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Identification of stakeholder related barriers in sustainable manufacturing using Social Network Analysis

Abstract

Sustainable manufacturing (SM) is crucial for our future manufacturing and it starts to have an evolutionary development. However, manufacturing industries are difficult to adopt sustainability measures because of considerable barriers under the triple bottom line (TBL): economy, environment and people. Previous research works mainly focused on the originality and the definitions of the barriers in SM, they seldomly consider the stakeholder-related affairs on SM and the causal relationships between the barriers in SM. Therefore, this study aims to propose a comprehensive analysis of barriers in SM using social network analysis (SNA), with detailed consideration of stakeholder concerns in terms of TBL. This study applies SNA to recognize and investigate the underlying stakeholder-related barriers and their causal relationships in SM, and the suggestions were provided upon the findings of SNA to help for mitigating the negative influences from critical barriers to SM. The validation is provided by showing the effectiveness of suggestions in which decreases in the network density and average geodesic distance simultaneously after the modification. This study contributes to not only displaying the efficient way to probe the stakeholder-related barriers in SM, but also offering the guideline to support the measures proposing in the future by using the same analytic technique in SNA which is demonstrated in this study.

Keywords: Social network analysis; Sustainable manufacturing; Stakeholder; Barriers to sustainability; Triple bottom line

1. Introduction

Sustainable development is a process that continuously matches human activities as well as retains the ability of natural function and ecosystem for offering the natural sources to our community, with the considerations of environment, economy, and society (Daly, 2006). In order to prolong operations in organizations, the operations must enable to fulfill the needs of the present state and avoid undermining the rights and resources of our future generation. The preferred outputs of sustainability are that living conditions and natural resources are capable to be used continuously without diminishing the integrity and reliability of the natural and ecosystem. With adequate consideration for our future generation, the processes initiated by organizations could be continuously conducted, bringing substantial benefits to our society and economy.

The attention to sustainability has been drawn strictly by academia and industries today. Sustainability is a crucial issue for the current and our future generations. Because of the limited natural resources and capacities of our plants, the damages and exhausts from human activities to our environment are not appointed to be replaceable. According to a literature report, sustainability is defined as growth that meets the needs of the present situation without scarifying the capability of the next generation to satisfy the current needs (Seidel et al., 2007). Sustainability development definitely covers the entire community including the human being, lying into the triple bottom line: economy, environment, and plant (Garetti and Taisch, 2012).

2. Literature Review

The sustainability concept has already been applied in several areas especially manufacturing and engineering. Actually, manufacturers growingly concern about sustainability issues, in particular to the recognition of the relationships between manufacturing operations and the affected stakeholders, which play a crucial role in the decision-making of strategies of sustainable development (Rosen andKishawy, 2012). In which, Sustainable manufacturing (SM) is broadly defined as the practices and implementations of technologies to convert materials into desired products with remarkable reductions in energy consumption, emission of pollutants, generations of wastes and good use of renewable materials and non-toxic materials (Madu, 2012). SM is treated as one of the main directions for future manufacturing (Jovane et al., 2008), and an endless improvement with reasonable implementation time to respond to this challenge in order to facilitate the smooth executions of SM. However, involvement in sustainability activities remains a challenge to industries as the sustainability concept is incredibly complicated (Rashid et al., 2013) with inclusions of many barriers especially the concern of stakeholders.

With the complexity adding by barriers, barriers of SM are focused to investigate, and researchers tend to establish effective ways to break through the barriers for implementing SM successfully. In order to mitigate the barriers, the considerations of enormous factors across various manufacturing processes and the linked stakeholders are needed. Hence, the understandings of differences between factors and causal relationships between stakeholders are necessary, which is one of the important tasks for highlighting the gap and being filled up by this study. However, previous studies about SM do not mainly consider the factors from the perspective of stakeholders, for example, Malek and Desai (2019) evaluated the SM barriers and consider them into different areas such as organizational, social and environmental barriers. DuPreez and Oosthuizen (2019) considered the barriers of SM and focused on the areas of cost savings, time savings, increased quality and waste reduction. Sen et al., (2019) concentrated on the machining parameters in executing SM and discussed the SM difficulties in the direction of cutting fluid. Barriers related to stakeholders for executing SM are still not discussed in detail in academia. Furthermore, previous works on SM do not seriously consider the interrelationships relating to the fundamental factors and their factual influences with a network basis. Therefore, this study aims to develop a network model to determine and connect the stakeholder-related barriers in SM by using social network analysis (SNA) and provides suggestions to mitigate the barriers with the considerations of the entire barrier network built up in SNA. Actually, SNA is a tool for investigating social structures by applying the network and graph theories. In recent years, SNA has attracted enormous attention because of the favorable outcomes of online social networking. SNA is started to employ by researchers for several research topics such as medical (Gardy et al., 2011) and agricultural innovations (Hermans et al., 2017; Wood et al., 2014). It has been used as a statistical tool and acted as a bridge to connect the different topics for interdisciplinary researches such as psychology, anthropology, economics, geography and biology (Bonchi et al., 2011). For the detail of SNA and calculations of the metrics for SNA, they would be discussed in later sessions. In this study, critical barriers concerning related stakeholders that significantly affect SM are identified by SNA, and coherent strategies are drawn up to pose the challenges encountered in the executions of SM in industries in terms triple bottom line (TBL).

3. Method

In this study, the relationships between the barriers of SM are used to construct the SM network and determine the influences of the barriers corresponding to the particular stakeholders on another barrier, in terms of TBL. The SM network is established based on the causal relationship of the barriers, after that, the network theory especially of the network metrics is used to describe the characteristics of the stakeholder-related barriers. The detail of SNA is discussed below.

3.1 Theory

Social network analysis (SNA) has been widely applied in various fields including ecology (Farine and Whitehead, 2015), tourism (Luo and Zhong, 2015), sport science (Loughead et al., 2016) and education (Cooc and Kim, 2017). Nevertheless, the use of SNA in the SM area is rare, which the analysis of stakeholder-related barriers in SM is still a blank which needs to be filled up. Generally, the processes for implementation of SNA in research are gone through few steps: (1) identification of the related factors as the nodes at the network construction, (2) establishment of the factor interrelations, (3) determination of the matrices for analysis using SNA theory. For steps (1) and (2) in this study, they would be conducted by literature review in this study. For the step (3), the determinations of main matrices, degree centrality, closeness centrality and between centrality in SNA, are signaled by the equations shown in following session.

Degree centrality is obtained by calculating the ratio of the number of direct links to the corresponding nodes, which its formula C_D is

$$C_D(n_i) = \sum_i x_{ij} = \sum_j x_{ji} \quad (1)$$

where x_{ij} is the number of links connecting between node I and node j. It is equal to 1 if there exists a connection between n_i and n_j. Degree centrality is normally normalized as a percentage. Degree centrality expresses the sources of the behaviors from the network members in the network. Degree centrality demonstrates the level of network members influencing other network members by their behaviors directly and indirectly. The nodes with relatively high C_D mean that network members are active among the other network members within the network. In the case of SM network of stakeholder-related barriers, degree centrality represents the level of visibility caused by the activities from the particular nodes. More specifically for the topic of the stakeholder-related barriers of SM, it indicates the level of influences of the barriers on the other barriers at the same network under consideration of different stakeholders.

Closeness centrality can be obtained by the calculation based on the geodesic distance $d(n_i,n_j)$ between two nodes, which is expressed as the shortest length of the path between node n_i and node n_j (Frenken, 2000; Hakimi, 1964). It is worth knowing that for the directional network, the geodesic distance from node n_i to node n_j is not generally identical to the geodesic distance from node n_j to node n_i. The closeness centrality C_c is denoted as:

$$C_c(n_i) = \left[\sum_{j=1}^{g} d(n_i, n_j)\right]^{-1} \quad (2)$$

where $\sum_{j=1}^{g} d(n_i, n_j)$ is the total distance of node n_i connected with other nodes in the network. Normally, the value of closeness centrality demonstrates the class of closeness of one node to other nodes within the same network numerically. A node is said to be high closeness centrality if it has the highest number of network members with relatively shorter paths. The nodes having high closeness centrality have a relatively high likelihood to draw on the resources, in contrast to the other nodes in the same network. In the case of the SM network, closeness centrality represents the ability of the barriers to acquire resources from other barriers at the same network. More specifically, it indicates the ability of stakeholder-related barriers to influence the performance of SM and the ability to navigate the other barriers in order to cause significant effects on SM.

The value of betweenness centrality shows the class of the network member joining the shortest path over all the combinations of network pairs. A network member is treated as a bridge in the entire network. If the network member with high betweenness centrality is separated or moved apart from the network, the communications between other dependent network members in the same network will be disrupted significantly, leading to an untenable exchange in resources within the network. Betweenness centrality C_B is determined by

$$C_B(n_i) = \sum_{j<k} \frac{g_{jk}(n_i)}{g_{jk}} \quad (3)$$

where g_{jk} is the total number of geodesic connections between node i and node j, $g_{jk}(n_i)$ is the number of geodesic connections dependent on node n_i. Betweenness centrality is then calculated by summarizing all the probability of reaching the node positioning between other nodes in the same network. Betweenness centrality is considered as the ability of “gatekeeping” of certain nodes for the other network members at the same network (Borgatti and Everett, 2006), and it represents the function of controlling the information flow from upstream members to the downstream members in the network. Therefore, in the case of the SM network, it means the ability of particular barriers to act as a hub function to transfer the influences on the entire SM network.

3.2 Research steps

Figure 1 shows the steps of how to execute SNA to analyze the stakeholder-related barriers of SM in this study. The first step in this study is to identify the stakeholders in SM nowadays through literature. With the confirmation of the stakeholders in SM, the related barriers in SM that directly affecting the implementations of SM strategies are enabled to search from the related literature, which aims to connect the main actors/network members with their relationships referring to literature, and consequently found out the related barriers with the TBL concept. The detailed literature reviews of SM and barriers with related stakeholders are conducted. The papers with highlights of barriers to sustainable development in the current society are chosen. After selecting the papers, the dependent contents in the papers are undergone screening processes to extract out the corresponding barriers, which those extracted barriers are matched with the stakeholders who are facing the difficulties causing by that barriers. After that, a coding process is required for each barrier with the specific stakeholder, in which all barriers are assigned with unit codes, and those codes are set as nodes in SNA in the later process.

The second step in this study is to establish the interrelationships between each barrier in SM. In this study, the links between the barriers are defined as the influences of the barriers corresponding to the particular stakeholder on another barrier. The links are again found out simultaneously in the stage of identification of stakeholder-related barriers during the literature review, in which the literature contents of the selected papers normally state the relationships implicitly. For the third step, the barrier network is constructed based on the inputs of the links and nodes obtained in the first and second steps to the NodeXL Pro software, which Nodexl Pro software enables to deliver the graphic network and the main metrics using the information of the constructed network and the linkages of nodes. It is an effective software to implement an advanced network metric analysis and calculation. With the inputs of all nodes and ties, the stakeholder-related barrier network of SM focusing on the TBL concept is obtained, and it helps to gain the overall insight for the interrelationships and the classifications of each barrier. In the fourth step, the main metrics related to the barrier network of SM are determined by the calculations defined in the SNA theory. The network density is also determined as this is the main indicator for showing the overall feature of the network. With the results of the main metrics of the network, the descriptive analysis could be performed. This step aims to acknowledge the interrelationship of barriers in the network and inspect worthy interactions that contain the metric scores over the threshold value, but not pointing toward the key inspected nodes. Therefore, in this step, the nodes with abnormally large or small values in the main metrics would be chosen to examine deeply and explore the particular influences on other stakeholder-related barriers.

The classification of the barriers is demonstrated in this study and it is one of the essential procedures for obtaining the input of SNA, which the approach of classification is inspired subsequently by the work of Li et al. (2016). Li et al. (2016) identified the stakeholders and the risk factors affecting the prefabrication housing production by dividing the stakeholders into several groups with various categories relating to the barrier nature. This study refers to the classification and applies the similar logic of the work of Li et al. (2016) in order to determine the stakeholder-related barriers of SM with the TBL concept. In this study, the modification of the approach has been done in order to divide the barriers into the three aspects of TBL and suits for the aims of this study. Therefore, in this study, there is the formation of two categories and they share the barriers with the same characteristics, it contributes to revealing the barriers with the features of more than one category. The multi-features of the network members in this study are new and novel, and it contributes to allowing similar studies in which they are required to divide more than one category for their research aims.

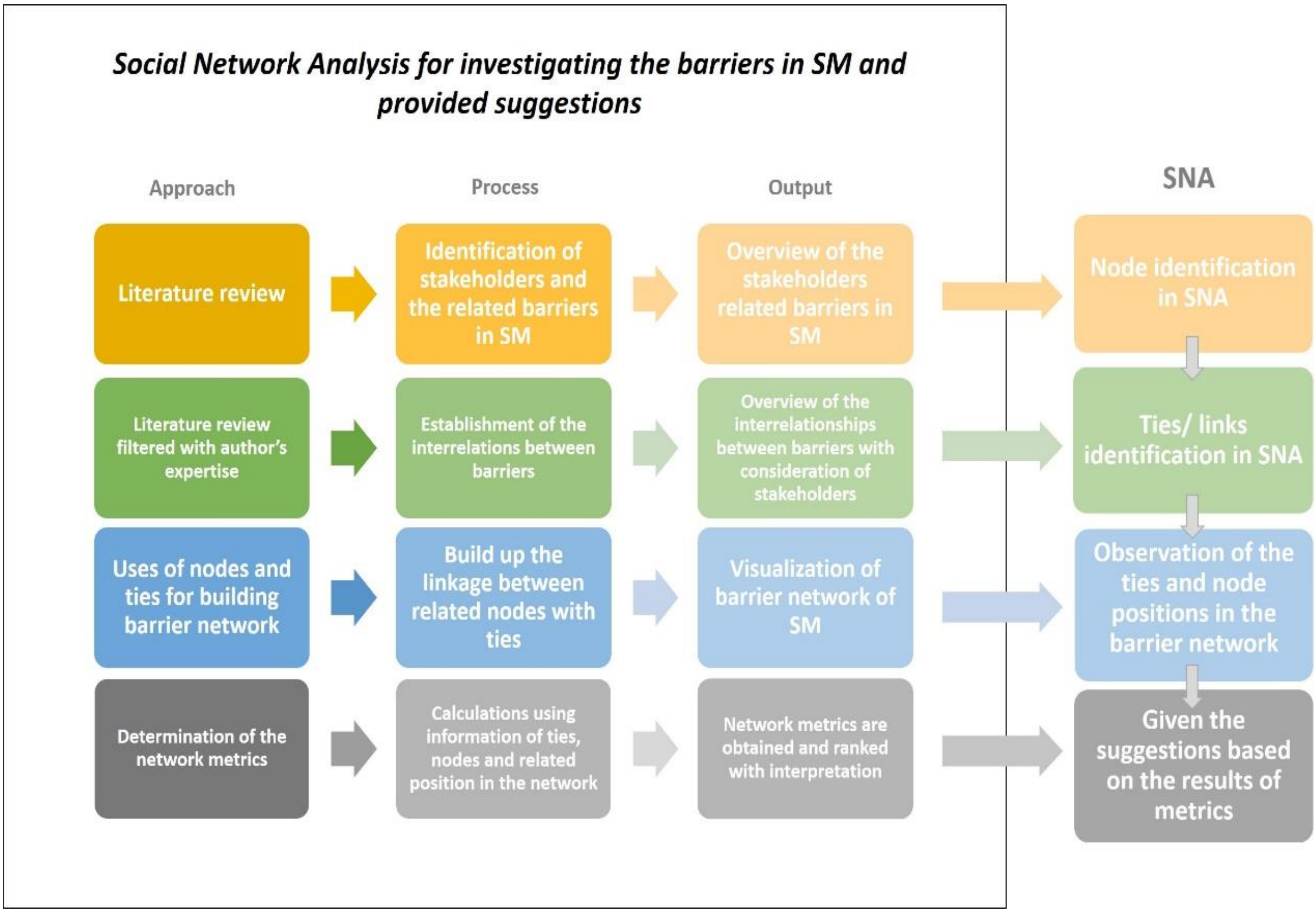

Figure 1. The research steps of analysis barriers in SM using SNA

3.3 Identification of stakeholder and related barriers in SM and corresponding coding

There are six identified stakeholders in this study which are shown in Table 1, they are customer, manufacturer, investor, supplier, community and retailer, and they are assigned with the codes of S1, S2, S3, S4, S5 and S6 respectively. After the determination of stakeholders of SM, the stakeholder-related barriers for corresponding parties are recognized. In this study, there are 21 barriers in SM revealed, with assignments of coding as B1-B21, and are demonstrated in Table 2. Moreover, the stakeholder-related barriers are classified into two categories, which Category 1 is related to the three aspects of TBL: environment, economy and society, while Category 2 is dependent on the nature of the stakeholder-related barriers defining in different areas, as shown in Table 3. Finally, all the stakeholders and stakeholder-related barriers are integrated, which the stakeholder-related barriers are assigned to the corresponding stakeholders, and the different combinations of barrier ID are generated, as shown in Table 4. The nodes of each stakeholder-related barrier are expressed as a code of S_xB_y, in which x is denoted as a particular stakeholder and y is denoted as the related barriers for those stakeholders. In this study, there 85 stakeholder-related barriers are identified in total. Actually, the input of the classification of barriers in this study is from the information of literature review, which literature review enables to provide the overview of the investigation targets from the source in the interdisciplinary nature (Snyder, 2019). Literature review is a good way for synthesizing the results of different research works to reveal the evidence of the view at the macro level and to discover the theory without an experimental approach, which it is very important to generate the theoretical frameworks of conceptual design (Fuertes et.al ,2020) (Snyder, 2019). In order to avoid the personal basis of the authors, in this study, the sources from literature review are selected by the searching function of Scopus, one of the scholarly databases, using the common word strings of SM definition. As a result, there is a low possibility that the barriers of SM and classification of Table 4 are created by the authors' flawed assumptions. On the other hand, the relevant literature is important for this study, when the abstracts of related literature are gone through, the authors enable to generate the idea map and assess the SM area to make the study persuasive by justifying the classification in Table 4. This is generally denoted as the process of transformation of "literature review" to "theoretical framework", as one of the functions of literature review. Therefore, the input of classification of barrier in Table 4 relies on a series of literature review, which enhances the reliability of the data.

Table 1. The identified stakeholders and the corresponding codes in SM

Stakeholder	Code
Customer	S1
Manufacturer	S2
Investor	S3
Supplier	S4
Community	S5
Retailer	S6

Table 2. The identified stakeholder related barriers in SM and the corresponding codes

Barrier Code	SM barriers
B1	Insufficient knowledge to recognize the sustainable usage of the product
B2	Insufficient knowledge to recognize the sustainable development of the manufacturing process
B3	Unclear environmental benefit from sustainable manufacturing
B4	Lack of concept of environmental responsibility

B5	Requires high initial cost of equipment for sustainable manufacturing
B6	A long period of return on investments
B7	Complicated pre-project planning - parties need to consider the design complexity of reuse/recycle,
B8	Complicated waste management - conserve natural resources and environmental protection
B9	Incorrect linkage of financial benefits with sustainable manufacturing
B10	The changes in traditional manufacturing culture require a large number of resources, knowledge and investments
B11	Lack of support from the top management causes to attach to the conventional approaches
B12	No proper encouragement and regulation for sustainable manufacturing
B13	Lack of training programs for employees about sustainable manufacturing
B14	Lack of educations for the adoption of environmentally conscious practices
B15	Lack of standardized metrics or performance benchmarks
B16	Fear of competitors taking advantages during the transfer from conventional to sustainable manufacturing
B17	Low availability of credit from the Bank for sustainable manufacturing
B18	Hight Trade-off from conventional manufacturing to sustainable manufacturing
B19	Low customer demand for environment-friendly products especially price-sensitive and uninformed customers
B20	Absence of pressure by key social actors
B21	Uncertain return

Table 3. The stakeholder related barriers are classified into the two categories

Category 1	Category 2
Society	Knowledge and Skill
Environment	Environment Concept
Economy	Managerial consideration
	Organization
	Society Issue
	Managerial consideration
	Environment Concept

Table 4. The stakeholder, barriers and the classification of barriers in SM

ID	Stakeholder Code	Stakeholder	Barrier Code	Barriers of sustainable manufacturing	Source	Category 1	Category 2
S1B1	**S1**	**Customer**	**B1**	**Insufficient knowledge to recognize the sustainable usage of the product**	**Massoud et al., 2010**	**Society**	**Knowledge and Skill**
S5B1	**S5**	**Community**				**Society**	**Knowledge and Skill**

S2B2	S2	Manufacturer	B2	Insufficient knowledge to recognize the sustainable development of the manufacturing process	Zhu and Geng, 2013	Society	Knowledge and Skill
S3B2	S3	Investors				Society	Knowledge and Skill
S1B3	S1	Customer	B3	Unclear environmental benefit from SM		Environment	Environment Concept
S2B3	S2	Manufacturer				Environment	Environment Concept
S5B3	S5	Community				Environment	Environment Concept
S1B4	S1	Customer	B4	Lack of concept of environmental responsibility	Mangla et al., 2017	Environment	Environment Concept
S2B4	S2	Manufacturer			Mathiyazhagan et al., 2013	Environment	Environment Concept
S3B4	S3	Investors			Bhanot et al., 2017	Environment	Environment Concept
S4B4	S4	Suppliers			Singh et al., 2016	Environment	Environment Concept
S5B4	S5	Community				Environment	Environment Concept
S6B4	S6	Retailer				Environment	Environment Concept
S2B5	S2	Manufacturer	B5	Requires high initial cost of equipment for sustainable manufacturing	Bar, 2015	Economy	Managerial consideration
S3B5	S3	Investor				Economy	Managerial consideration
S6B5	S6	Retailer				Economy	Managerial consideration
S2B6	S2	Manufacturer	B6	A long period of return on investments	Cagno et al., 2012	Economy	Managerial consideration
S3B6	S3	Investor				Economy	Managerial consideration
S4B6	S4	Supplier				Economy	Managerial consideration
S6B6	S6	Retailer				Economy	Managerial consideration
S2B7	S2	Manufacturer	B7	Complicated pre-project planning - parties need to consider the design complexity of reuse/recycle,	Govindan et al., 2014	Economy	Organization

S3B7	**S3**	**Investor**				**Economy**	**Organization**
S4B7	**S4**	**Supplier**				**Economy**	**Organization**
S6B7	**S6**	**Retailer**				**Economy**	**Organization**
S1B8	**S1**	**Customer**	**B8**	**Complicated waste management**	**Govindan et al., 2014**	**Environment**	**Organization**
S2B8	**S2**	**Manufacturer**				**Environment**	**Organization**
S5B8	**S5**	**Community**				**Environment**	**Organization**
S2B9	**S2**	**Manufacturer**	**B9**	**Incorrect linkage of financial benefits with sustainable manufacturing**	**Mont and Leire, 2009**	**Economy**	**Managerial consideration**
S3B9	**S3**	**Investor**				**Economy**	**Managerial consideration**
S4B9	**S4**	**Supplier**				**Economy**	**Managerial consideration**
S1B10	**S1**	**Customer**	**B10**	**The changes in traditional manufacturing culture require a large number of resources, knowledge and investments**	**Mont and Leire, 2009**	**Society**	**Society Issue**
S2B10	**S2**	**Manufacturer**				**Economy**	**Society Issue**
S3B10	**S3**	**Investor**				**Economy**	**Society Issue**
S4B10	**S4**	**Supplier**				**Society**	**Society Issue**
S5B10	**S5**	**Community**				**Environment**	**Society Issue**
S6B10	**S6**	**Retailers**				**Economy**	**Society Issue**
S2B11	**S2**	**Manufacturer**	**B11**	**Lack of support from the top management causes to attach to the conventional approaches**	**Luthra et al., 2016**	**Economy**	**Managerial consideration**
S3B11	**S3**	**Investor**				**Economy**	**Managerial consideration**
S4B11	**S4**	**Supplier**				**Economy**	**Managerial consideration**
S6B11	**S6**	**Retailer**				**Economy**	**Managerial consideration**
S1B12	**S1**	**Customer**	**B12**	**No proper encouragement and regulation for sustainable manufacturing**	**Bhanot et al., 2015**	**Society**	**Society Issue**
S2B12	**S2**	**Manufacturer**				**Society**	**Society Issue**
S4B12	**S4**	**Supplier**				**Society**	**Society Issue**
S5B12	**S5**	**Community**				**Society**	**Society Issue**
S2B13	**S2**	**Manufacturer**	**B13**	**Lack of training programs for employees about sustainable manufacturing**	**Gong et al., 2017**	**Society**	**Organization**
S3B13	**S3**	**Investor**				**Society**	**Organization**

S4B13	**S4**	**Supplier**				**Society**	**Organization**
S6B13	**S6**	**Retailer**				**Society**	**Organization**
S1B14	**S1**	**Customer**	**B14**	**Lack of education for the adoption of environmentally conscious practices**	**Singh et al., 2016**	**Society**	**Knowledge and Skill**
S2B14	**S2**	**Manufacturer**				**Society**	**Knowledge and Skill**
S3B14	**S3**	**Investor**				**Society**	**Knowledge and Skill**
S4B14	**S4**	**Supplier**				**Society**	**Knowledge and Skill**
S5B14	**S5**	**Community**				**Society**	**Knowledge and Skill**
S6B14	**S6**	**Retailer**				**Society**	**Knowledge and Skill**
S1B15	**S1**	**Customer**	**B15**	**Lack of standardized metrics or performance benchmarks**	**Koho et al., 2011**	**Society**	**Environment Concept**
S2B15	**S2**	**Manufacturer**				**Society**	**Environment Concept**
S3B15	**S3**	**Investor**				**Society**	**Environment Concept**
S4B15	**S4**	**Supplier**				**Society**	**Environment Concept**
S5B15	**S5**	**Communities**				**Society**	**Environment Concept**
S6B15	**S6**	**Retailers**				**Society**	**Environment Concept**
S2B16	**S2**	**Manufacturer**	**B16**	**Fear of competitors taking advantage during the transfer from conventional to sustainable manufacturing**	**Koho et al., 2011**	**Economy**	**Managerial consideration**
S3B16	**S3**	**Investor**				**Economy**	**Managerial consideration**
S4B16	**S4**	**Supplier**				**Economy**	**Managerial consideration**
S6B16	**S6**	**Retailer**				**Economy**	**Managerial consideration**
S2B17	**S2**	**Manufacturer**	**B17**	**Low availability of credit from the Bank for sustainable manufacturing**	**Govindan et al., 2014**	**Economy**	**Organization**
S3B17	**S3**	**Investor**				**Economy**	**Organization**
S4B17	**S4**	**Supplier**				**Economy**	**Organization**
S6B17	**S6**	**Retailer**				**Economy**	**Organization**
S1B18	**S1**	**Customer**	**B18**	**Hight Trade-off from conventional manufacturing to sustainable manufacturing**	**Bey et al., 2013**	**Society**	**Environment Concept**
S2B18	**S2**	**Manufacturer**				**Economy**	**Managerial consideration**

S3B18	**S3**	**Investor**				**Economy**	**Managerial consideration**
S4B18	**S4**	**Supplier**				**Economy**	**Managerial consideration**
S5B18	**S5**	**Community**				**Society**	**Environment Concept**
S6B18	**S6**	**Retailer**				**Society**	**Managerial consideration**
S1B19	**S1**	**Customer**	**B19**	**Low customer demand for environment friendly products because of price-sensitive and uninformed customers**	**Yu et al., 2008**	**Economy**	**Environment Concept**
S2B19	**S2**	**Manufacturer**				**Economy**	**Environment Concept**
S3B19	**S3**	**Investor**				**Economy**	**Environment Concept**
S4B19	**S4**	**Supplier**				**Economy**	**Environment Concept**
S5B19	**S5**	**Community**				**Economy**	**Environment Concept**
S6B19	**S6**	**Retailer**				**Economy**	**Environment Concept**
S1B20	**S1**	**Customer**	**B20**	**Absence of pressure by key social actors**	**Mittal and Sangwan, 2011**	**Society**	**Society Issue**
S5B20	**S5**	**Community**				**Society**	**Society Issue**
S2B21	**S2**	**Manufacturer**	**B21**	**Uncertain return**	**Massoud et al., 2010**	**Economy**	**Managerial consideration**
S3B21	**S3**	**Investor**				**Economy**	**Managerial consideration**
S4B21	**S4**	**Supplier**				**Economy**	**Managerial consideration**
S6B21	**S6**	**Retailer**				**Economy**	**Managerial consideration**

4. Results

The stakeholder-related barrier network of SM composing of 89 stakeholder-related barriers with 1618 links is constructed, which is automatically counted by the software NodeXL with the in-built function. One of the strengths of the software NodeXL is to filter and simplify the complicated network to demonstrate the core features by automatically determining the main metrics. NodeXL determines the number of links based on the relationships of edges and nodes in the network. And, any change in the input of the constructed network will change the number of links and the metrics automatically by NodeXL. The node shapes and colors represent the types of stakeholder and category respectively. The overall networks of Category 1 and Category 2 are shown in Figure 2.

For a better understanding of the network level of the stakeholder-related barrier network of SM, the determination of the network-level metrics offers a clear view to analyze the network feature quantitatively. The network density is 0.19. Actually, network density mentions the average ratio of the potential connections for a node in a network to the actual connections for a node. The value of network density 0.19 means an average of 19% of links among the potential connections of a node connected, and it shows strong evidence that the stakeholder-related barrier network of SM in this study is dense. On the other hand, the average geodesic distance between each node pair is 1.78 and the maximum geodesic distance is 4. For the network with 1618 links, the average geodesic distance 1.78 and the maximum geodesic distance 4 are a relatively short distance for the communication between each network member.

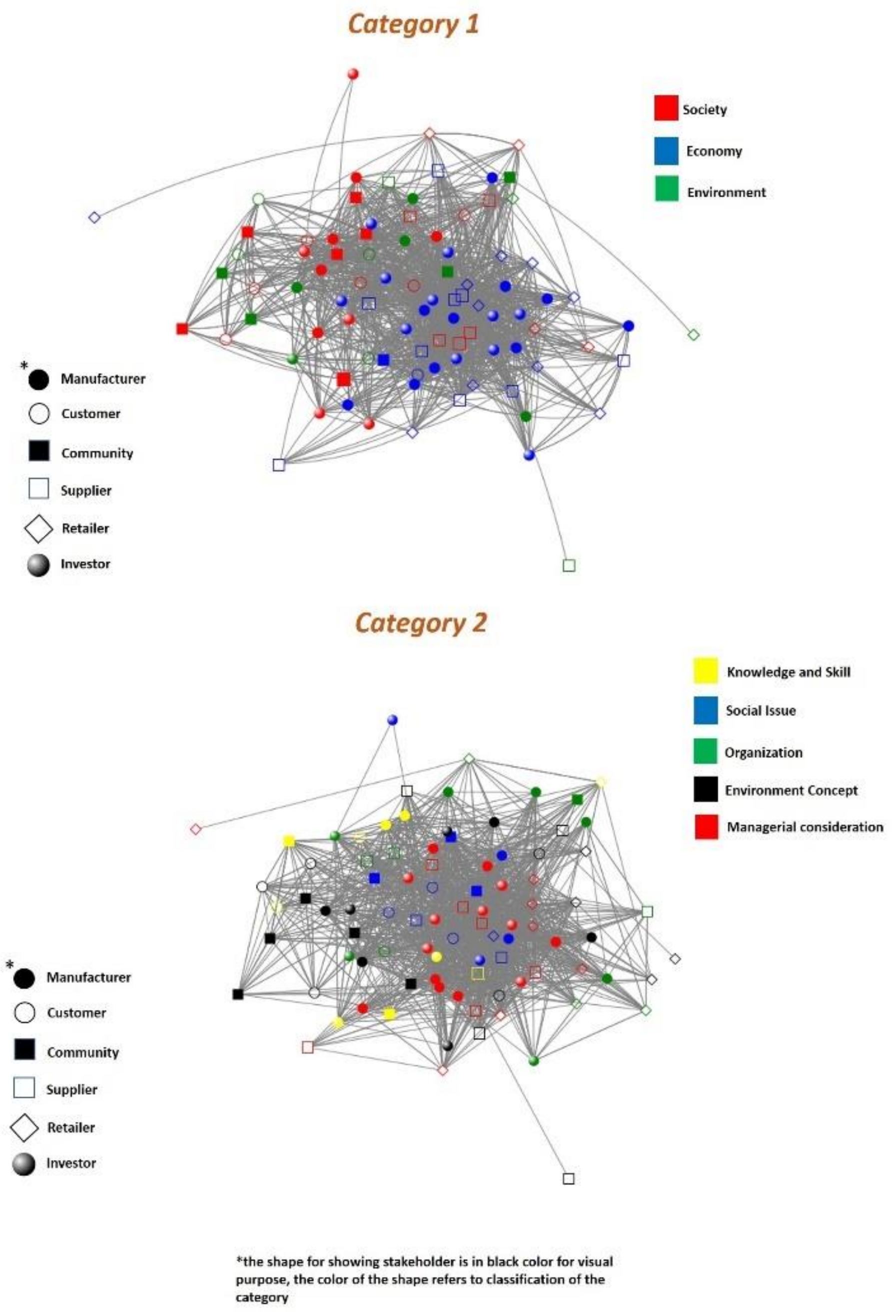

Figure 2. Stakeholder related barriers in SM for categories 1 and 2

In order to conduct the visual analysis of the main metrics of stakeholder related barrier network of SM through SNA, the sub-networks of the main metrics for Category 1 and Category 2 are shown in Figures 3 and 4 respectively, which each of them represents one of the main metrics, including in-degree, out-degree, closeness and betweenness.

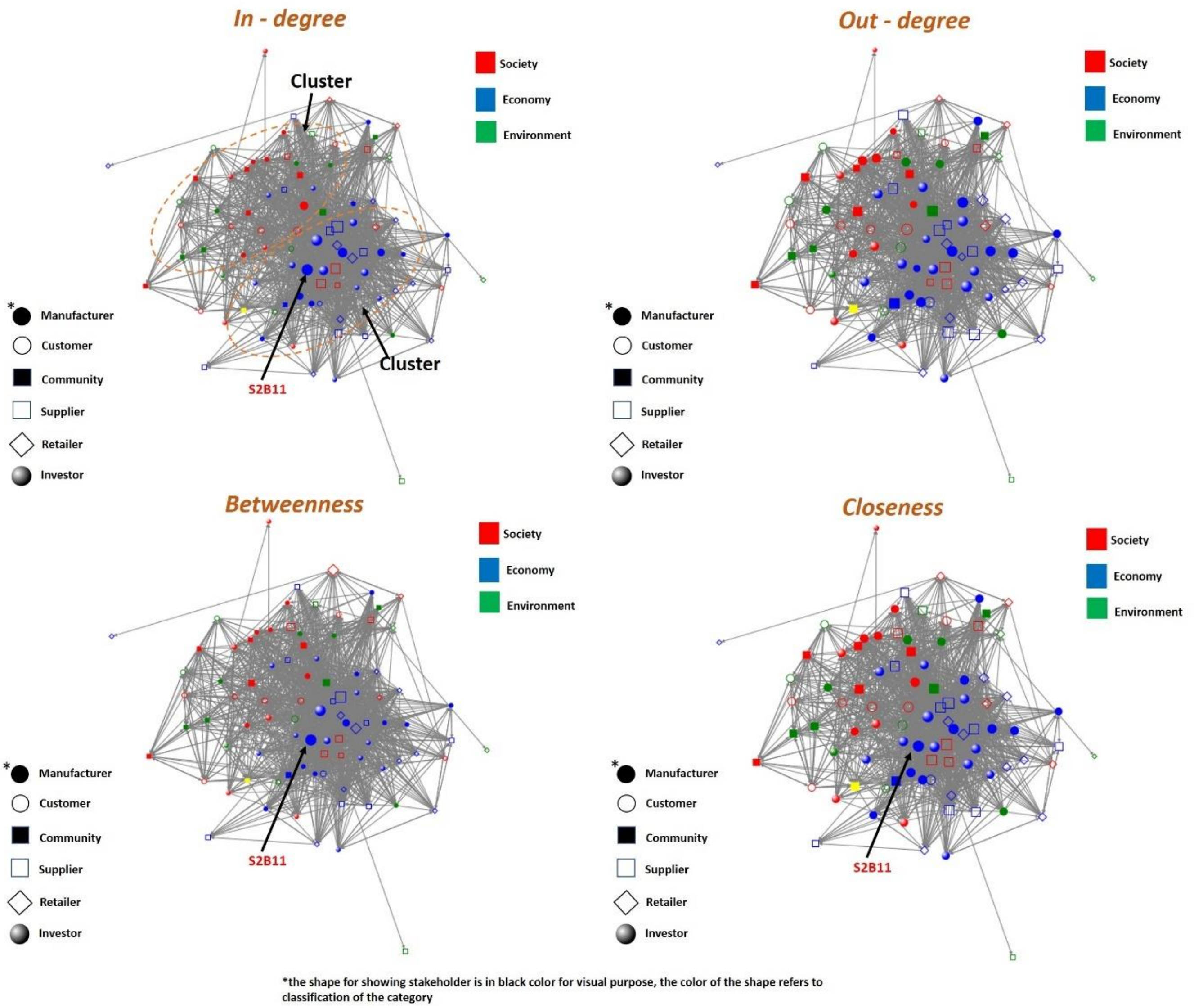

Figure 3. The sub-networks representing the metrics for Category 1

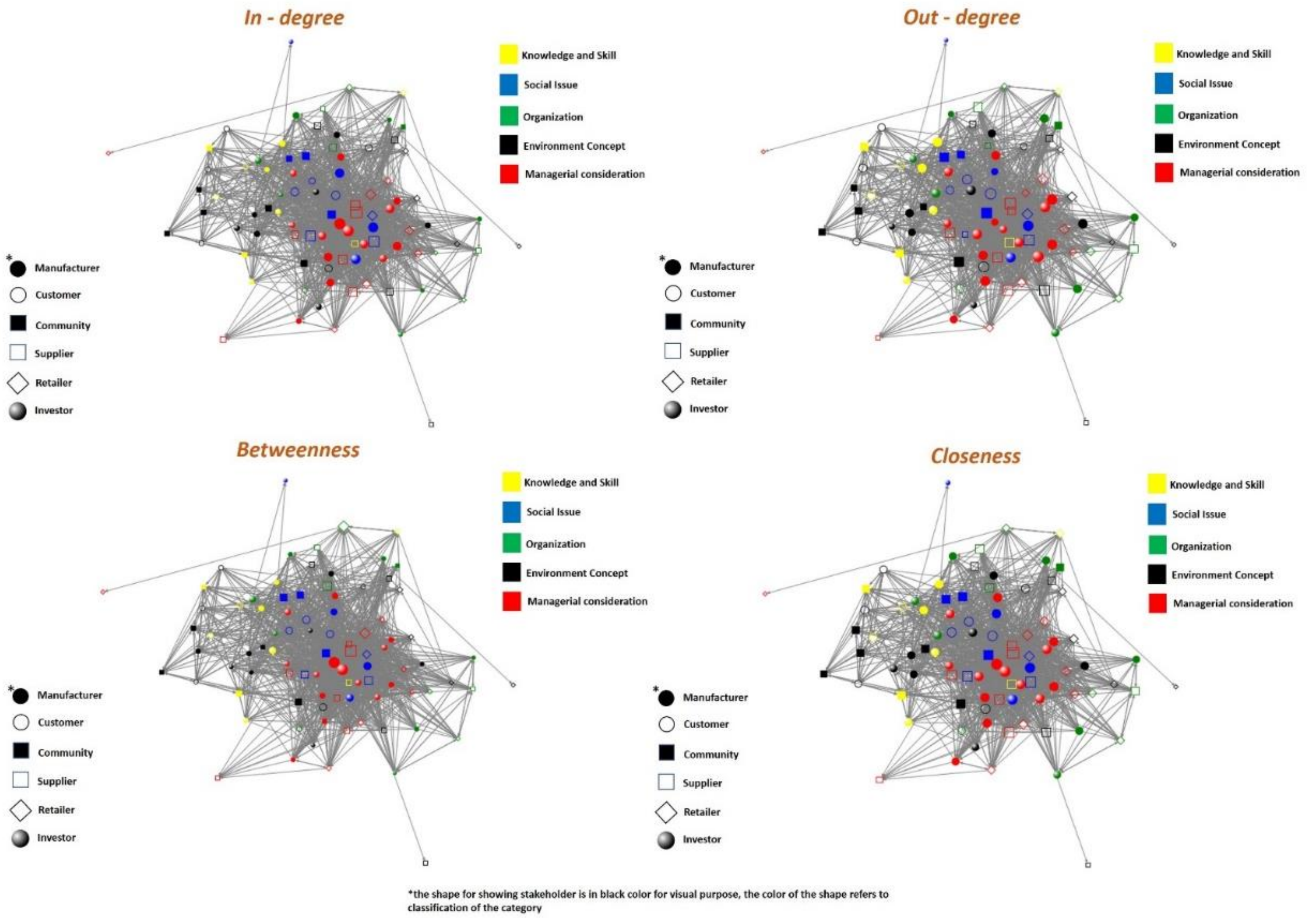

Figure 4. The sub-networks representing the metrics for Category 2

The numerical analysis of the main metrics in SNA is determined and demonstrated for the detailed interpretations of special nodes and their effects on the overall network members. The numeral values and the rankings of the four main metrics are shown in Tables 5 – 8.

Table 5. Top ten rankings of in-degree of stakeholder related barrier network

Ranking	Code	Value	Category 1	Category 2
1	S2B11	59	Economy	Managerial consideration
2	S3B11	57	Economy	Managerial consideration
3	S4B11	55	Economy	Managerial consideration
4	S6B11	49	Economy	Managerial consideration
5	S2B10	46	Economy	Society Issue
6	S6B10	44	Economy	Society Issue
7	S3B10	44	Economy	Society Issue
8	S4B10	44	Society	Society Issue
9	S4B12	39	Society	Society Issue
10	S2B12	39	Society	Society Issue

Table 6. Top ten rankings of Out-degree of stakeholder related barrier network

Ranking	Code	Value	Category 1	Category 2
1	S3B5	35	Economy	Managerial consideration
2	S6B5	34	Economy	Managerial consideration
3	S6B10	33	Economy	Society Issue
4	S1B10	32	Society	Society Issue
5	S5B10	32	Environment	Society Issue
6	S2B5	32	Economy	Managerial consideration
7	S2B10	31	Economy	Society Issue
8	S2B18	28	Economy	Managerial consideration
9	S3B18	28	Economy	Managerial consideration
10	S4B18	28	Economy	Managerial consideration

Table 7. Top ten rankings of Closeness of stakeholder related barrier network

Ranking	Code	Value	Category 1	Category 2
1	S2B11	0.008772	Economy	Managerial consideration
2	S3B11	0.008696	Economy	Managerial consideration
3	S4B11	0.008475	Economy	Managerial consideration
4	S6B11	0.008403	Economy	Managerial consideration
5	S2B10	0.007937	Economy	Society Issue
6	S6B10	0.007813	Economy	Society Issue
7	S3B10	0.007813	Economy	Society Issue
8	S4B10	0.007813	Society	Society Issue
9	S5B10	0.007463	Environment	Society Issue
10	S1B10	0.007353	Society	Society Issue

Table 8. Top ten rankings of Betweenness of stakeholder related barrier network

Ranking	Code	Value	Category 1	Category 2
1	S2B11	384.667173	Economy	Managerial consideration
2	S6B13	378.125769	Society	Organization
3	S3B11	367.961274	Economy	Managerial consideration
4	S6B11	350.737524	Economy	Managerial consideration
5	S4B11	334.271741	Economy	Managerial consideration
6	S4B13	192.582141	Society	Organization
7	S6B10	179.861039	Economy	Society Issue
8	S2B10	178.559198	Economy	Society Issue
9	S5B10	167.765265	Society	Society Issue
10	S3B10	149.931661	Economy	Society Issue

5. Discussion

Based on the results of this study, the findings are detailly discussed in this section, which include visual analysis of network, numerical analysis of metrics and cluster analysis.

5.1 Visual analysis of the network

The overall networks of Category 1 and Category 2 are shown in Figure 2. According to the Figure, the barriers with more links are in the relatively central location in the network, while the barriers with fewer links are located near the network edge. All stakeholder-related barriers are interconnected without leaving an unconnected individual node, therefore it implies the highly complicated structure for stakeholder-related barrier network of SM, and it explained that the high difficulty for implementations of SM strategies in practical situations as many causal relationships between each stakeholder related barriers.

Referring to Figure 2, for Category 1 of the stakeholder-related barrier network of SM, a large area of blue nodes is position at the center of the network, it interprets that the barriers relating to the economic dimension in the TBL contribute relatively large to the stakeholder relater barriers in executing SM in a practical situation, which it is consistent with the findings of what the literature reports in SM. According to literature, the attentions of the TBL currently are devoted imbalanced focuses on the economic dimension, with revealing from the practical sustainable activities up to now (Hollos et al., 2012); a considerable emphasis of the TBL is put on the economic dimension which the weight of the triple bottom line is a shift from the social dimension to the economic dimension (Schönsleben et al., 2016). Consequently, the nodes corresponding to the social and environmental dimensions in Category 1 locate at the edge dissipatedly in the network. On the other hand, the largest concentrated nodes regarding the economic dimension are positioned at the center of the network, which they show that the stakeholder related barriers of economic dimension are generally interrelated with high influential powers to other network members.

Apart from the overview and analysis toward the overall pattern of the network, refer to Figure 2, from the perspective of stakeholder with revealing as the shape in the network, two types of shape occupy those blue color nodes concentrating at the center, they are " solid disc - manufacturer" and "sphere - investor". They show that a large proportion of the economic dimensional barriers are built up by these two stakeholders in SM. On the other hand, the similar structural network as Category 1 is demonstrated for Category 2; there are two types of classifications (two-color nodes are concentrated at the center: blue and red) of stakeholder related barriers locating in the center of the network mainly, they are “managerial consideration” and “social issue”, which these two classifications have relatively high influential powers among of all the other stakeholder related barriers.

5.2 Cluster Analysis of subnetworks

The SM network of stakeholder-related barriers could be further extended to use for conducting the cluster analysis, in which the cluster analysis is employed to categorize the nodes into various groups according to the similarities in features of nodes by observing the grouping colors and the distance between nodes. Clusters are ready to observe from the network directly which it shows the similarity and aggregation within network members in order to know the features of network members (Liang et al., 2017), in which the clusters is represented using the main metrics (In-degree, Out-degree, Betweenness and Closeness) of SNA for the particular network members in this study. The network of the main metrics of stakeholder-related barrier network of SM is demonstrated here, in which the sub-networks of Category 1 and Category 2 are shown in Figures 3 and 4 respectively. For the analysis of the metrics of SNA using cluster analysis, the structure of the network enables to support the understanding of the level of influences of each network member with the three aspect concerns. For Category 1, the barriers in the economic and social dimensions are occupied in a large proportion of all the four metrics including in-degree, out-degree, betweenness, and closeness, in which the nodes with blue and red colors form two clusters separately. According to Figures 3 and 4, the greatest number of nodes with blue and red color are populated at the center of the network, these two clusters occupy half of the entire area of the network by the members of the particular aspects. On the other hand, most of the nodes with green color representing the barriers in the environmental dimension are located at the relatively edge side. They do not form a cluster as the nodes with red and blue colors. From the TBL perspective, the two clusters are obviously created from the network, e.g. society and economy. It means that the large influences of the barriers from the social and economic aspects are placed to the barriers within the three aspects in TBL. Therefore, if we plan to devise SM strategies for future manufacturing, the most dominant stakeholder-related barriers from the social and economic aspects that influence the SM system should be considered in the first priority and chosen to be the target to improve, which the above enables to enhance the efficiency of the execution of SM in the future.

On the other hand, the size of the node in the network can be one of the cluster groups. The size of nodes represents the value of the metrics, i.e. the node with a relatively higher value in the particular metric shows a larger size. According to Figure 3, for the metric of out-degree and closeness, the nodes with sphere shape show the relatively large size and location in the center color. The cluster of sphere shape is formed for the network of metrics of out-degree and closeness, and the dominant stakeholder influencing the metrics of out-degree and closeness is "investor". All of the above means that investors have relatively high out-going influential powers and the investors enable to reach and interact with the other stakeholder-related barriers as they have a comparably shorter path between all nodes. If the strategies are devised for enhancing the communication of stakeholders and influencing powers of activities for SM, the barriers related to the investor should be focused. With the above cluster analysis of sub-networks in SNA, the classification of the barriers and the stakeholders with high influential powers could be identified.

For Category 2, the sub-network for clustering the metrics is quite similar to that of Category 1. There are two classifications of stakeholder-related barriers occupying the center of the network dominantly and formed as clusters, they are "Social issue" and "Managerial consideration". The results are consistent with the network-level analysis, the influential power of stakeholder-related barriers in the social dimension is dominant. Actually, Mangla et al. (2017) and Mont and Leire (2009) stated that organizations do not achieve the balance between economic, environmental and social benefits based on the TBL. Especially for managerial classes within companies, they would normally think about "whether or not it pays to be green" and "what are the managerial implications and provisions for implementing sustainability considerations in business operations"(Stoycheva et al., 2018). The managerial decisions currently focus on the cost of implementing sustainable strategies and tend to discourage investment in SM. The right direction of managerial decision is important otherwise it will be one of the major costs in the implementation SM strategies (Siong Kuik et al., 2011).

5.3 Numerical analysis

In this section, the numerical analysis of the main metrics in SNA would be conducted for the detailed explanation of dominant nodes and their effects on the overall network members, in which the numerical values and the rankings of the four main metrics are displayed in Tables 5 – 8. According to the results from SNA, some nodes are shown high rankings for a few main metrics simultaneously. They are S2B11, S3B11, S4B11 and S6B11, and they represent "Lack of support from the top management causes to attach into the conventional approaches" for "manufacturer", "investor", "supplier" and "retailer". These nodes are highlighted in Tables 5-8 with different colors. Actually, these findings are consistent with those of previous research, in which the stakeholder-related barriers arising from the management class from various stakeholder types are reflected to be dominant in SM, in which managements come to decisions of avoiding taking proper SM activities. The significance of the highest values in in-degree centrality lies in receiving influential capacity from the overall stakeholder-related barriers, which means that the consequence of stakeholder-related barriers in SM generally follows to these few particular nodes. Actually. literature shows that most of the barriers in SM are the root obstacles and are belonged to internal barriers in the organization management, which further affect the policy and economy of the society (Mittal and Sangwan, 2014). Also, the academia indicates that the low level of top management commitment is made (Singh et al., 2012), which defers the ability to execute the SM strategies to facilitate and support the actual formulations and deployments of environmental initiatives for breaking through the internal barriers across the organization and other stakeholders. Furthermore, manufacturing firms are disturbed to embrace new SM practices because of insufficient technical and human resources (Wang et al., 2008).

For the interpretation of closeness centrality, the same nodes as in-degree centrality attain the top four ranks, which nodes are S2B11, S3B11, S4B11 and S6B11. Simultaneously, all the nodes are the same barriers arising from different stakeholders. The highest value in closeness centrality means that those particular nodes enable to take the shortest path averagely when they communicate with other nodes at the same network. For the case of stakeholder-related barriers in SM, the nodes with the highest values in closeness centrality mean there are lots of links developed between these four particular nodes with other nodes. With lots of shorter paths linking to different barriers in the network, the resources and information used for settling down these four barriers can be transferred to other nodes efficiently and acting as the resources to resolve the other barriers. Therefore, the barriers relating to the management support on SM should be paid attention, and the management team of different stakeholders could take a breakthrough by stepping out from the conventional approach of manufacturing strategies. The complicated management framework due to the interdependence in firms causes the weak motivation to put the resources for making changes from conventional to SM approach. Tang and Zhou (2012) investigated the literature in the area of operation management for sustainable business activities, they stated that considerable needs are required to feature out financial resources of the community for promoting sustainable developments. The barriers installed by the management teams of related stakeholders should be taken notices of, especially for the barriers indicated by the SNA in this study.

For the betweenness centrality, similar results as in-degree centrality and closeness centrality are given, again the four nodes S2B11, S3B11, S4B11 and S6B11 are positioned at the highest four rankings. Actually, betweenness centrality shows the level of the particular node posing the shortest path between all the combinations of the other node pairs within the same network. If a node with a comparatively high value in betweenness centrality is separated by the external reason in practical situations, other dependent nodes are blocked to transfer resources or communicate with other network nodes. Therefore, the node with high betweenness centrality is the so-called "gatekeeper". For the case of the stakeholder-related barrier network of SM, the four nodes relating to the management barrier obtain the highest values. This result gives out a suggestion that the separation of barriers arising from managements of different stakeholders is not recommended, as this action blocks the resource transferences between each SM strategy corresponding to the barriers. Instead of separation or ignorance of those barriers from management decisions, the approaches such as reacting with the barriers actively or putting the resources to minimize the resistance from management are the suitable ways to deal with those barriers, which they can make use of the characteristics of the relationships between the four barriers and other barriers to promote the SM strategies in SM efficiently.

5.4 Suggestions and validation for SM strategies based on SNA findings

The barriers which need to be resolved are actually based on the value of out-degree from SNA analysis. For the nodes with the highest out-degree centrality, it means that particular nodes influence the greatest number of neighborhood nodes. In the case of stakeholder related barrier network of SM, the barriers with the highest out-degree centrality express that the consequence of the barriers in SM would transfer to the most number of downstream barriers, which the negative impacts are accumulated to the received nodes/barriers and they lead to an intensive negative effect on their neighbor barriers in implementing SM strategies.

5.4.1 Suggestions

By using the results of SNA, the barriers with the most out-going influential power could be identified efficiently with the economic and simple approaches. The barriers at the top ten rankings in out-degree centrality are planned to remove to minimize the dominant-negative effects from the barriers with high influential power. The barriers therefore chosen to be removed are S3B5, S6B5, S6B10, S1B10, S5B10, S2B4, S2B10, S2B18, S3B18 and S4B18. However, simultaneously, some nodes overlap with the top ten rankings in the metrics of betweenness centrality. As mentioned in the previous section in this study, the nodes with relatively high betweenness centrality act as "gatekeepers" in the network, the communications between nodes at the same network would be blocked if the gatekeeper is separated or removed. Therefore, the nodes/barriers which appear at both top ten rankings in the out-degree and betweenness centrality metrics are exempted to remove. As a result, the barriers S3B5, S6B5, S1B10, S2B4, S2B18, S3B18 and S4B18 are finally selected to eliminate, for the aims of minimization of the tangle interrelationships between the stakeholder related barrier, thus, decrease the substantial resistances to implement SM strategies with consuming fewer resources.

The stakeholder-related barriers with the highest out-degree values are targeted to be minimized or removed. The detail of those barriers is shown in Table 10. The barriers are mainly two types, are B13 "Lack of training programs for employees about sustainable manufacturing" and B10 "The changes in traditional manufacturing culture require a large number of resources, knowledge and investments". The corresponding measures for transcending the barriers are discussed in detail. For B13, actually, constant investments of firms in the educations of employees and communities are absolutely beneficial to the development of the firms, which firms in different areas nowadays have already executed and extended the education program to the health and medical benefits across companies (Mani et al., 2015). Manufacturing firms have to develop an educational program called a behavioral-based safety culture system which enables to enhance the employee perspective to personal safety in manufacturing processes or working areas. Moreover, the firms can also train employees to encourage them to work under safe conditions, which previous reviews and inspections show the effective educational approaches to give out positive results in SM (Wang et al., 2015). For the barrier B10, the concept of the long-term benefit of SM should be introduced to the stakeholders of manufacturing firms, and so that they realize they enable to earn profits in running SM strategies in the future. Therefore, in such a case, the right categorization of indicators for SM should be employed in order to show the accurate benefit bought from SM to the firms, motivating firms to step out to make investments for changing the traditional manufacturing culture to SM.

Among many SM indicators, the categorization of sustainability indicators from the National Institute of Standards and Technology (NIST) is suggested to apply, which the set of the indicators complies with several appropriate categories and subcategories to offer the reasonable structure to combine most of the indicators decisively from firms nowadays (Joung et al., 2013). In sustainability development, sometimes opposite opinions are made because of the different interpretations of the indicators in SM, which confuse the firms that they are going to invest largely without certain returns. In this case, the sustainability indicators from the NIST can minimize such complicated relationships between each indicator, as it tries to meet the need of different decision-makers for sustainability developments. The NIST indicators cover the process/product level, the company/organization level, and the nation/region level, to the global level, which the indicators cover the needs of different decision-makers with five categorizations of sustainability: environmental stewardship, economic growth, social well-being, technological advancement, and performance management (Mani et al., 2014). These five categorizations definitely enable to show the comprehensive view of benefit bought from SM to the firms. These indicators have been proved to have strong power to show a clear map to their readers (Feng and Joung, 2011; Wein and Baveja, 2005).

5.4.2 Validation

To evaluate the new network with the removal barriers, the main network metric, betweenness centrality, is focused to investigate. The reason behind this is that betweenness centrality is a type of indicator for showing the level of tanglesome of a network. The less effectiveness of the gatekeeper in a network means that there are fewer dependencies on the node to transfer the consequence, resources and information to other network members, implying a less complicated network and less intense interrelationships between each barrier.

The approach of removal of barriers is the validation process for this study. Actually, in this study, the constructed network is static, therefore, herein, we use the concept of a static network of SNA, so that the removal of barriers would not affect the remaining members at the same network, and minimize the effects of generation other barriers to the SM network. Actually, the real-world network is not permanently static and it suffers from different kinds of changes. Changes are substantially induced by participating in or withdrawing nodes to the community (Nguyen et al., 2012) and generate another network member to the network. Therefore, dynamic/static SNA is a significant characteristic of the SNA network. A dynamic network is normally used to deal with problems that consist of fast and frequent change by network members (Wang et al., 2018). For the static SNA which is constructed in this study, it owes edges and nodes that are not present at the time of occurrence of the information/data flow. The static network enables to suggest the transmission in between each individual and its neighbors, therefore, the focus on the static network is to capture the fact that all the network members are affected base on a specific start point (Farine, 2018). And in this study, the removal assumption is made based on the static SNA mechanism, in which the constructed network has no comparison with the environment outside under the time series. And the detailed consideration of static networks is made in this study, from both perspective in the research question and data collection in this validation part.

The assumption of removing barriers is made and shown in Table 9. The betweenness centrality, network density and average geodesic distance of nodes of the new network are recalculated. The results and the corresponding changes in the values and the rankings are shown in Tables 10-11. After removing the dominant barriers, the new values of betweenness of nodes generally decrease, which the decreasing percentage is ranged from 2.44% - 5.04%. Also, some nodes with high rankings originally are found to be a decrease in ranking in the new network. For the nodes S4B13, S6B10, S2B10, and S3B10, their rankings decrease about 30% - 42.86%. For the network level, the network density decreases from 0.19 to 0.178 and the decreasing percentage is up to 6.38%, while the average geodesic distance decreases from 1.78 to 1.75 with a decreasing percentage 1.69. The results are encouraging because the network density decreases with average geodesic distance decrease, it means the tangle level of the stakeholder-related barrier network is unravel considerably and, the average distance of transferring information and resource from one node to the other nodes is shortened simultaneously after the suggestions are adopted. The above results show the effectiveness of barrier removal upon the findings obtained from SNA.

Table 9. The identified stakeholder related barriers for minimizing or removing

Code	Barrier	Stakeholder

S6B13 S4B13	Lack of training programs for employees about sustainable manufacturing	Retailer Supplier
S6B10 S2B10 S5B10 S3B10	The changes in traditional manufacturing culture require a large number of resources, knowledge and investments	Retailer Manufacturer Community Investor

Table 10. The original and modified values, rankings of betweenness centrality

Betweenness						
Code	Original Value	Modified Value	Decrease %	Original Ranking	Modified Ranking	Decrease %
S2B11	384.67	375.29	2.44	1	1	-
S6B13	378.13	363.19	3.95	2	2	-
S3B11	367.96	351.10	4.58	3	3	-
S6B11	350.74	333.05	5.04	4	4	-
S4B11	334.27	318.92	4.59	5	5	-
S4B13	192.58	185.83	3.51	6	8	33.33
S6B10	179.86	182.75	-1.61	7	10	42.86
S2B10	178.56	181.47	-1.63	8	11	37.50
S5B10	167.77	205.04	-22.22	9	7	-22.22
S3B10	149.93	152.77	-1.89	10	13	30.00

Table 11. The original and modified values, rankings of network density and average geodesic distance

	Original Value	Modified Value	Decrease % in Value
Network density	0.19	0.178	6.32
Average geodesic distance	1.78	1.75	1.69

Apart from the numerical analysis of SNA metrics for the new network, visual analysis is also provided in this session. Figure 5 shows the new networks after the modification. For Category 1, before the modification, there are red and blue nodes occupying the center of the network dominantly and concentratively; after modification, the situation can relief. The blue and red nodes change to locate the entire network evenly in comparison to the previous network; also, the ties are less tangled than the non-modified one. For Category 2, due to the removal of dominant nodes with high out-going influential power, the nodes with other colors rather than only red color start to move to the center of the network. Referring to Figure 5, the nodes with black and yellow colors migrate to the center position of the network, which the red color nodes are less dense in comparison to the previous one. The above implies that if the suggestions provided in this study are executed in practical situations, less complicated interrelationships within the stakeholder-related barriers are accomplished. Also, less intensive influences from barriers are wielded so that the related stakeholders enable to distribute the resources to barriers with other classifications such as improving "knowledge and skill", and strengthen "environment concept", which they are treated as the barrier roots and should be reduced through implementing SM strategies finally.

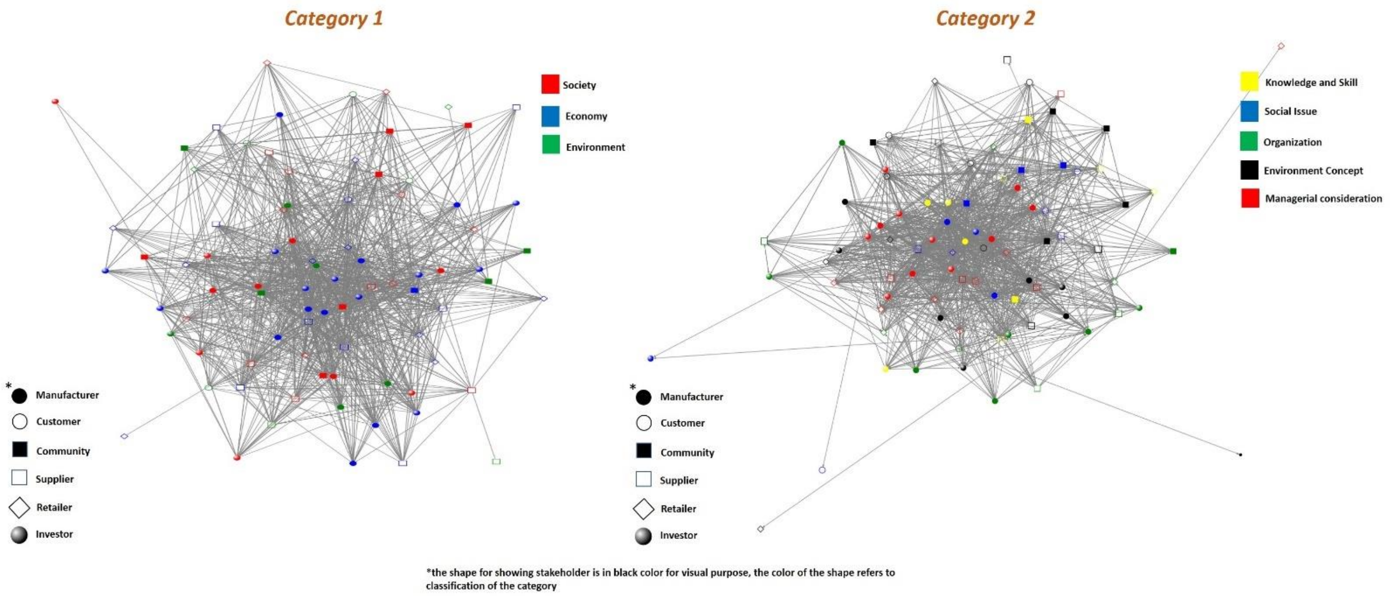

Figure 5. The network of stakeholder related barrier after modifications

5.5 Breakthrough, contribution and limitation of this study

Actually, SNA is a kind of quantitative technique that makes use of causality to build up the relationship between actors and enables to determine the network characteristics by showing the metrics of SNA theory (Valente, 2010). By prioritizing and organizing the metrics of each stakeholder-related barrier of SM in the study, the characteristics of the network members (stakeholder-related barriers of SM) would be known clearly and defined. Moreover, in SNA, the issues related to the coordination of network members, information flow within the network and the relationship are enabled to show qualitatively, therefore, in this study, the coordination of stakeholder related barriers of SM could be revealed using SNA approach, especially the relationship of barriers between the different aspects of TBL, which this contribution is priorly made by this study. On the other hand, this study makes uses of the technical capability of SNA to find out the barriers of

SM and categorized the barriers using the TBL concept currently for the first time, which this methodology has not yet applied before in the sustainable and environmental development of industries according to the best of the authors' knowledge. Furthermore, this study is that this research belongs to the multi-disciplinary nature combining of computer science, sustainability development and mechanical engineering, which aims to make the breakthrough the existing gap of the sole disciplinary. We use the advantages of each discipline and combined them to identify the barriers of SM focusing on TBL, and detailly investigate and analyze the interrelationship of the barriers on a categorized basis. The barriers of SM are seldomly classified as three individual aspects as this study mentions; in literature, the barriers of TBL are discussed in the entire phenomenon without classification. Therefore, the novelty and contribution of the study are unique and apparent. Finally, the comprehensive analysis of SM is delivered at the end by organizing and providing the importance of obtained barriers with suggestions. The SNA approach can handle the network information in both structural and individual levels separately (Kim et al., 2011) and visualize SM in the form of a network, providing the influences of each network member to the other by using social relation relationships. In this study, the interaction between network members and the stakeholder-related issues are determined, which enables us to offer the complete view on how the stakeholder related activities are diffused and influenced, to examine the effects of social, environmental and economic on SM, and to reveal the opportunities for future SM strategies.

However, this study consists of limitations as every discipline and research faces. SNA is a quantitative approach employing the visualization of the network and network theory, which it is not feasible to analyze the reasons, the motivation of the SM activities, and the perceptions of network members behind the SM network. Therefore, once we have identified the stakeholder-related barriers for SM, we may further need to apply another approach for obtaining the rationale of the formation of the barrier in order to devise the SM strategies attentively. Also, as SM is a wide theme that covers broad areas including traditional manufacturing, non-conventional manufacturing, chemical manufacturing etc., the stakeholders identified in this study may not cover all areas of them. Therefore, in this study, the definition of SM will be narrowed to accurately cover the possible and potential stakeholders. In this study, manufacturing of SM means mechanical manufacturing which uses a subtractive removal mechanism for manufacturing. Furthermore, as the barriers of SM are originated from various dimensions, therefore, the identification and aggregation of those barriers are challenge and time-consuming at the beginning of SNA status. Also, as the technological advancement nowadays, it is foreseeable that manufacturing firms will deal with much more complicated manufacturing processes in the coming future (Mittal and Sangwan, 2014) (Bhanot et al., 2017), the relationships between barriers and the interaction of barriers with outside factors become tangles, therefore the identification of the barriers of SM consists a challenge after a certain time period, which it is one of the limitations of the study. For future research, overcoming these shortages of SNA approach should be the main direction, which the preliminary idea for overcoming these would be the application of thematic analysis and dynamic SNA.

6. Conclusion

Because of considerable environmental, social and economic benefits from SM to our society, there have growing pressures to resolve the barriers of SM in order to execute it smoothly. Therefore, the needs for identifications with suggested solutions for the potential barriers leading to difficulties in implementing SM strategies are the motivation of this study. Through SNA theory and the considerations of related stakeholder concerns, this study examined the underlying inter-dependences of stakeholder-related barriers in SM. With the identifications of stakeholder-related barriers, the interrelationships of each barrier are then established and input to SNA for deeper investigations. The main metrics and the visual network of the stakeholder-related barriers are obtained with detailed interpretations by SNA. Referring to the findings of metrics and visual networks, two types of barriers, "Lack of training programs for employees about sustainable manufacturing" and "The changes in traditional manufacturing culture require a large number of resources, knowledge and investments", are suggested to focus to deal with. Investments in the education and training of employees and facilitation of the employee perspective to personal safety in manufacturing processes are recommended. Furthermore, the long-term benefit of SM should be introduced to the stakeholders of manufacturing firms so that manufacturing firms enables to realize the long-term benefits from SM. The sustainability guideline from NIST is recommended to apply to provide a reasonable structure for the categorization of sustainability indicators when different opinions are made from different parties. The key nodes and links based on the findings of the network metrics are removed for validation, in which the network density and average geodesic distance for every network member of the new network are both decreased, showing the suggestions are effective to resolve the tangle level of the network and facilitate the information and resource transferences between the nodes in the network. This study contributes to providing an effective tool for the determination of the interrelationship of barriers in SM and making the corresponding recommendations to overcome them, ensuring the advantageous development of SM in the future.

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