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Digital manufacturing challenges through open innovation perspective

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Abstract

Companies digitized with the fourth industrial revolution should create an ecosystem of innovation that provides opportunities for dialogue with all the parties involved. Technological developments and transformations should be reflected in innovation processes based on Open Innovation principles. Hence, the purpose of this paper is to analyse and to discuss the Industry 4.0 in Open Innovation perspective. The operational approach consists in identifying and in ranking the determinants that characterize the phenomenon for studying the interrelations between them, using AHP and ISM methods. As a result, Dynamic Capabilities and Know-how emerged as relevant drivers. Anyway, Industry 4.0 paradigm in Open innovation perspective is led by other factors, even though they are weak drivers. Enhancing the understanding of these factors and their interrelations provides valuable insights for each stakeholders and policy maker in the I4.0 environment, thus facilitating this paradigm in Open Innovation perspective.

Keywords: Industry 4.0; Open Innovation; Analytic Hierarchy Process; Interpretive Structural Modeling; determinants, integrated approach

1. Introduction

Industry 4.0 (I4.0) is probably the most disruptive concept for most Industries. I4.0 enabled by the Internet of Things (IoT) allows for the integration of people, applications and assets within a company. It also fosters the integration of a company with its wider ecosystem, potentially consisting of subcontractors, customers, suppliers and R&D partners [1].

Major trends that encourage I4.0 are shorter product and service lifecycles and therefore the need to speed up time to market. This will increase the need for innovation and will introduce both complexity and cost. It may also bring organizations to their limit in terms of innovation capacity and capabilities in-house. Open Innovation can be an approach to master the innovation game and to stay competitive in fast-changing markets. The term Open Innovation was coined by Henry Chesbrough, a professor at UC Berkeley's Haas Business School. In his definition it is "the use of purposive inflows and outflows of knowledge to accelerate internal innovation and to expand the markets for external use of innovation". This approach is based on the acknowledgement that knowledge and experience within an organization are necessarily limited and that internal regulations and processes may even represent further limitations to innovation.

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I4.0 is all about connectivity including the integration with a customer`s ecosystem such as suppliers and customers. IoT and related solutions or platforms may provide the integration layer to drive joint innovation. Customers and consumers might also be integrated via “crowdsourcing” [2]. This method makes use of a group of people that will work on a dedicated development topic via an internet platform.

Furthermore, due to the contributions of numerous academic studies and a more thorough understanding of Open Innovation paradigm, Chesbrough et al. proposed a novel definition: *“a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with each organization's business model”* [3,4].

Starting from Chesbrough novel definition, the links between the chosen determinants try to demonstrate that all the interventions act and extend this new way of innovating characterized by in OI perspective. Since the introduction of Open Innovation to the literature, numerous academicians made contributions to develop and enhance the understanding of the paradigm [5]. Some academic studies argue that Open Innovation is a dynamic capability and carry Open Innovation into the domain of theories of firm strategy [6,7,8], while others focused on the relationship between Open Innovation and other main streams of research such as dynamic capabilities [6], resource-based view [9], absorptive capacity [10], internal R&D [11], intellectual property [4,12], now it is the time for I4.0.

The rest of the paper is organized as follows: Section 2 analyses research methodology; in section 3 the determining factors of I4.0-OI are identified; section 4 analyses interrelations among the determinants using ISM Methodology; discussion of the main results is presented in section 5. Finally, in section 6 the main conclusions of the study are presented.

Nomenclature

AHP	Analytic Hierarchy Process
AM	Additive Manufacturing
AMS	Advanced Manufacturing Solutions
AR/VR	Augmented Reality
DC	Dynamic Capabilities
DIH	Digital Innovation Hub
H/V Int	Horizontal and Vertical Integration
I4.0	Industry 4.0
I4.0-OI	I4.0 in OI perspective
IC	Inconsistency Index
ISM	Interpretive Structural Modeling
KET	Key Enabling Technology
LE	Large Enterprise
MADM	Multi-Criteria Decision Aid
OI	Open Innovation
R&D	Research and Development
SME	Small and Medium Enterprise
SSIM	Structural Self-Interaction Matrix

2. Research methodology

The aim of this section is to define the methodology to identify the driving factors in I4.0 paradigm and their relations within perspective of Open Innovation (I4.0-OI). Two existing methods have been used to achieve this goal: the Analytic Hierarchy Process to identify and screen the driving factors for I4.0-OI and the Interpretive Structural Modeling to analyse the connection between the driving factors I4.0-OI.

Each of the two methods requires choices. These were made by a group of academic experts composed of engineers, economists and statisticians.

2.1. Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a Multi-Criteria Decision Aid (MADM) method created by Thomas L. Saaty [13]. Individual experts’ experiences are utilized to estimate the relative magnitudes of factors through pair-wise comparisons. Each of the respondents has to compare the relative importance between the two items using Saaty’s scale from 1 to 9 [14]. An inconsistency index (IC) is then generated which must be at most 10% [15]. Usually, AHP is employed with the following four steps: 1) Step #1: Elaborate the decision hierarchy; 2) Step #2: Determine the importance of attributes and sub-attributes; 3) Step #3: Evaluate the performance of each alternative and 4) Step #4: Control the consistency of the subjective evaluations.

The SuperDecisions® software was used for AHP implementation.

2.2. Interpretive Structural Modeling

Original theoretical development of Interpretative Structural Modeling (ISM) is credited to J.W. Warfield. Farris and Sage [16], Sage [17], Sage and Smith [18] have contributed to the development and application of the ISM methodology for a variety of purposes. ISM has been used by researchers to understand direct and indirect relationships among various variables in different fields.

A stepwise procedure is to be adopted to develop an ISM. The steps used in this text are four and are the following:

1. Step #1: From the variables identified by AHP, a Structural Self-Interaction Matrix (SSIM) is developed for them, which indicates wise relationships between pairs between the variables of the system under examination.
2. Step #2: Reachability matrix is developed from the SSIM and the matrix is checked for transitivity. The transitivity of the contextual relation is a basic assumption made in ISM. It states that if a variable A is related to B and B is related to C, then A is necessarily related to C.
3. Step #3: The reachability matrix obtained is partitioned into different levels.
4. Step #4: A classification of the determinants is carried out.
5. Step #5: A directed graph, representing the ISM model, is drawn.

3. Determinants identification and screening

In this phase determining factors of I4.0-OI have been identified. First of all, a hierarchy has been established, since AHP has a hierarchical structure. The chosen AHP hierarchy consists of an overall goal at the first level, a group of Criteria at the second level and the Subcriteria at the last level. The hierarchical composition is as follows: 1) Goal: Selection of factors with greater influence; 2) Criteria: Groups of determinants and 3) Subcriteria: Six subcriteria that collect the determinants associated with each group.

The next step is to make comparisons in pairs between the determinants (Subcriteria), with reference to the group they belong to present at the upper level (Criteria), in the modalities and through the Saaty's scale.

3.1. Determinants identification and comparison

For the identification of the determinants (Subcriteria), the starting point was the definition of the drivers represented as macro-groups (Criteria). Their choice was based partly on experience and partly on available literature. The expert team has identified 6 groups, which represent the way to do I4.0 from an Open Innovation perspective.

The first group is represented by the types of collaboration, that are the joint venture, the acquisition and the merger [17]. In particular, Collaboration is the basic principle of the Open Innovation concept [20], but also for I4.0 which requires the strengthening of collaborations between companies or between business clusters, but also with the actors of the value chain.

The second group is the dynamic capabilities of an organization. Through them, companies are able to recombine internal and external resources and skills to respond to environmental changes and to create market change, but also to balance the growing need to open the company towards the surrounding environment with his need to preserve its identity. The dynamic capabilities identified were derived from the literature and are absorptive, adaptive, integrative, creative capabilities [21] and intuitive, reconfiguration capabilities [6].

The third group is represented by the nine Key Enabling Technologies of I4.0, defined by European Commission.

The fourth group consists of the company's Know-how, which represents the set of confidential technical-industrial and commercial knowledge. It is a competitive asset of extraordinary importance for every company. In this paper the Know-how applied to the organization, the process and the product have been chosen.

The fifth group concerns the policies that guide the two paradigms and, in particular, refers to international, national and local policies.

The sixth and final group includes the stakeholders, who are directly or indirectly involved in a project or in the activity of a company. Public stakeholders (universities, research centers, laboratories, business incubators, digital innovation hubs and competence center) have been chosen, because they are involved in technology transfer. Private stakeholders have been chosen as generators of innovation, i.e. small and medium enterprises and large enterprises.

All groups and each determinant are represented in Table 1.

Table 1. Groups and Determinants of I4.0-OI

Groups (Criteria)		Determinants (Subcriteria)
Collaboration		Acquisition Merger Joint Venture
Dynamic Capabilities		Absorptive Intuitive Reconfigurative Adaptive Integrative Creative
KET		Horizontal/Vertical Integration Industrial Internet Advanced Manufacturing Solutions Big Data & Analytics Cloud Cyber Security Augmented Reality Simulation Additive Manufacturing
Know-how		Organization Process Product
Policy		International National Local
Stakeholder	Public	Universities Research Centers Laboratories Business Incubators Digital innovation Hubs Competence Centers
	Private	SMEs LEs

Once all the factors had been identified, the SuperDecisions® software was used and the first pairwise comparison between the criteria was carried out. The comparison takes place in a matrix m × n-sized, where each row element *(i)* is compared with the column element *(j)*.

Table 2 shows the comparison matrix between the groups.

Table 2. Criteria comparison

Criteria	Dynamic Capability	KET	Know-how	Policy	Stakeholder
Collaboration	0,14	0,50	0,17	2	0,25
Dynamic Capabilities		7	2	9	3
KET	0,14		0,17	0,33	0,50
Know-how	0,50	6		7	2
Policy	0,11	3	0,14		0,25

The results reported in Table 3 show that dynamic capacities have an important weight of 41%, while collaboration methods have a marginal impact, together with the types of policy (5%) and the KETs (6%)

Table 3. Weigth of criteria

Criteria	Weight
Dynamic Capabilities	0,40981
Know-how	0,27888
Stakeholder	0,14854
Policy	0,05671
KET	0,05467
Collaboration	0,05139

The inconsistency that SuperDecisions® returned is equal to 0.08086 (margin of error of around 8%): it means that the choices were consistent. Similarly, the determinants (Subcriteria) were determined. In the following paragraphs the comparisons are reported in detail and the weights of each element is given with reference to the group to which it belongs.

3.1.1. Collaboration

Comparison of the collaboration, represented in Table 4, shows that the most influential modality is the merger between companies (Table 5). In fact, a permanent collaboration allows to benefit from the advantages linked to the high valorisation of existing competences, to a high development of new skills, as well as to quick access to competences of other companies.

Table 4. Collaboration comparison

Collaboration	Joint Venture	Merger
Acquisition	4	0,33
Joint Venture		0,14

Table 5- Weight of Collaboration determinants

Determinants	Weight
Merger	0,65863
Acquisition	0,26275
Joint venture	0,07862

3.1.2. Dynamic capabilities

Dynamic capabilities don't impact on goal in the same way. Starting from the comparison shown in Table 6, each weights determinant (Table 7) demonstrates that intuitive and absorptive capabilities are more influent than others. In fact, the first one includes all those skills that concern the scanning and monitoring of environmental changes, as to be able to perceive new business opportunities. The second one indicates the ability to absorb knowledge from the outside and implement it.

Table 6. Dynamic Capabilities comparison

Dynamic Capabilities	Adaptive	Creative	Integrative	Intuitive	Reconfigu-rative
Absorptive	2	4	5	0,50	3
Adaptive		3	4	0,25	2
Creative	0,33		2	0,17	0,50
Integrative	0,3	0,50		0,14	0,33
Intuitive	4	6	7		5

Table 7. Weight of Dynamic Capabilities determinants

Determinants	Weight	Determinants	Weight
Intuitive	0,42254	Reconfigurative	0,09300
Absorptive	0,23841	Creative	0,05961
Adaptive	0,14635	Integrative	0,04009

3.1.3. Key Enabling Technologies

Comparison of KETs is more interesting. From the comparisons between the criteria it emerged that the KETs have a low incidence with values that average around 10% (Table 3), although they are the main features that mark I4.0. Only the horizontal/vertical integration is found to have a non-negligible incidence equal to 33%.

This result is expected: digital technologies push to foster I4.0 from an Open Innovation perspective, but the fundamental aspect is that technologies do not remain restrict in the company. Regardless of the implemented technology, interaction with actors inside and outside the value chain is fundamental. In fact, the horizontal/vertical integration concerns information exchange related to digital technologies.

In Table 8 number value for comparison are shown and in Table 9 weight of determinants are shown.

Table 8. KETs comparison

KET	AM	AR/VR	Big Data	Cloud	Cyber Security	H/V Int	Industrial Internet	Simulation
AMS	5	4	1	2	3	0,3	0,50	4
AM		0,50	0,20	0,25	0,33	0,13	0,17	0,50
AR/VR	2		0,25	0,33	0,50	0,14	0,20	1
Big Data	5	4		2	3	0,25	0,50	4
Cloud	4	3	0,50		2	0,20	0,33	3
Cyber Security	3	2	0,33	0,50		0,17	0,25	2

Table 9. Weight of KETs determinants

Determinants	Weight	Determinants	Weight
Horizontal/Vertical Integration	0,33477	Cyber Security	0,05274
Industrial Internet	0,19369	Augmented Reality	0,03432
Advanced Manufacturing Solution	0,12315	Simulation	0,03432
Big Data & Analytics	0,12315	Additive Manufacturing	0,02369
Cloud	0,08016		

3.1.4. Know-how

The determinants evaluation of this criterion has all been considered equal, because the innovation can affect indifferently the organizational levels, the process or the product or all three together. It follows that the weight of the three factors is the same, as shown in Table 10 and Table 11.

Table 10. Know-how comparison

Know-how	Process	Product
Organization	1	1
Process		1

Table 11. Weight of Know-how determinants

Determinants	Weight
Organization	0,33
Process	0,33
Product	0,33

3.1.5. Policy

In this specific context, policies play a marginal role. Intended as incentive policies, these are only a further push for companies that intend to implement I4.0 solutions from an Open Innovation perspective.

The first objective is the internationalization, coordination and integration of national and local policies with European and global ones. The increasing weight of European resources compared to national ones and ultimately those with competitive access compared to ordinary ones, impose a paradigm shift in national planning activities. For this reason, it is a priority to integrate the programming and state resources with European resources organically. All this is confirmed by the comparison (Table 12), where it emerged that there is a hierarchy: international policies prevail over national ones which, in turn, prevail over local policies, as shown in Table 13.

Table 12. Policy comparison

Policy	Local	National
International	7	4
Local		0,3

Table 13. Weight of Policy determinants

Determinants	Weight
International	0,70494
National	0,21092
Local	0,08414

3.1.6. Stakeholder

Stakeholders importance depends to their nature, private or public actors. Companies play role of innovation generators. Public actors, on the other hand, play different roles, including sponsor, knowledge brokers, technology brokers and scientific researchers (R&D). It follows that, from an Open Innovation perspective, these have a key role to play. An example comes from universities that boast of a growing number of academic spin-offs. In fact, the university is at the top of the ranking with an influence equal to 33% (Table 15). This percentage is the result of the comparison shown in the Table 14.

Table 14. Stakeholder comparison

Stakeholder	Competence Center	DIH	Laboratories	LEs	Research Center	SMEs	University
Business Incubator	2	3	4	6	0,50	5	0,33
Competence Center		2	3	6	0,33	4	0,25
DIH	0,50		2	4	0,33	3	0,20
Laboratories	0,3	0,50		3	0,20	2	0,17
LEs	0,2	0,33	0,33		0,1	0,50	0,13
Research Center	3	4	5	7		6	0,50

Table 15. Weight of Stakeholder determinants

Determinants	Weight	Determinants	Weight
University	0,33132	Digital Innovation Hub	0,07094
Research Center	0,23066	Laboratory	0,04768
Business Incubator	0,15724	SMEs	0,03270
Competence Center	0,10590	LEs	0,02356

3.2. Determinants screening

The last step of this section consists of choosing the main determinants based on the relative weight of each ones. The weights calculated by SuperDecisions® are recalculated by comparing each determinants weight to the total weight of all 32 determinants, that is equal to 5,99998, hence relative weight is obtained. Then the determinants are sorted in ascending order. It has been decided to take the first eleven determinants (Table 16), thus explaining 70% of the phenomenon, while the last 21 determinants explain only 30% of it.

Table 16. Weight and relative weight

ID	Determinants	Weight	Relative Weight
1	International	0,70494	0,117490392
2	Merger	0,65863	0,109772033
3	Intuitive	0,42254	0,070423568
4	H/V Integration	0,33477	0,055795186
5	Organization	0,33333	0,05556
6	Process	0,33333	0,05556
7	Product	0,33333	0,05556
8	University	0,33132	0,055220184
9	Acquisition	0,26275	0,043791813
10	Absorptive	0,23841	0,039735132
11	Research Center	0,23066	0,038443461
	Total Weight		0,697337

Table 16 shows how the set of chosen determinants belongs to all the different drivers considered. In particular, there are: 1) International belonging to the criterion Policy; 2) Merger and Acquisition belonging to the criterion Collaboration; 3) Intuitive and Absorptive belonging to the criterion Dynamic Capabilities; 4) Horizontal/Vertical Integration belonging to the criterion KET; 5) Organization, Process and Product belonging to the criterion Know-how and 6) University and Research Center belonging to the criterion Stakeholder.

The completeness of the set chosen and the weight that it represents, lead to believe that it is a good set of determinants in order to estimate the integrated phenomenon of the I4.0 and Open Innovation.

4. Determinants interrelation analysis

In this phase, the ISM Methodology is used to identifying and to analyzing interrelations among the determinants.

The following paragraphs describe the phases of the process.

4.1. Structural Self-Interaction Matrix

As suggested by ISM Methodology [17,22], academic experts group involved in this step was able to identify the pairwise relationship between determinants.

To express the presence and the direction of the relationship between the determinants *i* (row determinants) and *j* (column determinants), four symbols in the SSIM are used:

- V: determinants *i* will lead to parameter *j*, so there is a dependence of the column parameter by the row parameter.
- A: determinants *j* will lead to parameter *i*, so there is a dependence of the row parameter by the column parameter.

- X: determinants *i* and *j* will lead to each other, so there is a interdependence between the row and column parameters.
- O: determinants *i* and *j* are unrelated, so there isn't any relationship between them.

On the basis of contextual relationship between determinants, the SSIM has been developed.

Final SSIM is presented in Table 17.

Table 17. Structural Self-Interaction Matrix (SSIM)

Determinants	1	2	3	4	5	6	7	8	9	10	11
International		V	O	V	O	O	O	X	V	O	X
Merger			A	X	V	V	V	O	O	V	O
Intuitive				X	V	V	V	A	V	V	A
H/V Integration					X	X	X	O	X	X	O
Organization						A	A	O	X	A	O
Process							O	O	A	A	O
Product								A	A	A	A
University									O	V	X
Acquisition										V	O
Absorptive											A
Research Center											

4.2. Reachability Matrix

In this second step, the SSIM is converted into a binary matrix, called Reachability Matrix, replacing the symbols explained in the previous paragraph with 1 and 0, in accordance with the following rules:

Table 18. Rules of transformation

(i, j) entry in the SSIM	Entry in Reachability Matrix *(i, j)*	*(j, i)*
V	1	0
A	0	1
X	1	1
O	0	0

The complete reachability matrix, shown in Table19, included the driver and dependence power.

The first one is the total number of determinants (including itself), which it may help to achieve, while the second is the total number of factors (including itself), which may help in achieving it.

Table 19. Reachability matrix

Determinants	1	2	3	4	5	6	7	8	9	10	11	Driver
1 International	1	1	0	1	0	0	0	1	1	0	1	6
2 Merger	0	1	0	1	1	1	1	0	0	1	0	6
3 Intuitive	0	1	1	1	1	1	1	0	1	1	0	8
4 H/V Int.	0	1	1	1	1	1	1	0	1	1	0	8
5 Organiz.	0	0	0	1	1	0	0	0	1	0	0	3
6 Process	0	0	0	1	1	1	0	0	0	0	0	3
7 Product	0	0	0	1	1	0	1	0	0	0	0	3
8 University	1	0	1	0	0	0	1	1	0	1	1	6
9 Acquisition	0	0	0	1	1	1	1	0	1	1	0	6
10 Absorptive	0	0	0	1	1	1	1	0	0	1	0	5
11 Research C.	1	0	1	0	0	0	1	1	0	1	1	6
Dependence	3	4	4	9	8	6	8	3	5	7	3	

4.3. Level partition

After creating the Reachability Matrix, this step consists of creating a partition level, with the aim to build the diagraph and final model.

For each determinant are reported: 1) On the first column the reachability set, that consists of the element itself and other elements that it may help achieve; 2) On the second column the antecedent set, that consists of the element itself and the other elements which may help achieving it; 3) On the third column the intersection between the previous columns.

The factors for which the reachability and intersection sets are the same is the top-level element in the ISM hierarchy. When the top-level element of the hierarchy is identified, it is separated out from the other elements.

Then, by following the same process, the next level of elements is found. This iteration is repeated till the levels of each factor are found.

The results of iterations are shown in Tables 20-25.

Table 20. Iteration 1

Det	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 4, 8, 9, 11	1, 8, 11	1, 8, 11	
2	2, 4, 5, 6, 7, 10	1, 2, 3, 4	2, 4	
3	2, 3, 4, 5, 6, 7, 9, 10	3, 4, 8, 11	3, 4	
4	**2, 3, 4, 5, 6, 7, 9, 10**	**1, 2, 3, 4, 5, 6, 7, 9, 10**	**2, 3, 4, 5, 6, 7, 9, 10**	**I**
5	**4, 5, 9**	**2, 3, 4, 5, 6, 7, 9, 10**	**4, 5, 9**	**I**
6	4, 5, 6	2, 3, 4, 6, 9, 10	4, 6	
7	4, 5, 7	2, 3, 4, 7, 8, 9, 10, 11	4, 7	
8	1, 3, 7, 8, 10, 11	1, 8, 11	1, 8, 11	
9	4, 5, 6, 7, 9, 10	1, 3, 4, 5, 9	4, 5, 9	
10	4, 5, 6, 7, 10	2, 3, 4, 8, 9, 10, 11	4, 10	
11	1, 3, 7, 8, 10, 11	1, 8, 11	1, 8, 11	

Table 21. Iteration 2

Det	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 8, 9, 11	1, 8, 11	1, 8, 11	
2	2, 6, 7, 10	1, 2, 3	2	
3	2, 3, 6, 7, 9, 10	3, 8, 11	3	
6	**6**	**2, 3, 6, 9, 10**	**6**	**II**
7	**7**	**2, 3, 7, 8, 9, 10, 11**	**7**	**II**
8	1, 3, 7, 8, 10, 11	1, 8, 11	1, 8, 11	
9	6, 7, 9, 10	1, 3, 9	9	
10	6, 7, 10	2, 3, 8, 9, 10, 11	10	
11	1, 3, 7, 8, 10, 11	1, 8, 11	1, 8, 11	

Table 22. Iteration 3

Det	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 8, 9, 11	1, 8, 11	1, 8, 11	
2	2, 10	1, 2, 3	2	
3	2, 3, 9, 10	3, 8, 11	3	
8	1, 3, 8, 10, 11	1, 8, 11	1, 8, 11	
9	9, 10	1, 3, 9	9	
10	**10**	**2, 3, 8, 9, 10, 11**	**10**	**III**
11	1, 3, 8, 10, 11	1, 8, 11	1, 8, 11	

Table 23. Iteration 4

Det	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 8, 9, 11	1, 8, 11	1, 8, 11	
2	**2**	**1, 2, 3**	**2**	**IV**
3	2, 3, 9	3, 8, 11	3	
8	1, 3, 8, 11	1, 8, 11	1, 8, 11	
9	**9**	**1, 3, 9**	**9**	**IV**
11	1, 3, 8, 11	1, 8, 11	1, 8, 11	

Table 24. Iteration 5

Det	Reachability set	Antecedent set	Intersection set	Level
1	**1, 8, 11**	**1, 8, 11**	**1, 8, 11**	**V**
3	**3**	**3, 8, 11**	**3**	**V**
8	1, 3, 8, 11	1, 8, 11	1, 8, 11	
11	1, 3, 8, 11	1, 8, 11	1, 8, 11	

Table 25. Iteration 6

Det	Reachability set	Antecedent set	Intersection set	Level
8	**8, 11**	**8, 11**	**8, 11**	**VI**
11	**8, 11**	**8, 11**	**8, 11**	**VI**

4.4. Determinants classification

In this step the determinants are classified into four clusters: 1) Autonomous variables; 2) Dependent variables; 3) Linkage variables; and 4) Independent variables.

All the determinants are positioned in the different four quadrants according their different driver and dependence power. According to ISM Methodology each cluster could be described in the following way:

- The Autonomous factors have weak driving power and weak dependence, so these factors are disconnected from the system. Anyway, in this work there aren't any determinants is in this quadrant.
- The Dependent factors have strong dependence but weak driving and lie close to the top of ISM hierarchy. All the determinants belonging to the driver Know-how, and the determinant Absorptive emerged as dependent factors.
- The Linkage factors that have strong driving power and strong dependence. In this model only the determinant Horizontal/Vertical Integration lies in this cluster.
- The Independent factors having strong driving power but weak dependence.
  In the model this cluster is the most populated; here, it is possible to find the determinants International, Merger, Intuitive, University and Acquisition.

The resulting classification is shown in Figure 1.

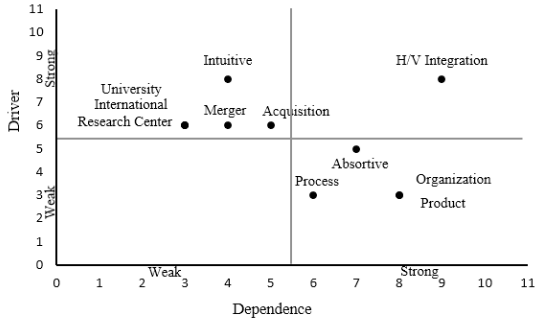

Figure 1. Driver and dependence diagram

4.5. ISM-Based Model Formation

The structural model is generated by means of vertices or nodes and lines from the Reachability Matrix (Table 20). If there is a relationship between factors *i* and *j*, this is shown by an arrow which points from *i* to *j*. After removing transitivity, the diagraph is finally converted into ISM, shown in Figure 2.

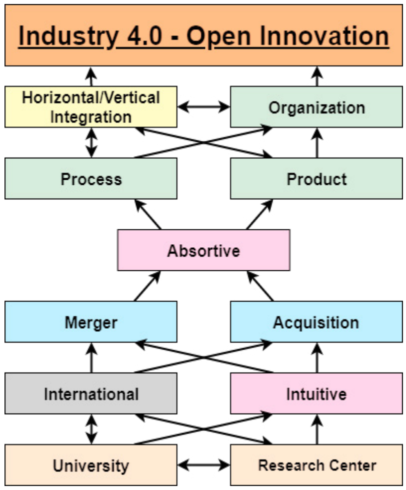

Figure 2. ISM-based model

5. Discussion

This paper provides a comprehensive model including direct and indirect effect of factors that analyse Industry 4.0 phenomenon starting from an Open Innovation perspective.

There will be a tradeoff between a maximum of innovation provided by the creativeness and input of several parties and the attempt to keep as much as possible of that innovation to oneself. Open and connected innovation as fostered by I4.0 will need to be considered by an integrated approach [23]. A better understanding of factors and their interrelation provide insight for a better understanding of current business environment, Open Innovation paradigm, so the near future of Industry 4.0

First of all, observing the ISM based model the level six, five and four put in evidence the bottom interrelations that involve four drivers on six, collaboration, policy, DC and stakeholders, with six determinant factors: merger, acquisition, international, intuitive, university and research center. This means I4.0 plan in OI perspective needs of several main factors related to significant drivers.

Furthermore, at level three of ISM-based model the absorptive DC is the central leverage that put in connection the previous levels (6, 5, 4) with next ones (2, 1) KET and Know-how. The central position of this determinant gives to this factor a core role, in other words it is like a glue to link bottom levels to up levels. Thus, from the formation of ISM-based model the next result is the definition of second and first level, respectively represented from Know-how and KETs drivers. The determinants of this ones at second and first level are in order process and product for the second, and organization and horizontal/vertical integration for the first level. In addition, final ISM model illustrates that availability of Know-how and KETs affect reachability of I4.0 plan in OI perspective. The results of this study illustrate the importance of access to up to date scientific knowledge in knowledge generation and quality of academic studies. Knowledge, unlike other assets, increases with share [24]. Hence, increasing access to digital technologies and all other KETs, along open innovation paradigm, empowers exponential growth in global knowledge generation [25]. Moreover, the results of this paper suggest that the inevitable trend of open innovation needs to be supported by digitalization and the whole I4.0 program, which is defined as the changes associated with the application of digital technology in all aspects of human society [26]. Finally, existence of more capable actors in an economy results in an increase in the number of collaborations and the level of openness, which is an inevitable trend in today's business conditions.

6. Conclusion

A contribution of this study is the illustration of strategic role of Know-how and KETs in facilitating the transformation from a closed approach to open innovation, policies and incentives to increase its availability and finally its contributions to national innovative performance.

Determinants of this study were defined starting from available literature and adding some more factors chosen through experience. Hence, subjective component of this approach affects AHP and SSIM results. This means that, if the judgement group changes, final result could be different. To reduce this limit, the suggestion for future research is to give a statistical validation to method used. Increase in quality of academic studies and knowledge intensity, therefore, make significant contribution to final value of all researches providing the ground for looking forward. After all, *"if you have an apple and I have an apple and we exchange these apples then you and I will still each have one apple. But if you have an idea and I have an idea and we exchange these ideas, then each of us will have two ideas"* (Charles F. Brannan, Secretary of Agriculture, from a broadcast over NBC, April 3, 1949).

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