectives, we generally find a set of solutions. Some basic multi-objective concepts are reviewed below to clarify the point. The general multi-objective minimization problem is formulated by:

$$\text{Minimize } \{f_1(x), f_2(x), \cdots, f_m(x)\},$$

$$\text{s.t. :}$$

$$g(x) \leq 0, \tag{1}$$

where $x = (x_1, x_2, \cdots, x_n)$ is a vector of the decision variables, $F(x) = (f_1(x), \ f_2(x), \cdots, f_m(x))$ is the vector of the solution in the objective space and $g(x)$ is the constraint vector. The CMS modeling has been developed with various assumptions and objectives [44–53]. The solution strategy for multi-objective problems is the ϵ-constraint method [54]. In the ϵ-constraint method, one of the objective functions is optimized using the other objective functions as constraints, incorporating them in the constraint part of the model. The details of the fuzzy building method can be found in Safaei's work [39].

3.2. Problem mathematical modeling

The mathematical model in this research was designed based on multi-objective modeling. The model was formulated as a nonlinear mixed-integer programming model. Due to the wide scope of the main problem, the model is formulated based on the following assumptions:

-Product:

1. Product times for all operations of a product on various firms (manufactures) are defined and deterministic.

2. Each product has various operations/cooper ation that must be accomplished as numbered, respectively.

-Firm:

3. All firms are assumed to be micro, small, and medium enterprises;

4. The benefit (value) of the cooperation class between firms is defined;

5. The benefit (value) of each firm is defined;

6. The capabilities of each firm are uncertain over the planning horizon capacity of each firm in each time horizon is given as piecewise an uncertain (fuzzy) number. The uncertain capacity of the firm is specified by the industrial cluster experts.

-Sub cluster:

7. The maximum number of sub-clusters/clusters can be defined in each time horizon is determined in advance;

8. The maximum sub-clusters'/clusters' size is defined in advance.

-Demand/inventory:

9. Demands are uncertain and constant over the planning horizon. The demand for each product in each time horizon is defined as a piecewise uncertain (fuzzy) number;

10. Demand for each product in each time horizon is uncertain;

11. The demand for a product in a given time horizon can be fulfilled before and after times;

12. Backlogging and shortages are not permissive;

13. The cost of transporting raw material/WIP from the supplier to the firm is included in the raw material procuring cost;

14. Cost of waste disposal is not contained in the problem;

15. Supply is equal to or more than the demands for each product at the sub-cluster/cluster, and shortage is not allowed because parameters are deterministic;

16. The important weight/coefficient of each object ive function is constant over the planning horizon;

17. In the supply chain of the cluster, there is a variety of activities, including manufacturing and services based on product value chains;

18. Planning horizon in the industrial cluster will be considered medium and long-term.

-Cooperation:

19. Cooperation between firms has positive effects, such as synergy;

20. When each firm has a guaranty benefit for co-operation so that it connects to sub-cluster/cluster;

21. Cooperation between firms to sub-cluster/ cluster will have had minimal benefit, but according to synergy theory, the benefit is more alone;

22. Cooperation between firms to sub-cluster/ cluster will have extended employment more than the firm's business alone;

23. Each firm can work in several operations with other firms/members of industrial clusters;

24. Each firm can work in several cooperation fields with other firms/members of industrial clusters;

25. The intervals for possible values of fuzzy parameters are defined by the expert as $[a^L, a^U]$, implicating a linear piecewise membership function.

In general, linear piecewise membership functions can be divided into two main intervals. The first interval, $[0, a^L]$, represents "*risk-free*". a^L is a predetermined aspiration level by the cluster planner. The second interval, $[0, a^U]$, represents "*full-risk*". While moving from "risk-free" toward "full-risk" values, it is moved from solutions with a high degree to solutions with a low degree of implementation [55]. In general, a^L and a^U indicate the optimistic and pessimistic orientation of the cluster planner, respectively.

Notations, indices, and parameters

λ	Lambda is named "decision level," which indicates the degree of membership of X^* in the fuzzy variables set D
Z_U	The objective function's maximum
Z_L	The objective function's minimum
c	Index for manufacturing firm's sub-clusters/clusters, $c = (1, \cdots, C)$
c'	Index for manufacturing firms at other sub-clusters/clusters, $c' = (1, \cdots, C')$
f	Index for firm (enterprise, manufacture) types, $f = (1, \cdots, F)$
f'	Index for firm (manufacture) types at other sub-clusters/clusters, $f = (1, \cdots, F)$
p	Index for product types, $p = (1, \cdots, P)$
h	Index for time horizons, $h = (1, \cdots, H)$
j	Index for operations that belong to product p, $j = (1, \cdots, J)$
k	Index for other cooperation that belongs to the product p, $k = (1, \cdots, K)$
P	Number of product types
F	Number of firm types
H	Number of time horizons
J	Number of cooperation's between firms (operations/process) for product p
K	Number of other cooperation's between firms (operations/process) for product p
C	Maximum number of sub-clusters/clusters that can be designed

D_{jph}	Demand for product p in cooperation (operations/process) j between firms at the period h
$D^{\sim}_{jph}$	Fuzzy demand expresses a tolerance value, and decision-making under this interval is risky or "full-risk" value-interval for the cluster expert, $D^{\sim}_{jph} = D^{L}_{jph}, D^{U}_{jph}$
D^{L}_{jph}	The fuzzy demand of operation j for product p in time horizon h was equivalent to the linguistic expression "about D^{L}_{jph} or less and low demand"
D^{U}_{jph}	The fuzzy demand of operation j for product p in time horizon h was equivalent to the linguistic expression "about D^{U}_{jph} or more and up demand"
Q_{ph}	Demand quantity of product p at time horizon h
$D^{\sim}_{ph}$	The fuzzy demand expresses a tolerance value, and decision-making under this interval is risky or "full-risk" value-interval for the cluster expert, $D^{\sim}_{ph} = (D_p h^L, D_p h^U)$
D^{L}_{ph}	The fuzzy demand of product p in time horizon h was equivalent to the linguistic expression "about D^{L}_{ph} or less and low demand"
D^{U}_{ph}	The fuzzy demand of product pin time horizon h was equivalent to the linguistic expression "about D^{U}_{ph} or more and low demand"
UB	Maximal cluster size
b_{jpf}	Benefit (value) for product p in cooperation (operations/process) j by firm f
w_{jp}	Cluster policy important weight for product p in cooperation (operations/process) j
w_{kp}	Cluster policy important weight for product p in cooperation (operations/process) k
β_{jkp}	Portion of benefit (additional benefit/award) for product p in cooperation fields (operations/process) j and k between firms
a_{jpf}	1 if cooperation (operations/process) j of product p can be done at firm f; 0, otherwise
a_{kpf}	1 if other cooperation (operations/process) k of product p can be done at firm f; 0, otherwise
T_f	The capacity of firm f in each time horizon
$T^{\sim}_f$	Fuzzy capacity expresses a tolerance value, and decision-making under this interval is risky or "full-risk" value-interval for the cluster expert, $T^{\sim}_f = (T^L_f, T^U_f)$
T^L_f	The fuzzy capacity of firm f in each time horizon was equivalent to the linguistic expression "about T^L_f or less and low capacity"
T^U_f	The fuzzy demand of operation j for product pin time horizon h was identical to the linguistic expression "about T^U_f or more and up to capacity"
UB_f	Maximal expected benefit of the firm
LB_{jp}	Minimal (lower bound) operation/cooperation j for product p
UB_{jp}	Maximal (upper bound) operation/cooperation j for product p
fc	Maximal (upper bound) profit of operation/cooperation j for product p in firm f to sub-cluster's/cluster's c at time horizon h
ic	Maximal (upper bound) profit of operation/cooperation k for product p in firm f to sub-cluster/cluster c at the time horizon h
E_{jpfch}	Employment number for product p in cooperation (operations/process) j in firm f allocated sub-cluster/cluster c at the time horizon h
EG_{jpfch}	Employment number for product p in cooperation (operations/process) j in firm f allocated sub-cluster/cluster c at the time horizon h for the green objective
E_{kpfch}	Employment number for product p in cooperation (operations/process) k in firm f allocated to sub-cluster/cluster c at time horizon h
α_{jp}	The minimal expected percentage for employment on operation/cooperation j for product p
W_p	Weight of product p
LW_{jp}	Weight of employment product p in cooperation (operations/process) j
LWG_{jp}	Weight of employment product p in cooperation (operations/process) j for green
S_{jpfch}	Green appraisal scores of operation j for firm f for product p allocated to sub-cluster's/cluster's c at time horizon h [56].

G^{q}_{jpfch} Green appraisals score of operation j for firm f for product p allocated to sub-cluster/cluster c at time horizon h for every item of q

W^{q} Importance weight of q items green appraisals

-Decision variables

X_{jpfch} If product p in cooperation (operations/process) j in firm f allocated to sub-cluster/cluster c at the time horizon h is assigned; 0, otherwise

X_{kpfch} If product p in cooperation (operations/process) k in firm f allocated to sub-cluster/cluster c at the time horizon h is assigned; 0, otherwise

N_{fch} Number firm f allocated to sub-cluster/cluster c at the time horizon h

By using mentioned notations, the proposed model under Mixed-Integer Non-Linear Programming (MINLP) that is a multi-objective industrial cluster optimization is written as follows (Eqs. (2) to (25)):

Z_1: Maximization of the objective function of the benefit (value chain) max λ.

$$(\mathrm{Z_U}-\mathrm{Z_L})\leq \mathrm{Z_U}-\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{c=1}^{C}N_{fch}.b_{fch}$$
$$+\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{j=1}^{J}X_{jpfch}.b_{jpf}.$$
$$\left[(1-\lambda).D^{L}_{jph}+\lambda.D^{U}_{jph}\right].w_{jp}$$
$$+\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{k=1}^{K}$$
$$\beta_{jkp}.X_{jpfch}.X_{kpfch}$$
$$+\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{j=1}^{J}\gamma_{jpf}.S_{jpfch}.X_{jpfch}. \tag{2}$$

Z_2: Maximization of the objective function of the employment.

$$\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{j=1}^{J}X_{jpfch}.E_{jpfch}.LW_{jp}$$
$$+\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{j=1}^{J}X_{jpfch}.EG_{jpfch}.LWG_{jp}. \tag{3}$$

Z_3: Minimization of the objective function of the material handling cost.

$$(\mathrm{Z_U}-\mathrm{Z_L})\leq \mathrm{Z_U}$$
$$\sum_{p=1}^{P}\sum_{h=1}^{H}\frac{\left[(1-\lambda).D^{L}_{ph}+\lambda.D^{U}_{ph}\right]}{B}\times\gamma^{inter}_{ph}$$
$$\times\left[\sum_{j=1}^{J}\sum_{p=1}^{P}J_{jp}.d_{f(f+1)}\right.$$
$$-\left(\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{f=1}^{F}\sum_{c=1}^{C}\sum_{h=1}^{H}\right.$$
$$\left.\left.d_{f(f+1)}.X_{jpfch}.X_{j+1,p,f+1,c,h}\right)\right]$$
$$+\sum_{p=1}^{P}\sum_{h=1}^{H}\frac{\left[(1-\lambda).D^{L}_{ph}+\lambda.D^{U}_{ph}\right]}{B}\times\gamma^{intra}_{ph}$$
$$\times\left(\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{f=1}^{F}\sum_{c=1}^{C}\sum_{h=1}^{H}d_{f(f+1)}.\right.$$
$$\left.X_{jpfch}.X_{j+1,p,f+1,c,h}\right). \tag{4}$$

Z_4: Maximization of the objective function of the green appraisals:

$$\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{c=1}^{C}\sum_{p=1}^{P}X_{jpfch}.S_{jpfch}, \tag{5}$$

$$S_{jpfch}=\sum_{q=1}^{Q=24}W^{q}.G^{q}_{jpfch}. \tag{6}$$

s.t.:

-Benefit (value) of industrial cluster constraints:

Constraints (7) and (8) are related to one-to-one assignments for every operation and joint activities:

$$\sum_{j=1}^{J}\sum_{f=1}^{F}\sum_{c=1}^{C}\sum_{p=1}^{P}a_{jpf}.X_{jpfch}=1, \qquad \forall h, \tag{7}$$

$$\sum_{k=1}^{K}\sum_{f=1}^{F}\sum_{c=1}^{C}\sum_{p=1}^{P}a_{kpf}.X_{kpfch}=1, \qquad \forall h. \tag{8}$$

Constraint (9) explains weights accumulate of product and operation is equal total number of products:

$$\sum_{j=1}^{J}\sum_{p=1}^{P} w_{jp} = \sum_{p=1}^{P} p. \tag{9}$$

Constraint (10) explains that the weights accumulating the product operation for every product are 1:

$$\sum_{j=1}^{J} w_{jp} = 1, \qquad \forall p. \tag{10}$$

Constraint (11) explains the firm capacity for every sub-cluster and planning horizon:

$$\sum_{j=1}^{J}\sum_{f=1}^{F}\sum_{p=1}^{P}\left[(1-\lambda).D_{ph}^{L}+\lambda.D_{ph}^{U}\right]$$

$$.X_{jpfch}.t_{jpf} \leq \left[(1-\lambda).T_{f}^{L}+\lambda.T_{f}^{U}, \qquad \forall c,h. \tag{11}$$

Constraint (12) explains the maximum size of the sub-cluster for every sub-cluster and planning horizon:

$$\sum_{f=1}^{F} N_{fch} \leq UB_c, \quad \forall c,h. \tag{12}$$

Constraints (13) and (14) explain the minimum size of the sub-cluster for every sub-cluster and planning horizon:

$$\sum_{c=1}^{C}\sum_{f=1}^{F} N_{fch} \geq 1, \quad \forall h, \tag{13}$$

$$\left(N_{fch}-N_{fc(h-1)}\right) \geq 0. \tag{14}$$

Constraints (15) explain the profit (value) of co-operation for every sub-cluster and planning horizon:

$$N_{fch} \times b_{fch} \geq \sum_{h=1}^{H}\sum_{f=1}^{F} b_{fh}. \tag{15}$$

Constraints (16) and (17) related to the upper and lower bounds of firm capacity and operations of products for every planning horizon:

$$\sum_{c=1}^{C}\sum_{f=1}^{F}\sum_{p=1}^{P} b_{jpf}.\left[(1-\lambda).D_{ph}^{L}+\lambda.D_{ph}^{U}\right].$$

$$X_{jpfch} \geq UB_f, \quad \forall h, \tag{16}$$

$$LB_{jp} \leq \sum_{c=1}^{C}\sum_{f=1}^{F}\sum_{p=1}^{P}\sum_{j=1}^{J}\left[(1-\lambda).D_{jph}^{L}+\lambda.D_{jph}^{U}\right].$$

$$X_{jpfch} \leq UB_{jp}, \quad \forall h. \tag{17}$$

Constraints (18) to (20) related to upper and lower bounds of operations, joint action, and product for every firm and sub-cluster and planning horizon:

$$LB_j \leq \sum_{j=1}^{J} X_{jpfch} \leq UB_j, \qquad \forall p,f,c,h, \tag{18}$$

$$LB_k \leq \sum_{k=1}^{K} X_{kpfch} \leq UB_k, \qquad \forall p,f,c,h, \tag{19}$$

$$LB_p \leq \sum_{p=1}^{P} X_{jpfch} \leq UB_p, \qquad \forall j,f,c,h. \tag{20}$$

-Employment of industrial cluster constraints:

Constraints (21) and (22) explain that network/sub-cluster employment is more than employment of horizon planning and positive:

$$\sum_{c=1}^{C}\sum_{f=1}^{F}\sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{h=1}^{H} E_{jpfch}.X_{jpfch}$$

$$+\sum_{c=1}^{C}\sum_{f=1}^{F}\sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{h=1}^{H} EG_{jpfch}.X_{jpfch} \leq \alpha_{jp}$$

$$\times\left(\sum_{j=1}^{J}\sum_{f=1}^{F}\sum_{c=1}^{C}\sum_{p=1}^{P} E_{jpfc}+\sum_{j=1}^{J}\sum_{f=1}^{F}\sum_{c=1}^{C}\sum_{p=1}^{P} EG_{jpfc}\right),$$

$$\forall h, \tag{21}$$

$$(E_{jpfch}+EG_{jpfch})-(E_{jpfc(h-1)}+EG_{jpfc(h-1)})\geq 0. \tag{22}$$

-Binary constraints:

$$X_{jpfch}, X_{kpfch} \in \{0,1\}. \tag{23}$$

-Non-negative constraints:

$$N_{fch}, D_{jph,}\beta_{jkp} \geq 0, \tag{24}$$

$$S_{jpfch,}E_{jpfch,} \geq 0. \tag{25}$$

3.3. Linearization of the industrial cluster multi-objective model

Two objective functions are nonlinear because of the quadratic terms in the first and third objective functions. Two binary decision-maker variables multiplied in these objectives. The nonlinear sentences can be linearized simply by defining auxiliary binary variables to replace them. Such changes require some additional constraints to be added to the model. The variables can be expressed by change of the variable:

$$Wsrijj\_kk\_ = XsrijkXs+1, rij\_k\_,$$

$$\forall i,j,j,r,s,k,k. \tag{26}$$

Through a change of the variable on a binary variable, the corresponding additional constraints are as follows:

$$Xsrijk+Xs+1,rij\_k\_ \leq 1+Wsrijj\_kk\_$$

$$\forall i,j,j,r,s,k,k, \qquad (27)$$

$$Xsrijk+Xs+1,rij\_k\_ \geq 2Wsrijj\_kk\_$$

$$\forall i,j,j\_,r,s,k,k. \qquad (28)$$

4. Experimental results

To examine the model, a case study of a stone industrial cluster has been defined that includes five similar firms with two main products, three product operations, three corporation operations within firms, two sub-clusters (networks), and two horizons. In the first step of the research, the firms are clustered according to their similarities. This will lead to a decrease in the size of the problem and, thereby, experiments. By using this step, the number of firms was reduced to 5 clusters (representative firms) among 100 firms using 111 variables. In the second step of the research, the network is constructed using a mathematically introduced model in 2019. It is distinguished that the problem is non-convex/nonlinear and has four objectives that cannot be optimally solved within a suitable and rational time. By increasing problem dimensions, solving time becomes very high. Therefore, the model is a hard problem and a very complex one that was solved very hard. This research used Minitab and GAMS software. The model was solved by GAMS coding under Win7. Table 4 presents data on uncertain production capacity and the demand of industrial cluster firms in two horizons. The production capacity of firms is constant in each period because of the change of capacity needed for investment and strategic decisions; however, market demands and orders are dynamic and cover triangular fuzzy linguistics data.

The results of optimal or near-optimal solutions are presented in Table 4 under deterministic and uncertain conditions. The one number in Table 5 shows which firm f allocates to sub-cluster c that assigns to process operation j of product p on time horizon h. These draw to sub-cluster arrangement maps in the cluster context. Each objective function in the multi-objective has an important weight that is used in Lp-metric and ϵ-constraint methods [57]. For the determination of w_i, two methods were applied: expert judgment and experiments. Experimental results showed that w_i in the experimental method creates the best solutions. Finally, a parameter setting for $W_1 = 0.1$, $W_2 = 0.05$, $W_3 = 0.8$, and $W_4 = 0.05$ gives the best results for model objectives.

The assignment patterns show horizontal and vertical cooperation with/within firms. When some firms do the same activity, it is named horizontal cooperation in the sub-cluster that supplies market demand aided capacity together, like firms 1 and 2 in sub-cluster 1 working together in operation $j1$ for product 2 on horizon 1 and also firms 2, 4, and 5 in sub-cluster 1 working together in operation $j2$ for product 2 on horizon 1. On the other hand, when some firms do different activities that complete together and have an operation sequence, it is named vertical cooperation in the sub-cluster that produces a final product/service like firms 2, 4, and 3 in sub-cluster 1 having operation sequences $j1$, $j2$, and $j3$ for product 1 on horizon 1, respectively. The model clustering efficiency in sub-clusters is determined by the Neighbor Clustering Efficiency (NCE) and the Ones Clustering Efficiency (OCE) methods. Tables 6 and 7 show clustering efficiency results.

Table 5 shows a relationship pattern of a firm's activities. The activities include production operations

Table 4. Uncertain production capacity and demand of industrial cluster firms.

(m^2/pieces)	$F1$	$F2$	$F3$	$F4$	$F5$
T (f)	70000	150000	150000	70000	70000
L (f)	35000	75000	75000	35000	35000
U (f)	95000	205000	205000	95000	95000

(m^2/pieces)	$j1.p1$	$j2.p1$	$j3.p1$	$j1.p2$	$j2.p2$	$j3.p2$
$h1$ (D)	6600	5300	4800	27000	2300	2100
$h2$ (D)	8660	6930	6320	3470	2700	2530
$h1$ (LD)	3300	2700	2400	14000	1200	1100
$h2$ (LD)	4330	3500	3200	1750	1400	1300
$h1$ (UD)	9000	7200	6500	37000	3200	2800
$h2$ (UD)	12000	9400	8600	4700	3600	3500

Table 5. Optimal solutions from the uncertain model for the industrial cluster.

P	$\boldsymbol{W_1}$			$\boldsymbol{W_2}$			$\boldsymbol{W_3}$			$\boldsymbol{W_4}$		
1	0.1			0.05			0.8			0.05		
$H1$	***C*1**						***C*2**					
P	P_1			P_2			P_1			P_2		
J	$J1$	$J2$	$J3$	$J1$	$J2$	$J3$	$J1$	$J2$	$J3$	$J1$	$J2$	$J3$
$F1$		–	–	1	–	–	–	–	–	–	–	–
$F2$	1	–	–	1	1	1	–	–	–	1	–	–
$F3$	–	–	1	–	–	1	–	–	–	–	–	–
$F4$	–	1	–	–	1	–	–	–	–	–	–	–
$F5$	–	–	–	–	1	–	–	–	–	–	1	–
H2	***C*1**						***C*2**					
P	$P1$			$P2$			$P1$			$P2$		
J	$J1$	$J2$	$J3$	$J1$	$J2$	$J3$	$J1$	$J2$	$J3$	$J1$	$J2$	$J3$
F1	–	–	–	1	–	–	1	–	–	–	–	–
F2	–	–	–	–	–	–	–	–	–	1	–	–
F3	–	–	–	–	–	–	–	–	–	–	–	1
F4	–	1	–	–	–	–	–	–	–	–	1	–
F5	–	–	–	–	–	–	–	–	–	1	1	1
H1	***C*1**						***C*2**					
P	$P1$			$P2$			$P1$			$P2$		
K	$K1$	$K2$	$K3$	$K1$	$K2$	$K3$	$K1$	$K2$	$K3$	$K1$	$K2$	$K3$
$F1$	1	1	1	–	–	–	1	1	1	–	–	–
$F2$	1	1	1	1	1	1	1	1	1	–	–	–
$F3$	1	1	1	–	–	–	1	1	1	–	–	–
$F4$	1	1	1	–	–	–	1	1	1	–	–	–
$F5$	1	1	1	–	–	–	1	1	1	–	–	–
$H2$	***C*1**						***C*2**					
P	$P1$			$P2$			$P1$			$P2$		
K	$K1$	$K2$	$K3$	$K1$	$K2$	$K3$	$K1$	$K2$	$K3$	$K1$	$K2$	$K3$
$F1$	1	1	1	–	–	–	1	1	1	–	–	–
$F2$	1	1	1	–	–	–	1	1	1	–	–	–
$F3$	1	1	1	–	–	–	1	1	1	–	–	–
$F4$	1	1	1	–	–	–	1	1	1	–	–	–
$F5$	1	1	1	–	–	–	1	1	1	1	1	1
Lp	$\boldsymbol{Z_1^*}$ **(K.USD)**			$\boldsymbol{Z_2^*}$ **(Person)**			$\boldsymbol{Z_3^*}$ **(K.USD)**			$\boldsymbol{Z_4^*}$ **(Score)**		
14.78	39621.337			11.880			13814.20			2389.760		

j and supporting operations k where the number 1 determines assignment status. So, co-operation production plans in time horizons for various products in vertical and horizontal networks are prepared for planners. For example, vertical co-operation network for product-1($P1$) in time horizon-1($H1$) have located in subcluster-1($C1$) and the vertical network has arranged to firm-2, firm-4 and firm-3 for operation route 1-2-3, respectively ($F2 - J1$, $F4 - J2$, $F3 - J3$). The horizontal co-operation network for product-1($P1$) in time horizon-1($H1$) is located in subcluster-1($C1$), and the horizontal network has been arranged from firm-1

Table 6. Efficiency measures for clustering of firms in the industrial cluster under uncertainty.

Fuzzy: $C1H1$, $C2H1/jpf$	**Raw (no.)**	**Column (no.)**	**Result**
The Neighbor Clustering Efficiency (NCE)	4	6	36%
The Ones Clustering Efficiency (OCE)	3/5	3/8	37%
$C1H2$, $C2H2/jpf$	**Raw**	**Column**	**Result**
The Neighbor Clustering Efficiency (NCE)	4	2	50%
The Ones Clustering Efficiency (OCE)	1	1	0%
$C1H1$, $C2H1/kpf$	**Raw**	**Column**	**Result**
The Neighbor Clustering Efficiency (NCE)	48	48	0%
The Ones Clustering Efficiency (OCE)	5/2	6/2	17%
$C1H2$, $C2H2/kpf$	**Raw**	**Column**	**Result**
The Neighbor Clustering Efficiency (NCE)	46	48	4%
The Ones Clustering Efficiency (OCE)	5/2	6/2	17%

Table 7. Efficiency of firms in industrial cluster networks under uncertainty.

$j/H1$	Frequency	E_f	E_c	$k/H1$	Frequency	E_f	E_c
$F1$	1	0.42	–	$F1$	6	0.91	–
$F2$	5	1	–	$F2$	9	1	–
$F3$	2	0.83	–	$F3$	6	0.91	–
$F4$	2	0.83	–	$F4$	6	0.91	–
$F5$	2	0.83	–	$F5$	6	0.91	–
	2.4	3.91	0.78	–	6.6	4.64	0.93
$j/H2$	**Frequency**	**E_f**	**E_c**	**$k/H2$**	**Frequency**	**E_f**	**E_c**
$F1$	2	1	–	$F1$	6	0.91	–
$F2$	1	0.5	–	$F2$	6	0.91	–
$F3$	2	1	–	$F3$	6	0.91	–
$F4$	2	1	–	$F4$	6	0.91	–
$F5$	3	1	–	$F5$	9	1	–
	2	4.5	0.9	–	6.6	4.64	0.93

*. Total efficiency average of 0.88 (88%)

to firm-5 for separate joint actions 1-2-3. The first network is $F1$, $F2$, $F3$, $F4$, and $F5$ for joint action-1($K1$), which is material common buying, and so on. The preferred solution among the Pareto optimal solutions is extracted according to the planner's preferences. In the numerical example, it was assumed by experimental tests that the preferred weights of four objectives are 0.1, 0.05, 0.8, and 0.05, respectively. However, it can be changed in different situations or industrial sectors.

Tables 6 and 7 show the efficiency of clustering in networks that focus on firms that are assigned to a network where more percentages present higher quality in assignment. An amount equal to and more than 80% is usually a suitable decision. In continue Tables 8 to 11 show the solving results of the model in various status.

5. Conclusion and discussion

This paper presented a novel Mixed-Integer Non-Linear Programming (MINLP) model for a developed and extended industrial cluster model under dynamic and uncertain conditions with fuzzy demand and fuzzy firm capacity [29]. The current global business atmosphere follows rapid changes; therefore, more suitable and real models must be dynamic and uncertain. A dynamic environment mentions the changing product demand in

Table 8. Comparative of deterministic and uncertain models with optimal solutions of clusters.

$T_{(f)}$	W_1	W_2	W_3	W_4	Z_1	Z_2	Z_3	Z_4	Min (Z (L_p))
Deterministic	0.1	0.05	0.8	0.05	34155.710	11.580	13814.200	2285.380	0.025
Fuzzy	0.1	0.05	0.8	0.05	39621.337	11.880	13814.200	2389.760	14.787
Improvement rate of optimal solutions for firms capacity upper bound					5465.627	0.300	0.000	104.380	–
					16.00%↑	2.59%↑	0.00%	4.57%↑	–

Table 9. Model sensitivity analysis with optimal solutions of clusters.

$T_{(f)}$	W_1	W_2	W_3	W_4	Z_1	Z_2	Z_3	Z_4	Min($Z(Lp)$)
Fuzzy	0.1	0.05	0.8	0.05	39621.337	11.880	13814.200	2389.760	14.787
Fuzzy ($\lambda = 0.7$)*	0.6		1.45		53309.337	11.880	16212.210	2389.760	13.862
Improvement	DLB*		DUB*		34.55%↑	0%	–17.36% ↓	0%	6.26%↑

*. DLB: Demand lower bound; DUB: Demand upper bound; Parameter setting of fuzzy membership (λ): 0.6-0.7.

Table 10. New approach of the cluster model in the old and new proposed combinations of the network.

Network size	Model status	W_1	W_2	W_3	W_4	Z_1	Z_2	Z_3	Z_4	Min ($Z(Lp)$)
$8F_{\text{Old}}$	Deterministic	0.1	0.05	0.8	0.05	96826.37	12.66	19502.43	2367.71	11.438
$5F_{\text{Old}}$	Deterministic	0.1	0.05	0.8	0.05	34155.710	**11.580**	13814.200	2285.380	0.0250
$5F_{\text{New}}$*	Deterministic weighted	0.1	0.05	0.8	0.05	43700.972	6.840	16435.750	1952.190	4468.049
$5F_{\text{New}}$	Deterministic Lp metric	0.1	0.05	0.8	0.05	74021.782	10.740	11896.904	2352.280	**0.0226**
$5F_{\text{New}}$	Fuzzy Lp metric	0.1	0.05	0.8	0.05	**95430.382**	10.020	**9862.318**	**2433.150**	0.797

*$5F_{New}$: New composition of networks consisting of 5 and 8 firms: [$(F1-5)+(F1-8)=(F1, F2, F6, F7, F8)$].

Table 11. Comparison of changes and growth of model objectives with the number of optimal members of the research and experimental co-operation networks.

Method	F (up, low)	Size	Z_1 (max)	Z_2 (max)	Z_3 (min)	Z_4 (max)
Experience	[8,12]	1.50	1.31	1.41	1.87	1.66
Research	[5,8]	1.60	2.44 ↑	1.07 ↓	1.41 ↑	0.99 ↑
Improvement	[37.5,33.33%]	6.67%	86.26%	–24.11%	24.60%	40.36%

each time horizon. The proposed model determines the optimal sub-cluster arrangement for each period with the four objectives of maximizing profit, employment, and green appraisal, minimizing inter/intra sub-cluster material handling of firms. The principal advantage of the proposed model is that it considers dynamic and uncertain conditions at the same time and covers important dimensions of the cluster business environment with sustainable conditions. Other benefits of the model are alternative product plans, sequence operation, a firm's suitable arrangement, and shared firm resources. The main constraints of the proposed model are the maximal cluster size and fuzzy firm capacity. A new fuzzy programming approach was used for handling such a hard model under an uncertain environment. This approach was based on the concept of maximizing the decision proposed by Bellman and Zadeh [58].

The research applied a fuzzy method while the technological coefficients were repeated in the objective function(s). The results presented that the developed fuzzy method could give the optimal solution with the most desirable fuzzy objective(s) and constraints under dynamic and uncertain conditions. The results of the model showed more improvement in solutions, as shown in Table 8. The profit objective Z_1 gained 16%, the employment objective Z_2 gained more than 2.59%, the material handling cost objective Z_3 was not changed, and the final green appraisal objective Z_4 gained 4.57%. Generally, the solution was improved, and the decision-maker's objectives were satisfied more. The efficiency of firms' assignment in industrial cluster networks under uncertainty for corporation operation k was 93%, operation j was 78% and 90%, and total average was 88%. The efficiency amount for this model was suitable and acceptable.

The sensitivity analysis is used in the business world of the clusters and the field of economics and industries. Sensitivity analyses study how various sources of uncertainty in a mathematical model contribute to the model's overall uncertainty. In this research, the sensitivity analysis of the fuzzy model determines the suitable Demand Lower Bound (DLB) and Demand Upper Bound (DUB). The range of the demand coefficient is shown in Table 9. The results show that the profit objective (Z_1) is improved by 34.55% and 6.26 % for total function. The transportation objective (Z_2) decreases by 17.36%, and other objectives are not changed. The suitable range of the demand coefficient is found in the DLB [0.5–0.6] and the DUB [1.45–1.55].

After solving the model for each co-operation network, this paper proposes a new approach to network design. In this part of the research, there are two separate cooperation networks in the industrial cluster. Networks have five and eight firms inside each subcluster. In this approach, a new network with five firms is created randomly between the members of the two networks. The solution of the new co-operation network is compared to the previous networks in Table 10.

Results show that a new network with five firms, using the fuzzy and Lp-metric methods, has a better solution. The objective function values Z_1, Z_3, and Z_4 have better solutions; however, the objective function value Z_4 is better in the old network with a deterministic status. Figures 2 to 5 show the position of the objective functions in different states of their analyses.

On the other hand, one of the most important practical findings of this study is the appropriate and efficient number of members in the co-operation network, as shown in Table 11. In the literature on networking in the development of industrial clusters in India, Tunisia, and more than 31% in Italy by UNIDO [59], qualitative studies have sho wn that the average number of network members in the clusters is between 8 to 12 members, while this study proves that

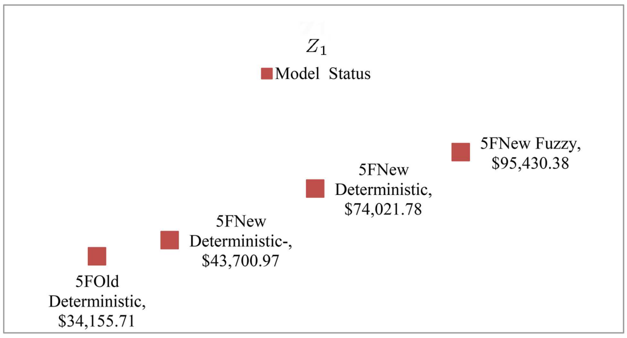

Figure 2. Improvement trend of the profit objective function.

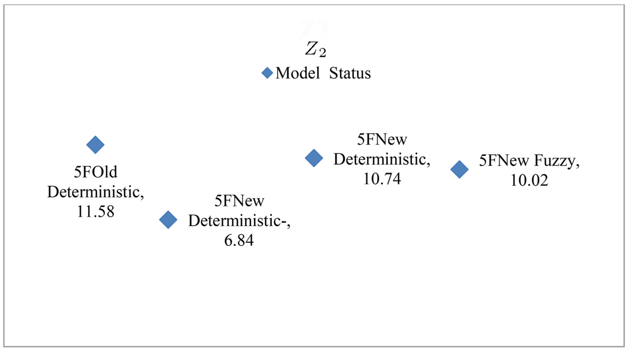

Figure 3. Improvement trend of the employment objective function.

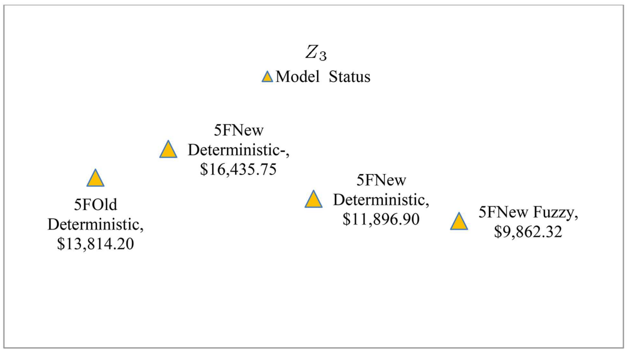

Figure 4. Improvement trend of the transportation cost objective function.

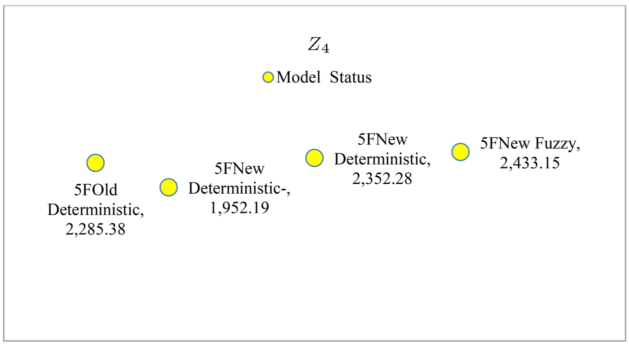

Figure 5. Improvement trend of the green appraisal objective function.

the range of the appropriate and an optimal number of firms within the network is between 5 to 8 members.

The practical advice for industry and regional economy is based on research pointing to scientific networking in clusters, from qualitative methods to optimal and exact methods used in a suitable pattern of networks, relationships, and flows between them. This study offers solutions to arrangements and their linkages with/within networks for players of the cluster. The most important action of planners in the development programs of clusters is networking. The vertical and horizontal networks of cooperation are the core of action plans for development agents and their organizations. These networks in vertical status (e.g., joint production, complementary processes, consortium, and sub-contracting) and in horizontal status (e.g., common lab, design center, and joint purchasing of material) as well as so other types of networking (e.g., Subcontracting and Partnership Exchange (SPX) networking model and consortiums).

This fuzzy method conducts nonlinear crisp programming that cannot be solved within a reasonable time, even for small-sized problems. Thus, the meta-heuristic algorithms that can help to solve the models in large sizes are proposed for future research. So, the industrial cluster system has a wide variety of objectives for suitable economic development that can be developed and tested. So, in future studies on the main decision variable, other scenarios can be developed in dimensions and indices. In a co-operation network, if the firms have various or parallel production lines with different technologies, it can be considered in the developed model. Moreover, the labor assignment can be considered during the network design as well as the clustering stage as another direction for future study.

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