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Deviation from a state of perfect uniformity: An indicator of structural complexity in projects

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Abstract

The complexity of projects arising from interconnectedness between activities is believed to be one of the most significant challenges for managing projects. Although the literature has long appreciated the significance of measuring complexity, research on this topic is weakened by the lack of a method that accounts for a diverse set of structural characteristics of project networks. To evade this pitfall, this paper introduces the concept of perfect uniformity and develops a comprehensive measure of structural complexity in projects. The proposed method is validated by applying it in two real-life projects. The validation results confirm that project complexity is positively associated with a higher level of deviation from a state of perfect uniformity. This research is among few studies that draw on the concept of emergence and point out the importance of a system-level approach in project management to analyse the interdependency between multiple interconnected activities.

KEYWORDS

centrality, emergent properties, entropy, project complexity, uniformity

1 | INTRODUCTION

Aristotle states in his cosmological treatise, *De Caelo*, that, 'The least initial deviation from the truth is multiplied later a thousand fold'. This statement reflects a defining feature of a complex system where small perturbations in its constituent elements propagate within the system and can ultimately cause a considerable threat to the overall performance of the system (Zarghami & Gunawan, 2020). Viewed from this perspective, projects are real-life examples of complex systems because a disruption in a critical activity propagates as cascades across its succeeding activities leading to a significant delay and cost overrun in the project. A complex project is conventionally defined as a project consisting of multiple interrelated activities where the interconnectedness between these activities gives rise to complexity and consequently affects the project objectives (Bakhshi et al., 2016). It is widely recognized that projects are less likely failed due to technical issues (Klein, 2016), but mainly due to the complexity caused by interdependence between project activities that creates sensitivity to even small changes (Kapsali, 2013). As a response to tackle the increasing complexity of projects, the research domains of project management and complexity science have been intertwined, resulting in the publication of several articles that address the nexus between complexity theory and the project management field (Marle, 2020).

Measuring project complexity is an integral part of studying complexity (Luo et al., 2020). The literature has acknowledged that a complexity measure is a necessary tool for projects because it is impossible to develop effective approaches to reduce complexity without measuring it (Sinha et al., 2006). There is however an apparent research gap in measuring the structural complexity of project networks arising from the interconnectedness between project activities. Most existing studies ignore the key attribute of project complexity highlighted in its definition. In fact, there has been little development of complexity measures concerning the interconnectedness between project activities as the key element in project complexity's definition. The diversity of contexts upon which the complexity of project networks can be evaluated has been the main impediment to the development of a comprehensive measure of structural complexity in project networks (Lin et al., 2021). Despite this diversity, however, there is a direct correlation between the level of structural complexity and the uniformity of project activities (Ellinas et al., 2018). Existing studies have identified non-uniformity or heterogeneity as a common trait among all complex systems, which can have significant impacts on system performance (Fisher & Pruitt, 2020). I draw on this common trait of complex systems to fill this research gap and to develop a comprehensive complexity index that simultaneously takes into account various structural characteristics of project networks.

In this context, I turn towards entropy theory to measure complexity via the level of uniformity of project networks. In doing so, I first map a project onto a network of activities. I then employ three prototypical examples of centrality measures, namely, degree, betweenness and eigenvector centrality to evaluate various structural characteristics of a project network. Rooted in entropy theory, the current state of uniformity of the project network is measured by means of the joint entropy of centrality values. Finally, I measure the deviation from a state of perfect uniformity by calculating the fractional differences between the joint entropy of centrality values and the maximum achievable entropy.

In what follows, this paper provides an overview of the literature on conceptualization and measurement of project complexity. It then proceeds with the discussion of the concept of uniformity and its association with complexity. Next, the development of a two-tiered research approach is presented. This paper demonstrates the proposed method in two real-life projects followed by discussions of theoretical contribution and practical implications of this research.

2 | LITERATURE REVIEW

This section discusses the view of literature on the concept of project complexity. It then reviews the existing studies on measuring project complexity.

2.1 | Conceptualizing and tackling project complexity

Baccarini (1996) is among the first studies that conceptualized project complexity based on two dimensions that generate or influence the complexity of projects, namely, the organizational and technological. Following Baccarini's definition, William (1999) introduced uncertainty in goals and means as a key dimension of project complexity. Building on these two pioneering works, scholars have identified other factors contributing to project complexity and proposed various frameworks to tackle this complexity. For example, Azim et al. (2010) proposed a project complexity triangle with three sides: people, products and processes. The authors identified the people side of the triangle as the most important factor that contributes to the complexity and highlighted the role of soft skills in managing complex projects. Muller et al. (2012) suggested three dimensions for project complexity known as the complexity of faith, the complexity of fact and the complexity of interaction. Based on empirical data, the authors analysed the role of leadership competencies in managing complexity. In their review, Bakhshi et al. (2016) listed 125 factors that influence the complexity of projects. These factors cover a broad range of project elements as diverse as stakeholders, project cost, law, project resources and scope. Through the lens of complexity and variety management, Regaliza et al. (2017) and Tannir et al. (2019) treated projects as complex networks with self-organizing characteristics. In so doing, the authors adopted the Viable System Model (VSM) to investigate the viability condition of projects in changing environments.

To find solutions to tackle the increasing complexity of projects, researchers have turned to other disciplines to develop a range of tools that assist in managing complexity in projects. The main contention is that traditional project management tools cannot solve the issues associated with the complexity of projects (Saynisch, 2010). This has resulted in the wide employment of multidisciplinary tools to manage project complexity. Network theory (Zarghami & Dumrak, 2021a), system dynamics (De Marco et al., 2016), system engineering (Sheffield et al., 2012) and Actor Network Theory (Pollack et al., 2012) are examples of fields outside of project management domain that has attracted the attention of project management scholars.

2.2 | Measuring project complexity

The review of the literature reveals two streams of research on measuring project complexity: (1) Perceived complexity approach that measures the complexity of projects based on experts' judgements (Schlindwein & Ison, 2004) and (2) Descriptive complexity approach that treats complexity as an intrinsic property of a system (Nguyen et al., 2019).

The first stream of research employs the commonly used subjective methods such as surveys, Delphi, fuzzy logic and the Analytical Hierarchy Process (AHP) to measure the complexity of projects. For example, Vidal et al. (2011) adopted the AHP to evaluate the complexity of a project based on the experts' judgements. The ratio of the resulting value and the initial perception of project complexity was used as a complexity score. Xia and Chan (2012) used a Delphi questionnaire to identify six key factors of complexity for building projects. The authors developed a composite complexity index based on the importance weightings obtained from the questionnaire. Shafiei-Monfared and Jenab (2012) aggregated experts' opinions and developed a fuzzy graph-based model to measure the relative complexity of maintenance projects. Using fuzzy AHP and based on the opinions of project managers and team members, Nguyen et al. (2015) determined the weights of 36 factors contributing to project complexity. The geometric mean method was then used to combine the opinions of experts. Built on the results of questionnaire surveys, Luo et al. (2017) utilized factor analysis to develop measurement scales for five dimensions of project complexity including information, task, technological, organizational, environmental and goal complexities.

A relatively little attention has been given to the second stream of research that measures complexity by taking a descriptive approach. Most existing studies in this stream of research use a certain aspect as a representative indicator of project complexity. For example, Lu et al. (2015) opined that hidden works in projects are reflective of complexity and accordingly suggested the fraction of hidden and direct workloads in projects as a metric to evaluate the complexity of projects. Using centrality metrics, Parraguez et al. (2015) analysed information flow between activities in engineering design projects. The overall weighted distribution of centrality metrics was then used as a measure of project complexity. Ellinas et al. (2018) adopted degree and betweenness centrality metrics as indicators of structural complexity. The degree of the structural complexity of projects was then evaluated in the form of average as well as the percentile contribution of each metric.

As the literature review revealed, most studies on measuring project complexity do not address the structural complexity of project networks arising from the interconnectedness between project activities. This is an important research gap because the interconnectedness between project activities is a key element of the definition of complexity that governs the behaviour of projects as complex systems. The few existing studies on measuring the structural complexity of projects rest on a narrow range of structural properties of project networks. These studies do not take into account the simultaneous effect of multiple structural characteristics of a project network.

3 | UNIFORMITY AND ITS ASSOCIATION WITH COMPLEXITY

The theory of distribution and abundance of animals has a long tradition in evolutionary ecology. In this theory, the concept of 'spreading of risk' explicates how genetic variability of species leads to the spread of risk, enabling species to adapt to changing environments (Andrewartha & Birch, 1986). In particular, Den Bore's concept of 'spreading of risk' indicates that the risk of extinction in multiple smaller populations of animals is lower than in a single population of comparable size (Reed, 2004). In other words, the spreading of risk in space favourably influences the chance of survival of the population as a whole (Den Boer, 1968). In a comparable way, in a project where risks to the achievement of the project objectives are uniformly spread among project activities the likelihood of achieving project objectives is higher than a project where few activities have dominant impacts on the achievement of project objectives. The latter case promotes complexity by creating non-linear flows of resources and workloads. The existence of dominant activities in a project results in the emergence of bottlenecks (Casiraghi et al., 2021; Wallis, 2021). Consequently, emergent properties, as a distinguishing feature of complex systems, stem from these bottlenecks in the project network as well as the non-linearity in the interrelation between project elements (Morales-Matamoros et al., 2010). To explain in greater detail, emergence is referred to 'sudden arising of new patterns and structures possessing new properties' (Goldstein, 2005, p.2). In the project management context, emergent properties are not predetermined during the project planning process and thus cannot be deduced from the behaviour of project activities at the micro-level. Instead, emergent properties appear at the macro-level, which span and correlate the individual activities into a higher-level unity at the project network level (Goldstein, 1999; Goldstein et al., 2010).

Against this backdrop, I opine that structural complexity can be measured based on the degree to which a project network diverges from a state of perfect uniformity. The catalyst for this thinking centres on the fact that non-uniformity pushes the project towards complexity in the sense that the more deviation from a state of perfect uniformity is, the more complex the project will be. It is therefore sensible that the degree of complexity can be quantified by measuring how far the project network diverges from a state of perfect uniformity. Recent studies have substantiated the direct correlation between the non-uniformity (or heterogeneity) and complexity of real-life systems. For example, Nunes et al. (2020) measured the statistical heterogeneity of time-series data as a proxy to measure complexity. Ji et al. (2021) evaluated the heterogeneity of strata in oil and gas extraction projects by measuring the complexity of logging data. Elnawawy et al. (2022) pointed out the positive association between complexity and the heterogeneity of human societies.

4 | RESEARCH APPROACH

To measure the degree to which a project network deviates from a state of perfect uniformity, this paper employs a two-tiered approach (see Table 1). In Tier 1, this paper conducts a centrality analysis to capture various structural characteristics of the project network. Tier 2 uses the results of Tier 1 and develops an index to measure the complexity of the project network.

4.1 | Tier 1—Centrality analysis of project network

In the first tier, a centrality analysis is performed to evaluate the structural characteristics of a project network. This provides an input for the second tier in which the level of uniformity of centrality values is assessed.

Centrality analysis is a well-established method in network theory that aims to analyse the structural characteristics of components in a network. There exist more than 200 centrality measures to analyse networks from the structural point of view. These centrality measures can be classified into three categories, namely, geometric, path-based and spectral measures (Boldi & Vigna, 2014). Geometric centrality measures assess the importance of nodes by taking into account the number of nodes that exist in every distance. Path-based centrality measures take account of the number of paths passing through a node. Spectral centrality measures centre on the fact that a node is important if its neighbours are also important. Therefore, spectral measures evaluate the importance of a node based on the importance of its neighbours.

In order to provide a more precise measure of centrality for project activities, this paper adopts three prototypical centrality measures from each of the three categories discussed herein. These measures are (1) *Degree Centrality* as an example of geometric measures, which counts the number of in-coming links from and out-going links to a project activity (2) *Betweenness Centrality* as a representative example of path-based measures, which measures the extent to which an activity lies on the paths between other activities and (3) *Eigenvector Centrality*, which is a spectral measure that calculates the combined centrality measures of an activity's neighbours. The three prototypical centrality measures have been selected because their juxtaposition provides a complete representation of the structural characteristics of project networks (Zarghami & Dumrak, 2021b). In addition, these three measures have set the basis for the development of the most available centrality measures (Zarghami et al., 2019). Table 2 provides an overview of these three prototypical examples of centrality measures.

4.2 | Tier 2—Measuring the complexity of the project network

The second tier uses the values of centrality measures obtained from Tier 1 and develops an index that measures the degree of structural uniformity in a project

TABLE 1 A two-tiered research approach

Tier	Objectives	Method(s)
Tier 1. Centrality analysis of project network	1—Capturing the geometric characteristic of the project network 2—Capturing the path-based characteristics of the project network 3—Capturing the spectral characteristics of the project network	1—Degree centrality 2—Betweenness centrality 3—Eigenvector centrality
Tier 2. Measuring the complexity of the project network	1—Measuring a state of the structural uniformity of the project network 2—Measuring deviation from a state of perfect uniformity	Shannon entropy

TABLE 2 An overview of the three prototypical examples of centrality measures

Centrality measure	Mathematical expression	Parameters
Degree Centrality	$C_d(i) = deg(i)$	$deg(i)$: The number of direct connections to preceding and succeeding activities $C_d(i)$: Degree centrality of activity i
Betweenness Centrality	$C_b(i) = \sum_{s \neq r \neq i} \frac{n_{s,r}(i)}{n_{s,r}}$	$n_{s,r}(i)$:The number of shortest paths between s and r passing through i $n_{s,r}$: The number of shortest paths between s and r $C_b(i)$: Betweenness centrality of activity i
Eigenvector Centrality	$C_e(i) = \frac{1}{\lambda} \sum_{j \in M(i)} C_e(j)$	λ: The largest eigenvalue of the adjacency matrix $M(i)$: A set of the neighbours of activity i $C_e(i)$: Eigenvector centrality of activity i

network. Further, this tier investigates the extent to which the current state of uniformity deviates from a state of perfect uniformity. This is achieved by employing Shannon entropy as a fundamental concept of information theory (Mavrofides et al., 2011). Shannon entropy has been extensively employed in a wide variety of fields including complexity science as a measure of choice, heterogeneity and uncertainty (Zarghami et al., 2018).

Let μ_{ij} denotes the centrality value of activity i using the centrality measure j. The set of centrality values of project activities, when the centrality measure j is used, can be represented by an n-tuple vector $\overrightarrow{\mu_j}$ as follows:

$$\overrightarrow{\mu_j} = \left(\mu_{1j}, \mu_{2j}, \ldots, \mu_{nj}\right), \qquad i = 1, 2, \ldots, n \tag{1}$$

where n is the number of activities in the project network.

Further, let $P_j = \left\{p_{1j}, p_{2j}, \ldots, p_{nj}\right\}$ be the probability distribution associated with vector $\overrightarrow{\mu_j}$. The Shannon entropy of P_j is given by

$$H_j = -\sum_{i=1}^{n} p_{ij} \log_2 p_{ij} \tag{2}$$

where H_j is the Shannon entropy of $\overrightarrow{\mu_j}$ and p_{ij} can be obtained from:

$$p_{ij} = \frac{\mu_{ij}}{\tau_j} \tag{3}$$

where $\tau_j = \sum_{i=1}^{n} \mu_{ij}$, which is used to generate the probability distribution P_j from vector $\overrightarrow{\mu_j}$.

By substituting Equation (6) into Equation (2), we arrive at

$$H_j = -\sum_{i=1}^{n} \frac{\mu_{ij}}{\tau_j} \log_2 \frac{\mu_{ij}}{\tau_j} \tag{4}$$

Solving Equation (4) gives

$$H_j = \log_2 \tau_j - \sum_{i=1}^{n} \frac{\mu_{ij}}{\tau_j} \log_2 \mu_{ij} \tag{5}$$

The intuitive interpretation of H_j is that a dominant activity with a high level of interdependency with other activities contributes more to the non-uniformity of the project network, thereby attaining a lower value of H_j. Thus, from the complexity perspective, a project in a state of perfect uniformity where all its activities share similar structural properties is more desirable. Mathematically, the state of perfect uniformity is associated with the maximum possible value of H_j. H_j is maximum when the values of μ_{ij} are equal. Hence, for the maximum achievable value of H_j, the following equation holds:

$$p_{ij} = \frac{1}{n} \tag{6}$$

By substituting Equation (6) into Equation (2), we obtain

$$\left(H_j\right)_{max} = -\log_2 n \tag{7}$$

Up to this point, this paper has measured the degree of uniformity as well as the state of perfect uniformity for a given centrality measure. To provide a comprehensive representation of the structural characteristics of a project network, I now combine the three prototypical examples of centrality measures discussed in the preceding section. Since these three centrality measures are statistically independent variables, the combined entropy can be obtained by calculating the sum of individual entropies of these measures as follows:

$$H_T = \sum_{j=1}^{3} H_j = \sum_{j=1}^{3}\left[\log_2\tau_j - \sum_{i=1}^{n}\frac{\mu_{ij}}{\tau_j}\log_2\mu_{ij}\right] \tag{8}$$

where $j = 1$, 2 and 3 are respectively the identifiers for the degree, betweenness and eigenvector centrality measures, and H_T is the joint entropy of these centrality measures.

Note that H_T attains its maximum value when every H_j is maximum. Hence,

$$(H_T)_{max} = \sum_{j=1}^{3}(H_j)_{max} = -3\log_2 n \tag{9}$$

Conceptually, $(H_T)_{max}$ represents a state of perfect uniformity for the project network. To measure the degree of complexity, I now define the Complexity Index, parametrized by CI, as the fractional differences between H_T and $(H_T)_{max}$. That is,

$$CI = 1 - \frac{H_T}{(H_T)_{max}} \tag{10}$$

Substituting Equation (8) and Equation (9) into Equation (10) gives

$$CI = 1 + \frac{\sum_{j=1}^{3}\left[\log_2\tau_j - \sum_{i=1}^{n}\frac{\mu_{ij}}{\tau_j}\log_2\mu_{ij}\right]}{3\log_2 n} \tag{11}$$

CI can be interpreted as a measure of distance from a state of perfect uniformity. The range of CI is $[0,1]$ interval where a higher value of CI implies a higher complexity. $CI = 0$ indicates a state of perfect uniformity where all project activities share similar structural characteristics.

5 | NUMERICAL ILLUSTRATIONS

In this section, I validate the proposed method by applying it in two real-life projects. These two case studies provide an interesting contrast in terms of their size. The first case study is a small-budget construction project, whereas the second case study is the development of a large-scale airport project.

5.1 | Case study 1

The first case study is the construction of a foundation system for a single-story residential building taken from Zarghami and Dumrak (2021a). The project includes 8 main activities and the planned duration of the project is 26 days. Table 3 presents the list of main activities of the project as well as the predecessors of these activities (Zarghami, 2022). Using the information from Table 3, I now map the project onto a network of activities. Figure 1 illustrates the project network diagram in which nodes represent the project activities and links show the dependency between these activities.

5.2 | Case study 2

A large-scale airport project, taken from Ma et al. (2015), is selected as the second case study. The project contains five work packages that are further broken down into 21 main activities. The project is planned to be completed within 348 days. Table 4 reports the work packages and the dependency between project activities. In a similar vein to the first case study, the project network is created, as shown in Figure 2. In this figure, project activities are represented by rectangles and the sequences that activities are implemented are shown by arrows.

5.3 | Results

I use the open-source *R/igraph* package to conduct a centrality analysis of the project networks for case studies.

TABLE 3 Dependency table—Case study 1

Activity ID	Activity	Predecessors
1	Excavation permit	—
2	Land surveying	—
3	Excavation	1,2
4	Formwork for footing	3
5	Placing concrete	4
6	Foundation drain	4
7	Retaining wall	3
8	Backfill foundation	5,6

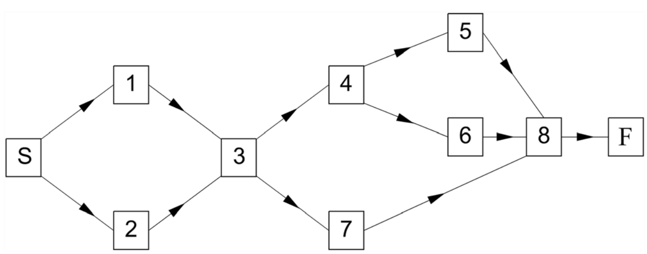

FIGURE 1 Project network diagram—Case study 1 (adapted from Zarghami & Dumrak, 2021a)

TABLE 4 Dependency table—Case study 2

Activity ID	Work package	Predecessors	Activity ID	Work package	Predecessors
1	Foundation	—	12	Wall& roof engineering	10
2	Foundation	1	13	Wall& roof engineering	12
3	Foundation	2	14	Decoration& fitment	12
4	Foundation	3	15	Implement installation	7
5	Structural works	4	16	Decoration& fitment	11
6	Structural works	4	17	Decoration& fitment	12
7	Implement installation	2	18	Decoration& fitment	12
8	Structural works	5	19	Decoration& fitment	13,18
9	Structural works	8	20	Decoration& fitment	14,15,16,17,19
10	Structural works	9	21	Decoration& fitment	6,20
11	Wall& roof engineering	10			

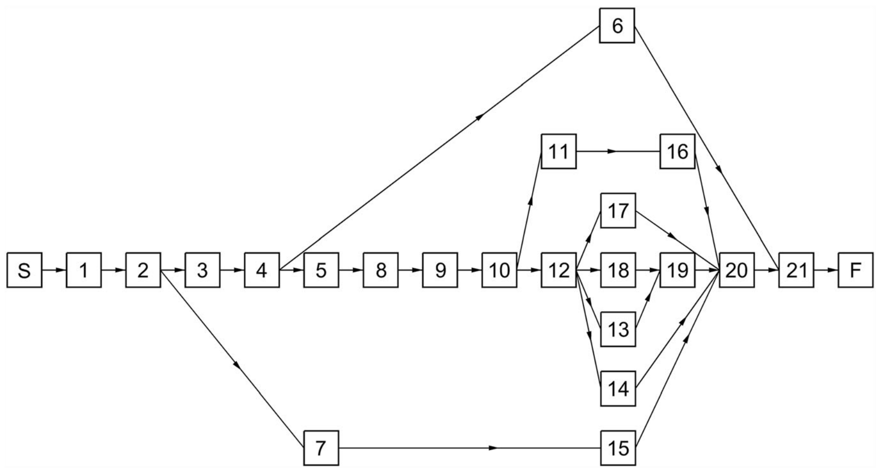

FIGURE 2 Project network diagram—Case study 2

TABLE 5 The values of centrality measures—Case study 1

Activity ID	Degree Centrality (μ_{i1})	Betweenness Centrality (μ_{i2})	Eigenvector Centrality (μ_{i3})
1	1	0	0.3965
2	1	0	0.3965
3	4	10	1
4	3	6	0.9829
5	2	0.5	0.7395
6	2	0.5	0.7395
7	2	3	0.7463
8	3	0	0.8823

Tables 5 and 6 report the values of degree, betweenness and eigenvector centrality for the first and second case studies, respectively.

Figures 3 and 4 illustrate the resulting rankings of project activities based on the degree, betweenness and eigenvector centrality measures for the first and second case studies, respectively. As can be seen in these figures, for a given activity, each centrality measure mainly assigns different rankings. For example, in the second case study, betweenness centrality identifies activity 10 as the most influential activity in the project network, whereas degree and eigenvector centrality measures locate this activity at 3rd and 8th positions, respectively. This is because each centrality measure determines a

TABLE 6 The values of centrality measures—Case study 2

Activity ID	Degree Centrality (μ_{i1})	Betweenness Centrality (μ_{i2})	Eigenvector centrality (μ_{i3})
1	1	0	0.0238
2	3	19	0.0725
3	2	29	0.0507
4	3	42	0.0823
5	2	46	0.05
6	2	3	0.1505
7	2	5	0.1469
8	2	54	0.07
9	2	60	0.1637
10	3	64	0.4297
11	2	11.333	0.278
12	5	46.667	0.8697
13	2	4.5	0.4996
14	2	4.33	0.6126
15	2	5	0.3758
16	2	5.333	0.4188
17	2	4.333	0.6126
18	2	4.5	0.4996
19	3	4	0.6551
20	6	15	1
21	2	0	0.377

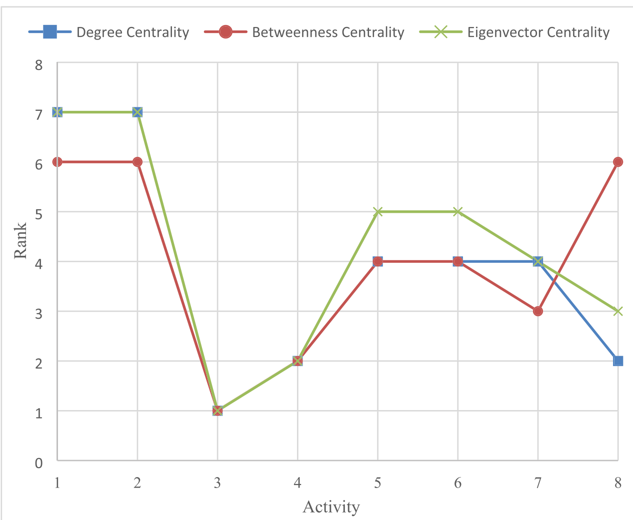

FIGURE 3 The resulting rankings of project activities using degree, betweenness and eigenvector centrality measures—Case study 1 [Colour figure can be viewed at wileyonlinelibrary.com]

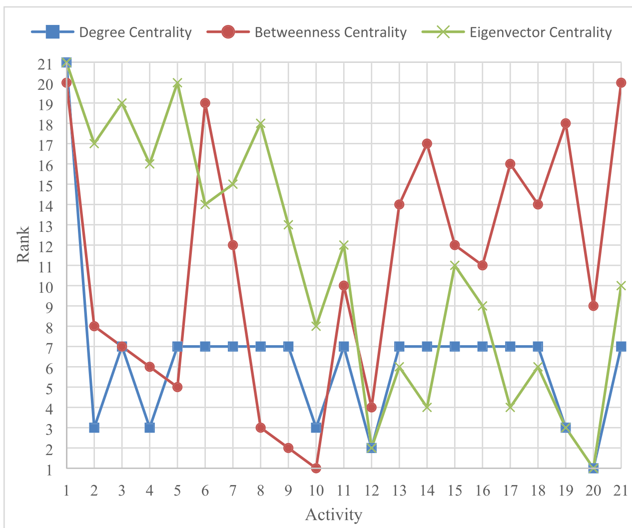

FIGURE 4 The resulting rankings of project activities using degree, betweenness and eigenvector centrality measures—Case study 2 [Colour figure can be viewed at wileyonlinelibrary.com]

particular structural characteristic of the project network. This confirms the results of the previous studies that the project network cannot be well analysed by the sole utilization of a particular centrality measure (Zarghami & Dumrak, 2021b). Thus, the existing studies that exclusively rely on a particular centrality measure fail to capture the complex interconnectedness between project activities. As a result, a comprehensive structural analysis of project networks accentuates the need for the juxtaposition of centrality measures. This need has been met in the proposed method by joint consideration of multiple centrality values.

To visualize the level of uniformity of centrality values, Figures 5 and 6 respectively illustrate the values of $\frac{\mu_{ij}}{\tau_j}$ for project activities for case studies. Further, Table 7 shows the values of CI and its constituent variables.

As can be seen in Table 7, the second case study exhibits a lower level of complexity ($CI = 0.1042$) compared to the first case study ($CI = 0.1675$). This can be ascribed to a higher degree of uniformity and accordingly a lower level of deviation from a state of perfect uniformity in the second case study. A contrast between Figure 5 and Figure 6 makes this result unsurprising. As depicted in Figure 5, in the first case study, the probability distributions associated with centrality values ($\frac{\mu_{ij}}{\tau_j}$) span a wider range of values ranging from 0 to 0.50. By contrast, as shown in Figure 6, a higher degree of uniformity in the values $\frac{\mu_{ij}}{\tau_j}$ for the second case study is

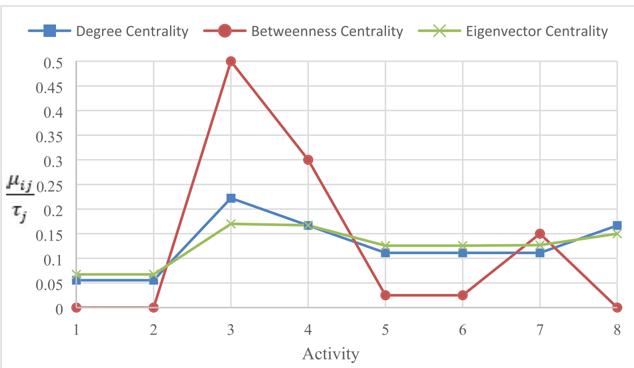

FIGURE 5 Values of $\frac{\mu_{ij}}{\tau_j}$ for project activities—Case study 1 [Colour figure can be viewed at wileyonlinelibrary.com]

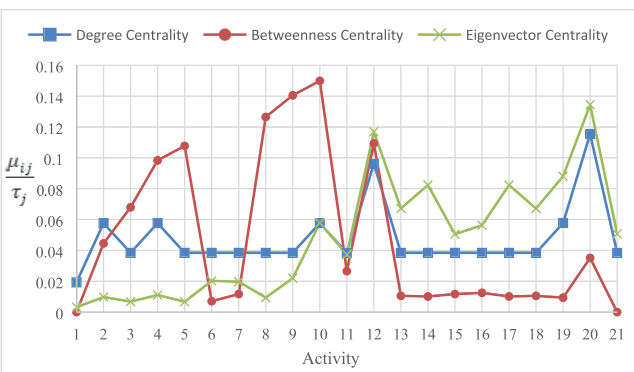

FIGURE 6 Values of $\frac{\mu_{ij}}{\tau_j}$ for project activities—Case study 2 [Colour figure can be viewed at wileyonlinelibrary.com]

observed. The difference in the level of uniformity in the centrality values of the case studies has been precisely captured by the proposed complexity index, and thus, the first case study has attained a higher value of CI than the second case study.

What is particularly striking about the results is that the size of the project in itself is not an indicator of complexity. Despite that the second case study (an airport project) is significantly larger than the first case study (a foundation system of a single-story residential building), it attains a relatively lower value of complexity index ($CI = 0.1042$) than the first case study ($CI = 0.1675$). This provides additional analytical evidence that the complexity of the project is not a matter of size.

6 | DISCUSSION

This section discusses the theoretical contributions as well as key practical implications that emerge from this research.

6.1 | Theoretical contributions

Two theoretical contributions emerge from this research. First, since the beginning of the modern project management era in the 1950s, the reductionist approach of breaking down a project into work packages and activities has been pervasive in the literature. Seven decades after the advent of the modern project management concept, a project is still planned by subordinating noncritical activities and subsequently paying attention to critical activities. However, the notoriously high rate of failure in projects has raised concern about the effectiveness of this approach (Zarghami & Gorod, 2019). The reductionist approach ignores the interdependency between project activities that leads to emergent properties as one of the most significant challenges in complex systems (Johnson, 2006). This is because reductionism simplifies the description of complex phenomena by looking at their smallest elements (Eskerod & Larsen, 2018). Although reductionism allows for an explicit focus on a few elements and therefore enables better comprehension, as it was first coined by Aristotle, 'the whole is greater than the sum of its parts'. This elevates the need for a substitute for the reductionist approach that decomposes a project into its smallest elements (e.g., project activities). This research is among few studies in project management literature that moves away from an exclusive reductionist approach by drawing on the concept of emergence in complex systems. It

TABLE 7 The values of the complexity index for cases studies

Case study	Degree Centrality (H_1)	Betweenness Centrality (H_2)	Eigenvector Centrality (H_3)	$(H_T)_{max}$	*CI*
Case study 1	−2.8638	−1.6977	−2.9308	3	0.1675
Case study 2	−4.2747	−3.5974	−3.9319	4.3923	0.1042

contributes to project management research by discussing how the concept of emergence can be manifested in projects. In addition, this research points out the importance of a system-level approach in project management to analyse the interdependency between multiple interconnected with the aim of tackling the emergent properties that occur in projects.

Second, building on the mathematical field of graph theory, the proposed method provides the necessary ingredients for capturing the complexity arising from the interconnectedness between various types of entities. By developing a graph theory-based method, this paper maps projects onto the networks of nodes and links where nodes represent project activities and links denote the interdependencies between these activities. However, the suggested graph theory-based method is not constrained to the analysis of a set of connected project activities. It is flexible and therefore can be used to measure the complexity arising from the interrelationships between various types of entities. More specifically, using the proposed method, project actors (e.g., agents, individuals and organizations involved in projects) can be referred to as nodes and the relationships between these actors can be characterized by the links between nodes. This, in turn, provides the basis for further analysis of the complexity inherent in the interrelatedness of project actors.

6.2 | Practical implications

The results of this research have three main practical implications. First, many organizations face the complex problem of selecting a subset of projects from a variety of available projects (Rolstadås et al., 2015). A key decision point in the project selection process is the level of risk in completing a project on time and on budget. The value of *CI* can provide an identification of threats that may arise during the implementation of a project. That is, the higher value of *CI* indicates a higher level of risk in implementing a project, thereby a lower level of attractiveness for selecting the project.

Second, project schedulers can benefit from the proposed method for the pre-structuring of schedule networks. In the planning phase of a project, an acceptable threshold value of *CI* can be set for designing the schedule network. Once the draft of the schedule network is completed, if the value of *CI* crosses the threshold value, the draft can be either excluded from further development or revised to meet the threshold (Lange, 2011).

Third, Critical Chain Project Management (CCPM) is a scheduling methodology that is widely used in real-life projects. At the core of CCPM are contingency reserves, known as time buffers, which are inserted at critical points to protect the project schedule from a delay. The literature has acknowledged that an accurate estimate of time buffers guarantees the timely completion of projects (Zarghami et al., 2020). As a result, several methods have been developed to determine the size of time buffers. In this vein, researchers have recently directed their attention to the concept of network complexity as a key contributor to determining the size of time buffers. The proposed method can make an inroad into the process of estimating the size of time buffers by offering a comprehensive account of network complexity because it accounts for multiple structural characteristics of project networks.

7 | CONCLUSION

In order to effectively manage the increasing complexity of projects, we should be able to measure the level of complexity. However, there has been comparatively little research on measuring the structural complexity of project networks arising from the interdependency between project activities. In this paper, I have advanced a more comprehensive measure of project complexity that takes account of various structural characteristics of a network of project activities. By recognizing that non-uniformity in a project network promotes complexity and consequently causes emergent properties, this paper has proposed an index to quantify the complexity of project networks by measuring the deviation of the current state of the project network from a state of perfect uniformity.

Using the proposed index, this paper measured the complexity of two real-life construction projects. The new index was validated by showing that (1) it precisely captures the distinctions between the structural characteristics of two case studies regardless of their size, (2) project complexity is positively associated with a higher level of deviation from a state of perfect uniformity and (3) a comprehensive account of network complexity requires the juxtaposition of multiple centrality measures.

Albeit an improvement over the available methods, the proposed measure of project complexity has limitations. Although the proposed index reflects the emergent properties, it does not cover the whole range of characteristics of complex systems. Future research might seek to develop a complexity measure of projects that takes into account additional characteristics of complex systems such as self-organizing, autonomy and bifurcation. Further, from the scoping perspective, this research is limited to quantifying the structural complexity of projects. It would be helpful if future research could engage in incorporating human, organizational and technical factors into the proposed method. Additionally, it is suggested that this research be extended by combining the VSM and the centrality analysis of the project network. Such an integrative model assists in designing viable projects by joint consideration of two characteristics of complex systems, namely, self-organizing and emergence. Despite these limitations, the method developed herein is repeatable and can accommodate an unlimited number of variables that contribute to the complexity of projects. I hope that this research encourages future research that offers a wider application of complexity science in the project management field.

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DATA AVAILABILITY STATEMENT

All data, and models generated or used during the study, appear in the published article.

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