Using social network analysis for industrial plant layout analysis in the context of industry 4.0

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Abstract: Social network analysis (SNA) is a widely studied research topic, which has been increasingly applied for solving different kinds of problems, including industrial manufacturing ones. This paper focuses on the application of SNA to an industrial plant layout problem. The study aims at analysing the importance of using SNA techniques to study the important relations between entities in a manufacturing environment, such as jobs and resources in the context of industrial plant layout analysis. Here, performance measures such as maximum completion time of jobs (makespan), resource utilisation, and throughput time have been considered to evaluate the system performance. Later, with the simulation analysis, the relationships between entities and their impact on the system performance are evaluated. The experimental results revealed that the proposed SNA approach supports to find the key machines of the systems that ultimately lead to the effective performance of the whole system. Finally, the identification of relations among these entities supported the establishment of an appropriate plant layout for producing the jobs in the context of industry 4.0.

Keywords: industry 4.0; industrial engineering; systems engineering; resource utilisation; throughput time; makespan; simulation; network modelling; FlexSim.

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1 Introduction

Social network analysis (SNA) is the mapping and measuring of relationships and flows between people, groups, organisations, computers, URLs, and other connected information/ knowledge entities. The nodes in the network are the people and groups, while the links show relationships or flow between the nodes (Schott, 2013). The growing interest in the SNA techniques has been considered since the 1970s and has been especially marked in the last decades by Schott (2013), Hollenbeck and Jameson (2015), Thongphubate and Piekkoontod (2016) and Fischer (2015). Recent growth has been sparked, from one side, by the increasing emphasis on the importance of 'networking' in practical management guides and, from the other side, by the proliferation of 'social networking' websites such as Facebook and Twitter. This has encouraged many researchers to explore the advantages of using SNA (Schott, 2013).

An industrial plant layout problem involves the tenacity of positioning facilities in a most regimented way within the industry. The most common objective in a plant layout problem is to minimise the material handling costs between the resources and to reduce the facility resource costs, based on the flow amongst the resources and the distance between each resource location. An efficient layout contributes to the overall efficiency of a specific manufacturing industry and plays an essential role in saving production costs and inventory costs. Moslemipour et al. (2018) developed a quadratic assignment-based mathematical model which demonstrated the development of a robust plant layout design for the stochastic dynamic layout problem. The simulation and multi-criteria decision-making tools were applied to analyse the manufacturing-based plant layout by using the TOPSIS method of Rad et al. (2014).

The concept of the SNA approach in the manufacturing context was put forward by Manupati et al. (2016), in which a mobile agent-based negotiation protocol has been proposed for networked manufacturing environments. The intention of carrying out this present work is to use the concept of SNA for establishing an industrial plant layout, based on a previous work presented by Varela et al. (2016). Therefore, this paper presents a novel framework to analyse the plant layout through SNA, allowing analysing the relationship between a set of jobs that incorporate a set of tasks, which have to be performed on a set of resources. The aim is to prepare a plant layout, by checking the influence that may exist between entities, using typical SNA measures, such as degree centrality, closeness centrality and betweenness centrality, as well as other descriptive statistical analysis measures that might be of relevance. This analysis can allow proposing an appropriate layout for arranging the resources, according to a given production process for the jobs. This study differs from previous works done in this area in certain means. The authors put forward an approach, based on the SNA as an alternative regarding the currently existing traditional approaches, in order to better fulfil the requirements of the factory of the future concept. It is the belief of the authors that it can better serve the purpose of reaching promptly solutions for highly dynamic and big data-based plant layout establishment, arising in the context of widely spread collaborative networked organisations (CNO) and underlying virtual enterprises (VEs) manufacturing environments.

As a result, this paper can contribute to the industry 4.0 by presenting an innovative approach to the plant layout problem. The industry 4.0 concept, also known as the fourth industrial revolution (Schuh et al., 2014a), is a large German initiative (Kagermann et al., 2013) that is focused on extending traditional manufacturing systems by fully integrating physical, embedded and IT systems, including the internet (Wang et al., 2015). Therefore, the virtual world is integrated with the real world by using information and communication technologies (ICT). Collaborative productivity, which refers to the collaboration among the cyber and physical domains and the networks where companies operate, is crucial for industry 4.0 (Schuh et al., 2014b). Therefore, the SNA approach presented in this paper contributes to the concept of industry 4.0 by proposing industrial layouts in a smart and automated way, which can improve the efficiency and productivity of industrial resources. The validation of the proposed approach's effectiveness is carried out through comparison with a simulation analysis, by measuring the performance measures of the system. The detailed description of the framework, method and analysis is presented in later sections. We have proved that the key elements that are identified by the SNA method (SNAM) can influence the layout and they can play a significant role in improving the performance of the layout.

This paper is organised as follows. Section 2 presents a brief literature review on some related work about the application of SNA techniques. Section 3 presents a framework and the logical steps of the execution of a case study through the proposed SNA. Section 4 describes the case study carried out in this work for supporting the establishment of an industrial plant layout, along with the SNA and some other important measures about network structure. Section 5 details the analysis part of the experimentation method based on SNA (SNAM), and the experimentation to validate the analysis with simulation analysis is explained in Section 6. Finally, Section 7 presents the main conclusions and directions for future work.

2 Literature review

Research on social networks has grown significantly over the last few years (Borgatti, 2006). A social network consists of a finite set of actors and the ties between them (Borgatti and Halgin, 2011). The three basic elements in social networks are actors, ties and graphs (Hawe et al., 2004). Actors are network members that can be distinct individuals or collective units. Ties, which can be formal or informal, allow to link actors within a network. Graphs are visual representations of networks, displaying the actors as nodes and the ties as lines (Barabási, 2002). SNA is the study of a social structure (Wellman and Berkowitz, 1988) and describes a group of quantitative methods for analysing the ties among social entities and their implications (Wasserman, 1994). An important aspect in SNA is to identify key players in a network (Freeman, 1979).

According to the Bohn et al. (2011), SNA provides tools to examine relationships between people. Text mining (TM) allows, for example, capturing the text that is produced in Web 2.0 applications. However, it neglects their social structure. Bohn et al. (2011) applied an approach to combine the two methods named ‘content-based SNA’. Using the R mailing lists, R-help and R-level, they show how this combination can be used to describe people’s interests and to find out if authors who have similar interests actually communicate. As stated in Bohn et al. (2011), they found that the expected positive relationship between sharing interests and communicating gets stronger as the centrality scores of authors in the communication networks increases. Moreover, they refer that the paper shows how content-based SNA can be used to find people’s interests in mailing list networks.

Additionally, by comparing communication graphs and networks showing who has similar interests, a relationship between the correlation of these two and node centrality could be found. Accordingly, the authors conclude that the expected relationship between sharing interests and communicating exists only for very active authors while less active authors do not answer everyone who has similar interests. Thus, they infer that the communication efficiency can be regarded to be high for very active mailing list authors while it is moderate for middle-active authors. The paper also suggests using only the subjects for finding the relationship between communicating and sharing interests because the content contains more noise (Bohn et al., 2011).

Another interesting contribution is presented in Lienert et al. (2013), where a case study examines infrastructure planning in the Swiss water sector. According to the authors, water supply and wastewater infrastructures are planned far into the future, usually on the basis of projections of past boundary conditions, but they affect many actors, including the population, and are expensive. Therefore, their objective consisted on investigating fragmentation in water infrastructure planning, to understand how actors from different decision levels and sectors are represented, and which interests they follow (Lienert et al., 2013). Through network analysis they did confirm their hypothesis of strong fragmentation, as they stated that they found little collaboration between the water supply and wastewater sector (confirming horizontal fragmentation), and few ties between local, cantonal, and national actors (confirming vertical fragmentation).

Moreover, according to the authors, infrastructure planning was clearly dominated by engineers and local authorities, and little importance was given to longer-term strategic objectives and integrated catchments planning, which was perceived as more important in a second analysis carried out by the authors, that went beyond typical questions of stakeholder analysis. In their study, the authors concluded that linking a stakeholder analysis, comprising rarely asked questions, with a rigorous SNA is very fruitful and enables to generate complementary results. Moreover, this combination gave them deeper insights into the socio-political-engineering world of water infrastructure planning, which according to their opinion is of vital importance to the general welfare (Lienert et al., 2013).

As stated in Cross et al. (2002) coordination increasingly occurs through networks of informal relations rather than channels tightly prescribed by formal reporting structures or detailed work processes. However, while organisations are moving to network forms through joint ventures, alliances, and other collaborative relationships, executives generally pay little attention to assessing and supporting informal networks within their own organisations. Moreover, the authors refer to SNA is a valuable means for facilitating collaboration in strategically important groups such as top leadership networks, strategic business units, and new product development teams, communities of practice, joint ventures, and mergers. Moreover, by making informal networks visible, SNA helps managers to systematically assess and support strategically important collaborations (Cross et al., 2002).

Another interesting example of the application of SNA is provided in Martíneza et al. (2003), where a mixed evaluation method is presented; combining traditional sources of data with computer logs, and integrates quantitative statistics, qualitative data analysis and SNA in an overall interpretative approach. The authors propose the use of several computer tools to assist in this process, integrated with generic software for qualitative analysis. The authors applied their evaluation method and tools incrementally and validated them in the context of an educational and research project that had been going on for three years. The use of their proposed method was illustrated on their paper through an example consisting on the evaluation of a particular category within their project. Moreover, the proposed method and tools aimed at providing an answer to the need for innovative techniques for studying new forms of interaction emerging in computer-supported collaborative learning (CSCL), for increasing the efficiency of the traditionally demanding qualitative methods. Martíneza et al. (2003) concluded that their methods can be used by teachers in curriculum-based experiences, and at the definition of a set of guidelines for bridging different data sources and analysis perspectives.

Borgatti and Li (2009) provided another kind of application of SNA, for supply chain researchers with an overview of SNA, covering both specific concepts (such as structural holes or betweenness centrality) and the generic explanatory mechanisms that network theorists often invoke to relate network variables to outcomes of interest. As stated by the authors, one reason for discussing mechanisms is to facilitate appropriate translation and context-specific modification of concepts rather than blind copying. Therefore, they have also taken care to apply network concepts to both 'hard' types of ties (e.g., materials and money flows) and 'soft' types of ties (e.g., friendships and sharing of information), as according to them, both are crucial (and mutually embedded) in the supply chain context. Moreover, the authors also aimed to point to areas in other fields that they thought would be particularly suitable for supply chain management (SCM) to draw network concepts from, such as sociology, ecology, input-output research and even the study of romantic networks. According to their statement, they believe that the portability of many network concepts is important to provide a potential for unifying many fields. A consequence of this for SCM is to reduce the conceptual distance between SCM and other branches of the management science.

Putnik et al. (2016) presented a new model for students' evaluation based on their behaviour during a specific course and its validation in comparison with the traditional model of students' evaluation. Their validation is made by studying the correlation between some SNA measures and the grades obtained by students at the end of the course. The authors suggest that the correlation results can be used to evaluate students' performance based on their interactions (behaviour) analysis, making the evaluation partially automatic and increasing the productivity of teachers by allowing a more scalable evaluation process.

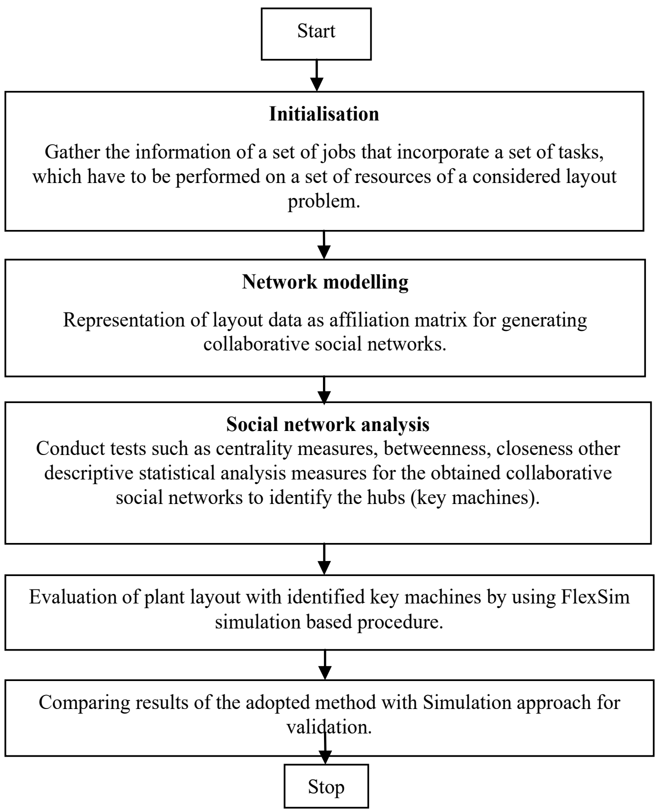
The mobile agent-based negotiation protocol for networked manufacturing environments with SNA is presented in Manupati et al. (2016). SNA helped in developing a relationship matrix, identifying how critical factors facilitated risk communication and interactions in the context of crisis management, as detailed in Shi et al. (2017). Ouyang and Scharber (2017) have used the SNA approach to examine the variation in an instructor's discussion design for construction of an online learning community. Badi et al. (2017) conducted comparative SNA studies which focused on tie strength, ego-network density and prominence of key stakeholders in Chinese SMEs with Guanxi ties dominating the construction business enterprise. Hermans et al. (2017) investigated the structural properties of the collaborative, knowledge exchange and influence networks of multi-stakeholder platforms in agricultural research and compared it against value propositions using SNA. Many other examples of SNA application can be found in other research areas such as ergonomics, knowledge management, information science, animal behaviour, biology, and supply networks (Costa and Putnik, 2014).

Although much research has already been put forward about SNA in many different areas there is still open space about contributions regarding plant layout analysis, were we can easily find out many other kind of approaches, as some of them are briefly referred next.

Krishnan et al. (2008) designed a new compromise facility layout that can minimise the maximum loss in material handling costs for both single and multiple periods, applying a genetic algorithm approach. Khosravian Ghadikolaei and Shahanaghi (2013) proposed a simulated annealing-based solution to develop the multi-floor dynamic facility layout with consideration of changes in material flow data over time. Altuntas et al. (2013) assessed the facility layout problem in a cellular manufacturing system using Fuzzy weighted association rule-based data mining approaches. Wang et al. (2017) optimised the position of plant layout, whose objective was piping cost and safety cost, with the help of a genetic algorithm approach. Zhang et al. (2018) evaluated an optimised plant layout and the production process in industry 4.0 by considering simulation-based approach. Abbasi et al. (2017) proposed a mathematical model for selecting a proper layout design based on the special features of the departments which was further used to place departments in a two-dimension space with the help of CPLEX 12. Moslemipour et al. (2018) developed a quadratic assignment-based mathematical model which demonstrated the development of a robust plant layout design for the stochastic dynamic layout problem. The simulation and multi-criteria decision-making tools were applied to analyse the manufacturing-based plant layout, where each decision-making criterion selected were evaluated using the TOPSIS method and the best ones were selected to improve the efficiency of the layout in Rad et al. (2014).

As we can realise through the overview presented in this section, SNA-based approaches are still under-explored regarding plant layout problems, and this kind of approaches and underlying techniques can be applied to many different domains, in general, and also to some more specific areas, for instance, in the context of industrial management. Therefore, the aim of this work is to apply SNA for establishing an industrial plant layout, based on a previous work presented in Varela et al. (2016), and an extension of this work is put forward in this paper.

Figure 1 Framework of the proposed methodology



3 Framework of the proposed SNA-based approach

It is evident from the literature that there is a lack of research on the analysis of industrial plant layouts with SNA. To respond to the identified research gaps, it is imperative to cultivate different kinds of approaches that can meet the requirements of the current plant layout problems. In this section, we propose a step by step process of SNA and its implementation on an industrial layout problem with a framework illustrated in Figure 1. The flowchart has been divided into three phases:

1 network modelling

2 SNA method

3 evaluation of plant layout with identified key machines by using FlexSim simulation-based procedure.

Based on the above framework, details of the collected data and the description of the proposed SNA method's steps are elaborated in the following sections.

4 Case study

In this study, a set of 25 jobs (J1, …, J25), including a set of tasks, varying from 1 up to 5, have been considered to be processed on manufacturing resources, among a set of five available resources (R1, …, R5). For each job, 300 workloads were considered, and the process was run for three shifts. The objective is to analyse, through the application of an SNA technique, measures of centrality, closeness and betweenness, among other relevant descriptive statistical analysis for supporting the establishment of an appropriate plant layout for producing the jobs.

In SNA, first, a network needs to be modelled. Therefore, a matrix was created with all ties identified between the jobs and the corresponding manufacturing resources, for producing the jobs. This data is presented in the affiliation matrix expressed in Table 1, where 1 is assigned in cases when a given manufacturing resource processes an operation on a given job, and 0 for the opposite situation. The matrix was uploaded in the software UCINET, which was the software tool used for the SNA technique execution.

After that, using the same software, the social network graph was created (Figure 2). In this figure, all the ties that occurred between the different entities (jobs and manufacturing resources) for accomplishing the underlying tasks are represented. With this social network graph, it is possible to realise how many manufacturing resources the jobs interact with, and also to observe the entities that have more intense activity in this production scenario.

Figure 2 Social network graph of the production scenario (see online version for colours)

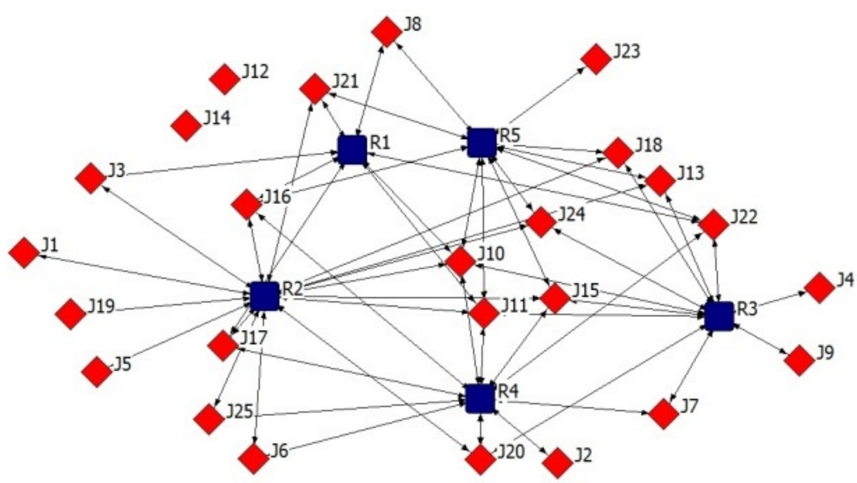


Table 1 Jobs affiliation matrix

	R1	*R2*	*R3*	*R4*	*R5*
J1	0	1	0	0	0
J2	0	0	0	1	0
J3	1	1	0	0	0
J4	0	0	1	0	0
J5	0	1	0	0	0
J6	0	1	0	1	0
J7	0	0	1	1	0
J8	1	0	0	0	1
J9	0	0	1	0	0
J10	1	1	1	1	1
J11	1	1	1	1	1
J12	0	0	0	0	0
J13	0	1	1	0	1
J14	0	0	0	0	0
J15	0	1	1	1	1
J16	1	1	0	1	1
J17	1	1	0	1	0
J18	0	1	1	0	1
J19	0	1	0	0	0
J20	0	1	1	1	0
J21	1	1	0	0	1
J22	1	0	1	1	1
J23	0	0	0	0	1
J24	0	1	1	0	1
J25	0	1	0	1	0

5 SNA-based method

In this section, an experimental method based on SNA (SNAM) is proposed for enabling to describe how the manufacturing execution data can be extracted and viewed as a network with nodes. Consequently, through our considered case study, the data was extracted and analysed through various SNA measures. Finally, we carried out a process for identifying different characteristics of the obtained network in detail. The SNAM is categorised into two steps:

a network modelling

b network analysis as it is mentioned in the following Sections 5.1 and 5.2.

5.1 Network modelling

A network consists of a set of nodes connected through ties, which indicate interaction. This section briefly describes how the manufacturing system execution data can be represented as a network. In this step, we have fed the input data, which is in the form of an affiliation matrix, into the UCINET software package. Using Net Draw we have represented the matrix in the form of a collaboration network. The network is a highly expressive and meaningful way of data representation by enabling to show a variation in the representation of the resources and jobs in terms of shape, size, and colour. The considered resources (R1, …, R5) are represented by a blue coloured square shape and the jobs (J1, …, J25) are shown as a red diamond. The arrows connecting the jobs and resources clarify that a particular resource is required to complete a given job. This collaborative network can thus be effectively used to understand which resource is highly influential and the interrelations among them. With the data that has been collected from the case study and their corresponding details through the use of three centrality measures, it is possible to obtain a proper visual interpretation, as can been seen in Table 2. The relationship between the attributes (jobs and resources) is represented in Figure 2.

5.2 Network analysis

The main objective of network analysis is to break down and comprehend the complex information of the structure into collaboration networks for the extraction of potential synergies. In order to obtain the information of the structure, crucial features about descriptive statistics such as degree centrality, betweenness centrality, and closeness centrality about the network have to be considered to examine the complexity, interdependencies and interrelationships involved on it. In this research, we have considered the three most popular centrality measures such as Freeman's degree, closeness and Freeman's betweenness centrality about each attribute. The centrality is used to find how influential a node is in the network and also the interrelations among them for its complete analysis. In Table 2, values of the three centralities about the collaboration networks for the above-referred scenarios regarding five resources and 25 jobs are presented.

The degree centrality measures influence on the node from and to its closest neighbour with the complexity of $O(n)$ to linearly scale the nodes in the network, where n is the number of nodes. The jobs and resources with higher degree centrality represent strongly connected ones, whereas the jobs and resources with lower degree centrality exhibit very fewer connections. Thus, we have identified the key resources which are having higher degree centrality and can act as hubs and also serve as the central elements of the industrial plant.

The other two centrality measures, betweenness and closeness, give us information about the shortest path involved among the various attributes of the network. The betweenness centrality has the higher level of control on the information floating between different nodes in the network, while the closeness centrality is a measure of how closely the nodes are connected with each other. This data can be used to analyse the order in which the resources of the plant need to be arranged and how close each resource need to be from each other.

From the above analysis, we have gained a complete understanding of the various relations among the resources to complete the assigned jobs effectively. The resources that are key machines work as hubs of the industrial plant used for completing a maximum number of jobs which are identified by degree centrality. The arrangement of the resources in the plant layout based on their interrelations is also understood through the betweenness and closeness centrality measures. In this way, the complete industrial layout can be designed through the obtained statistical data.

Table 2 Centrality measures for the resources

	Degree centrality	*Betweeness centrality*	*Closeness centrality*
R2	16	142.896	27.619
R3	11	76.180	25.217
R4	11	64.360	25.217
R5	11	60.580	25.217
R1	8	24.977	23.967
J10	5	20.686	26.606
J11	5	20.686	26.606
J15	4	13.928	26.126
J16	4	10.613	25.217
J22	4	11.284	24.786
J18	3	7.478	25.217
J24	3	7.478	25.217
J13	3	7.478	25.217
J20	3	7.600	24.786
J17	3	5.292	24.370
J21	3	4.730	23.967
J3	2	1.706	23.200
J25	2	2.057	23.577
J6	2	2.057	23.577
J7	2	2.095	22.481
J8	2	0.831	21.481
J5	1	0	22.137
J1	1	0	22.137
J19	1	0	22.137
J2	1	0	20.567
J9	1	0	20.567
J23	1	0	20.567
J4	0	0	20.567
J14	0	0	0
J12	0	0	0

6 Results and discussion

The identified resources from SNAM and their impact on the manufacturing system performance regarding performance measures such as makespan, resource utilisation and throughput time is considered. Therefore, a simulated environment has been created through the FlexSim simulation tool. The setup of the problem description is shown as a screenshot in Figure 3. The simulation analysis was carried out and the results of the considered case study, i.e., the average content formed (job-setup), the resource utilisation, the state analysis of the resources, the throughput and the average maximum completion time of the jobs (makespan), are illustrated through Figures 4, 5, 6, 7 and 8 as Gantt charts and bar charts.

Figure 3 Snapshot of the FlexSim simulation setup (see online version for colours)

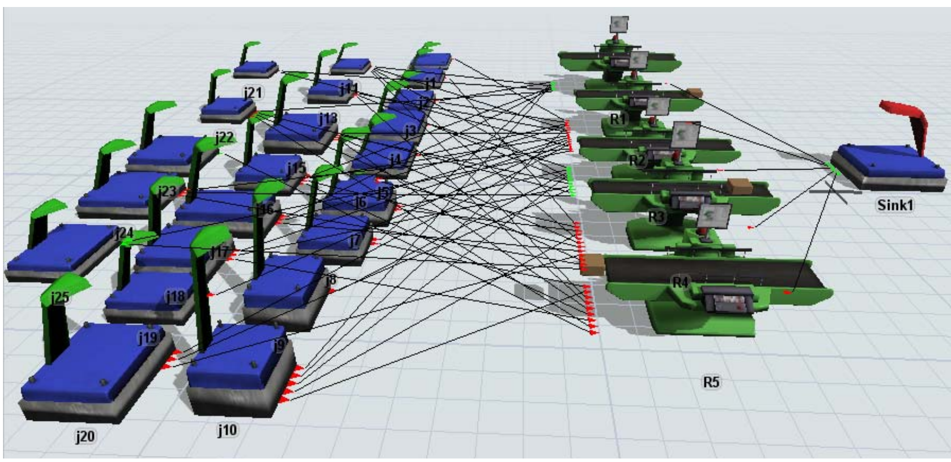


Figure 4 illustrates the average workloads that are completed per job in an interval of one day. The results range from nine contents to a maximum of 31 contents per job. It is clearly seen from this figure that the variation shows the completion of the jobs. Figure 5 reports the bar chart that presents the utilisation of the resources (R1, …, R5) for the completion of the jobs (J1, …, J25). The values are R1-1179 workloads, R2-1500 workloads, R3-1410 workloads, R4-1352 workloads and R5-1356 workloads. From the values presented, it is clear that R2 has been utilised at a maximum capacity compared to the other resources. This order of resources utilisation helps in completing the assigned jobs effectively. A resource that is a key resource, i.e., R2 in this scenario, works as a hub for completing a maximum number of jobs. Figure 6 summarises the state analysis of resources for the completion of the jobs. From the results of Figure 6, a proper conclusion can be made about the utilisation of resources. Results show that the idleness of R2 is 23.4%, while for R4 it is 26.5% and R1 has the highest idleness value.

Figure 4 Average workloads that are completed per job in one day (see online version for colours)

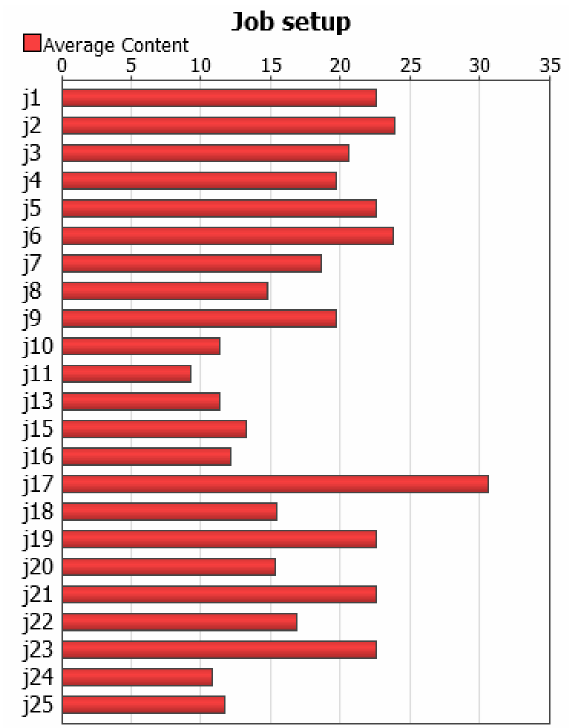


Figure 5 Resources utilisation for the completion of the jobs (see online version for colours)

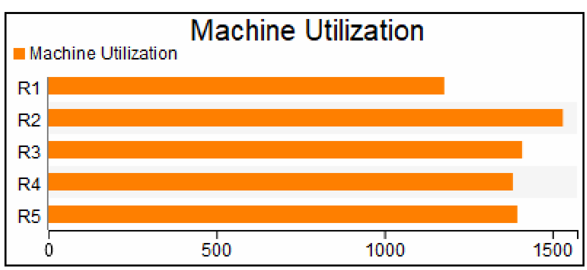


Figure 6 State analysis of the resources

State Analysis of machines

	Total	idle	processing
R1	100.0%	41.0%	59.0%
R2	100.0%	23.4%	76.6%
R3	100.0%	38.3%	61.7%
R4	100.0%	26.5%	73.5%
R5	100.0%	30.2%	69.8%

Figure 7 Throughput per hour for each of the resources (see online version for colours)

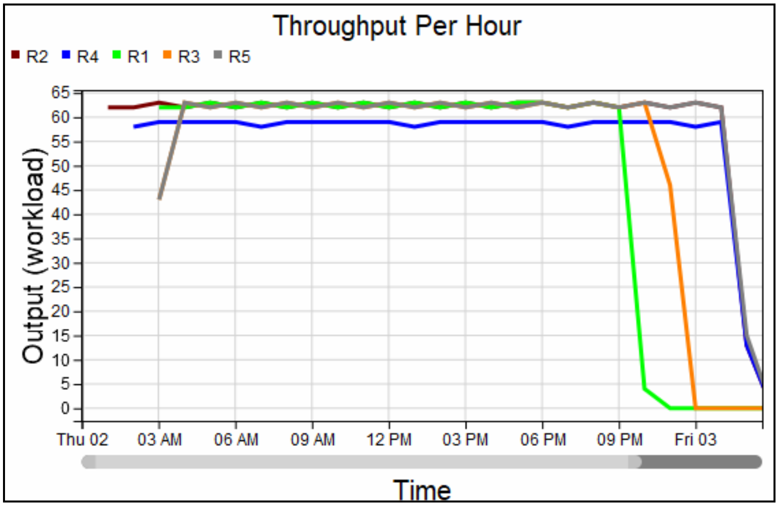


Figure 8 Gantt chart for the completion of all 25 jobs on five resources (see online version for colours)

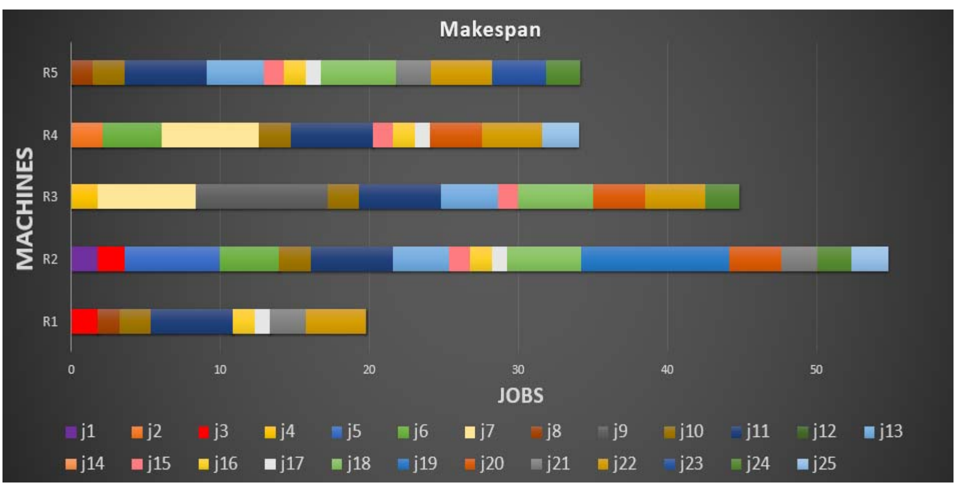


Figure 7 articulates the throughput per hour, which is usually the output statistic of the involved resources (R1, …, R5). From Figure 7, it is evidently observable that R2 is giving the maximum output throughout the simulation which ranges between 61–63 workloads/hr. Simultaneously, it is noticeable that R3 and R5 have a sudden increase in throughput which raises from 43 workloads/hr. to 62 workloads/hr., which shows that as time increase delivered the jobs assigned to these resources, an amplification has been directly replicated in the utilisation of these machines (Figure 5). Figure 8 demonstrates a Gantt chart that presents the makespan of the setup, i.e., the average time taken to complete all the jobs (J1, …, J25) with respect to the resources (R1, …, R5). The values are R1-19.6, R2-56, R4-43, and R5-34 hours respectively. Therefore, R2 is taking the maximum time, completing the largest number of jobs.

When a comparative study of results from FlexSim and centrality measures of SNA was carried out, a correlation was found. In both cases, R2 was found to be the key machine.

7 Conclusions

In this paper, we proposed a framework for analysing industrial plant layouts using SNA and a justification to the procedure through plant simulation. The study aimed at analysing the importance of using SNA techniques to examine the important relations between entities in a manufacturing environment, such as jobs and resources in the context of industrial plant layout analysis and establishment. Specifically, the study enabled to obtain relevant results for the identification of relations among these entities for supporting the establishment of an appropriate plant layout for producing the jobs. In addition, a simulation environment was created which assisted in validating the SNA approach and the obtained results regarding several important performance measures of the system, such as the makespan, the machines utilisation and throughput. An important aspect to highlight in this contribution is that the proposed SNAM can further appropriately fit the purpose of obtaining fast and accurate solutions for plant layout establishment under uncertainty, big data and dynamically changing manufacturing environments. These topics are nowadays rapidly spreading, in the scope of industry 4.0, requiring appropriate real-time-based manufacturing planning and control tools, for which we contribute with our proposed SNAM.

Although it has been pointed out how SNAM can create an impact in analysing industrial plant layouts, this paper has not suggested how resource maintenance time may impact the makespan and resource efficiencies. This aspect will be explored in further developments of this work. The paper is mainly focused on the application of SNA for the stage of layout analysis, while not discussing the implementation in system operation process.

Future work is planned for continuing to explore the application of SNA techniques to this kind of industrial plant layout problem, by exploring this problem in the context of CNOs/VEs, and underlying extended manufacturing environments, namely including big data analysis, and also to compare the application of SNA techniques with some other existing methods for industrial plant layouts establishment and analysis.

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