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Advancing Construction Scheduling: Unravelling Challenges Through GERT

K. Pregina[1], K. Vasugi[2*]

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Abstract: Many real-time projects face uncertainty and unpredictability in today's rapidly developing world, rendering conventional scheduling methods inadequate. In such circumstances, stochastic scheduling emerges as a valuable mechanism for formulating dependable and efficient schedules while simultaneously considering the intrinsic uncertainty and variability of the factors that impact the project. Graphical Evaluation and Review Technique (GERT) is a stochastic method employed in project management to model and analyses complex projects. The article provides an in-depth examination of GERT methodology literature, addressing its historical background, fundamental principles, methodologies, limitations, and practical applications. This comprehensive analysis involves informetric evaluation and content classification, encompassing a total of 96 journal articles, 10 book chapters, and 39 conference papers published from 1997 to 2023. It furnishes valuable insights to aid researchers and decision-makers in making informed decisions and enhancing the efficiency of project planning, scheduling, and control.

Keywords: *Project management tool; comprehensive review; research impact assessment; informetric analysis; Graphical Evaluation and Review Technique (GERT);*

1. Introduction

In today's dynamic environment, effective project management becomes indispensable for accomplishing organisational goals, optimising resource utilisation, and ensuring favourable outcomes. It has a notable impact on a broad range of industries, with construction being a prime example of its relevance and significance. The process of formulating a comprehensive schedule for the multiple phases involved in the construction of a building is a complex and challenging endeavour. However, the favourable results can be realised by implementing suitable project management methods. The integration of network modelling and scheduling is of the utmost significance in project management, as it enables the effective organisation and execution of projects. Incorporating these two key concepts impacts ensuring the timely and cost effective implementation of projects while simultaneously meeting the expectations of all stakeholders [1].

Challenges in Construction Scheduling

The management of construction projects stands as a sophisticated discipline, requiring adept handling of intricate variables to ensure the timely and efficient realization of endeavours. At the epicentre of this intricate process lies the art and science of construction scheduling, a domain fraught with challenges that demand a comprehensive understanding and strategic methodology. Since the 1950s, the scheduling of construction projects has been primarily conducted using traditional network-based project scheduling methodologies, such as the Program Evaluation and Review Technique (PERT), Critical Path Method (CPM), and Precedence Diagramming Method (PDM), among others. However, the current scheduling techniques remain insufficient in determining the critical factors for establishing precise schedules. The conventional methods in project planning rely on deterministic job durations and simplified task dependencies, which may not fully capture the uncertainties and complex relationships inherent in project planning [2]. Additionally, these methods are inadequate in addressing the stochastic nature of projects [3]. When using traditional methods, each activity is portrayed as a separate entity, and activities that take place frequently are considered to be separate occurrences [4]. The complexity of task dependencies poses a significant hurdle, making the effective representation and management of these relationships challenging [5]. Additionally, resource constraints, encompassing limited availability of labour, equipment, and materials, can result in delays and inefficiencies during task execution [6]. Uncertainties in duration estimates further compound the intricacies of construction scheduling, influenced by variables such as weather conditions, unforeseen site challenges, and changes in project scope [7-8]. The dynamic nature of

[1]*Research Associate, Division of Structural and Geotechnical Engineering, School of Civil Engineering, Vellore Institute of Technology, Chennai 600127, Tamil Nadu, India*
ORCID ID - https://orcid.org/0000-0002-4327-2730
[2*]*Associate Professor, Division of Structural and Geotechnical Engineering, School of Civil Engineering, Vellore Institute of Technology, Chennai 600127, Tamil Nadu, India*
[2]*Corresponding Email: vasugi.k@vit.ac.in*
ORCID ID - https://orcid.org/0000-0001-5858-4019

construction projects, characterized by changes in design, scope, and requirements, necessitates flexible scheduling approaches to adapt to evolving conditions [9]. Inherent risks, including delays, cost overruns, and unforeseen events, present formidable challenges to accurate and reliable scheduling in the construction industry.

Consequently, uncertainties can develop from diverse elements, including insufficient information, a lack of expertise, ambiguity, unanticipated events, or modifications in requirements. Uncertainty in scheduling can significantly impact project timelines, resource utilisation, and overall project completion. The potential for delay is one of the most severe consequences that might arise from imprecise scheduling. Delays can have a sudden and extreme effect on the entire schedule, leading to tardy targets, cost overruns, and loss of goodwill [10].Another key source of uncertainty in project management is the variability in project duration and cost estimates. These estimates are typically based on assumptions and experience, which may not always accurately predict the actual duration or cost of the project.

GERT: A Strategic Framework for Overcoming Construction Scheduling Challenges

Additionally, unforeseen events or changes in project requirements can further increase the uncertainty and unpredictability of the project [11]. Consequently, the heart of project management is to address two crucial factors: uncertainty and complexity. Using stochastic models is a potential strategy that could mitigate uncertainties related to scheduling, among other possible approaches [12-13]. Stochastic models are mathematical models that incorporate randomness or uncertainty into their structure. They describe systems that involve probabilistic elements, such as random variables or stochastic processes [14].

The Graphical Evaluation and Review Technique (GERT) is a stochastic approach utilised in project management for modelling and analysing complex projects [15-16]. The approach exhibits a broad spectrum of applications and finds relevance in different sectors, such as manufacturing, engineering, and software development. GERT emerges as a particularly significant tool, enriching project management practices with its unique planning and risk management approach. The GERT methodology facilitates a more streamlined approach to evaluating complex systems, reducing the need for repetitious examination [17].GERT is a powerful scheduling tool that offers several advantages over traditional methods, particularly when managing uncertainty and risk [18]. The GERT methodology incorporates the evaluation of multiple alternatives and the impact of uncertainty on the project schedule. Moreover, GERT facilitates the simulation of stochastic events like delays or unforeseen circumstances.

In the present review of the literature, an informetric approach is used to analyse the quantitative elements of research on GERT thoroughly. Informetrics is a branch of bibliometrics that efficiently quantifies and assesses literature's impact and characteristics. Bibliometrics, scientometrics, and informetric analyses are the three primary metrics that are used to conduct quantitative research on published research publications [19]. Bibliometric analysis focuses on statistically evaluating published literature, and scientometrics investigations assess researchers' achievements to track scientific progress. In contrast, informetric analysis aims to uncover implicit information not readily apparent through quantitative means. The principal goals of this investigation are twofold: first, this literature examines the historical evolution of GERT, its major principles, methodology, and applications, as well as its impact on project management practices across different sectors; second, to gain deeper insights into the quantitative landscape of this field, including publication and citation trends, authorship patterns, and the impact of GERT related research.

The structure of this literature review includes several key sections, including an introductory segment that sets the context, a historical examination of the development of GERT research, an analysis of publication and citation trends, insights into authorship, scrutiny of keyword usage, an assessment of the significance of journals within this domain, and a concluding section that synthesises our key findings and underscores the pivotal role of informetrics in unravelling the quantitative dimensions of GERT.

2. Theoretical Foundations of GERT

The GERT underwent a remarkable historical transformation, going from its initial use in defence to becoming a flexible and popular project management tool. It is imperative to fully comprehend PERT's historical origins to appreciate its long-term applicability in modern project management.

In 1966, Pritsker [20], Happ[21] and Whitehouse [22] developed the GERT methodology for stochastic network analysis. This technique is an extension of the basic algebra of analysis for network reduction in a Generalised Activity Network (GAN) developed by Elmaghraby[23]. GERT builds on the capabilities of GAN by allowing for more detailed modelling of project activities, especially those with uncertain or conditional dependencies [24]. Additionally, it is showcased as an efficient method for reducing complex equations representing complex problems when combined with the basic concepts of network algebra [25]. The GERT network model, like the PERT methodology, with the addition of decision trees and process flow graphs. To simulate redesign and rework, activities can branch based on the outcomes of the decision nodes and be repeated in loops [26]. It facilitates the modelling of decision making with uncertain events, allowing for more informed project planning and scheduling decisions [27]. GERT employs a network diagram to depict the project's tasks and their relationships. A node represents each task, and the arrows connecting the nodes indicate task interdependence. In addition to including the time and probability of each activity, the diagram also depicts its duration and frequency of occurrence.

GERT is a process for conceptualising and assessing a complex structure or an integrated framework incorporating a graphical perspective [28-29]. GERT is acclaimed as a potent tool for developing, investigating, and reviewing a multifaceted system utilising a graphical representation and defined preliminary framework and evaluation procedure [30]. Additionally, GERT is used to study inconsistencies and found to be beneficial because of the versatility of the coherent nodes, the scale and scope of the details conveyed by the network's different attributes, and the capability to formulate complex safety and reliability issues [31]. Furthermore, Randolph[32] used GERT to investigate the teaching and learning process and demonstrated the application of the topology equation for a network to acquire crucial parameters. An analogy between the Markovian model and GERT networks with EXCLUSIVE OR nodes demonstrates the efficacy of GERT approaches in studying learning theory.

It is essential to have a comprehensive understanding of the complex parts and their properties that constitute a stochastic network, as described by Pritsker[20] and G.E. Whitehouse [31], along with a detailed examination of the structure of the nodes.

Components of Stochastic Network

Initially, Pritsker outlined the integral components that make up the framework of the GERT network. The two elements that constitute an integral aspect in a stochastic network are logical nodes or vertices, which represent coherent operations, and branches or arcs or transmittances, which indicate the accomplished activity.

Vertices

In a GERT network, the logical nodes or vertices represent the onset or completion of the depicted activity and the criteria for an event or outgoing event. In a GERT network, a logical node has two terminals or components: the receiver (input) terminal and the emitter (output) terminal.

Input terminal: The input terminal defines the criteria for recognising the branch heading to the node. The input terminal of a node can be of one of three types, namely, ‘AND’, ‘INCLUSIVE OR’, and ‘EXCLUSIVE OR’.

a. AND: An AND node will only be realised if all the preceding activities denoted by branches incident on it are realised, and the incident activity with the longest duration dictates the duration required for the AND node to be accomplished.
b. INCLUSIVE OR: Any antecedent activity implied on a branch occurring on an INCLUSIVE OR node can be accomplished by the node to become materialised eventually. Consequently, the realisation period for the node is perceived as the shortest of all the durations of events that eventually lead up to an INCLUSIVE OR node.
c. EXCLUSIVE OR: An EXCLUSIVE OR node is realised when any incident activity indicated on a branch leading to it is performed; however, only one arc can actualise the node at a time, and other incident branches go inactive.

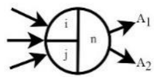
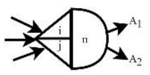
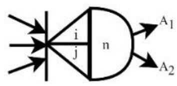
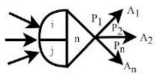
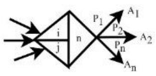
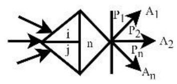
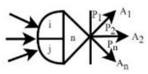
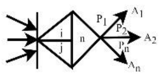
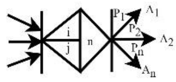
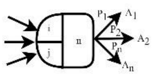
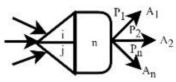
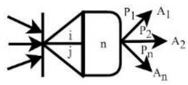
Emitter terminal: The emitter terminal indicates the conditions for realising the branches that emerge from the node. The emitter terminal of the node can be either deterministic or probabilistic.

a. Deterministic emitter terminal: The branches that emerge from the node with the deterministic emitter terminal are considered to commence simultaneously at the same time if the node is realised. All branches emerging from the deterministic node have an equal probability of occurrence.
b. Probabilistic emitter terminal: The probability of occurrence for each emanating branch is 1. Dawson and Dawson [33] further classified the output type assumed by A.A.B. Pritsker [20], W.W. Happ[21], and G.E. Whitehouse [22] into three different probabilistic forms of the emitter node: INDEPENDENT OR, EXCLUSIVE OR or DEPENDENT OR.
   i. Probabilistic INDEPENDENT OR: The activities that originate from a probabilistic INDEPENDENT OR node commence independently, each with its associated probability. It could result in all or none of the activities being initiated upon the realisation of the node.
   ii. Probabilistic EXCLUSIVE OR: If the node with probabilistic EXCLUSIVE OR emitter terminal is realised, only one of the branches emanating from the node is realised at a time, while the remaining arcs stay inactive (or are nullified). The total probability of branches emerging from the node is 1.
   iii. Probabilistic DEPENDENT OR: The branches emerging from a probabilistic DEPENDENT OR

node is mutually dependent on one another to result in accomplishment (i.e., one activity would be a prerequisite for the other). The sum of the probability of all the emanating branches is 1.

The different combinations of the nodes are illustrated in Table 1 as elaborated by Dawson and Dawson [33]. The key to effective network modelling is precisely defined node representation. The nodes in a GERT network are identified by node numbers (*n*). The node also indicates the number of activities required to be accomplished for the initial realisation of the node (*i*) and the number of activities needed to be realised for subsequent realisation (*j*) if the node is in a loop. The activities are depicted as A_1, A_2, …. A_n, and the associated probabilities are P_1, P_2, ….P_n, respectively. Any activity sequence can be graphically delineated by a GERT network by altering the values of (*i*) and (*j*). If the node is not included in a loop and if the node is realised only after the completion of all activity incidents on the node, then the positions of (*i*) and (*j*) may be left blank [34].

Table 1: Archetype of nodes in a GERT network [33]

Emitter / Receiver	AND 	INCLUSIVE OR 	EXCLUSIVE OR 
Deterministic 			
Probabilistic INDEPENDENT OR 			
Probabilistic EXCLUSIVE OR 			
Probabilistic DEPENDENT OR 			

In concisely, the vertices in a GERT network illustrate the following [35]:

- the number required the realisation of activities incident on the node for the first realisation of the node (*i*)
- the number required the realisation of activities incident on the node for the subsequent realisation of the node (*j*)
- the statistical quantity of the activities emanating from the node and the method of scheduling (i.e.) deterministic or probabilistic

Furthermore, A.A.B. Pritsker [36] describes the principles and representations that serve as the framework for a GERT simulation program. Additionally, demonstrates the use of the GERT simulation program and its modifications, including queue nodes (GERTS IIIQ), resource (GERTS IIIR), and cost (GERTS IIIC) [37]. A GERTS IIIQ network node with storage capacity was designed and added to the basic GERT simulation program to represent queuing systems. The nodes in the GERTS IIIQ network model indicate the initial number of activities in the queue and the maximum number of activities that can be accommodated. Figure 1 depicts a Q node with an INCLUSIVE OR node on the receiver end. The node specifies the node numbers (*n*), the number of activities in the queue at the commencement (a), as well as the maximum number of tasks that can be handled in the queue (*b*).

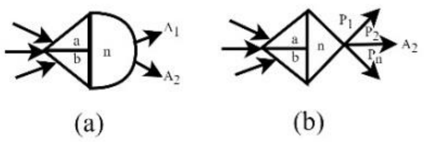


Fig 1: Representation of a Q node (a) Deterministic (b) Probabilistic

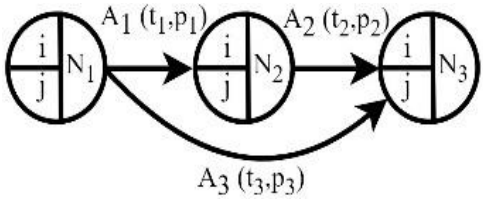


Fig 2: Representation of a branch in a GERT network

Transmittances

The branches or arcs or transmittances are another fundamental component of the stochastic network. A branch is a directed path connecting two nodes delineating an activity. The possibility that the activity depicted by the branch will eventuate (p_i) and the time (t_i) needed for the activity to be performed are the two attributes that govern any branch that emerges from an actualised node. The branches or arcs terminate at either the succeeding or the preceding node. The branches terminating in the succeeding node may be connected in series and parallel. Figure 2 depicts the deterministic nodes N_1, N_2, and N_3 connected in series by the arcs representing the flow of activities A_1 *and* A_2. The activity A_3 flow from nodes $N_1$and N_2 parallel to the activities A_1 *and* $A_2$with associated time (t_1, t_2, t_3)and probability (p_1, p_2, p_3).

If one of the associated arcs arrives at any node that occurred before the current node, then it is said to form a loop. Considering the features of the other input side nodes, i.e., until all branches have been actualised, an AND node cannot be realised. For the INCLUSIVE OR input type, only the activity with the shortest completion time indicating the first action completed is noticeable. However, only EXCLUSIVE OR node processes one branch at a time. The looping concept is appropriate when it is incident on the EXCLUSIVE OR node [38]. The loop can be comprehended as either a recurrence loop, a self loop, or a feedback loop. The Figure 3 illustrates the loops with activities (A_1, A_2, ... A_n), duration (t_1, t_2, ...t_n) and associated probabilities (p_1, p_2, ... p_n). A recurrence loop is an arc that is incident on any preceding node representing repetitions of the activities in sequence as depicted in Figure 3(a). If an arc emanates and is incident on the same node, then the arc is said to form a self loop as in Figure 3(b). A feedback loop shown in Figure 3(c) is an arc that is incident on any prior node representing an activity with an associated probability.

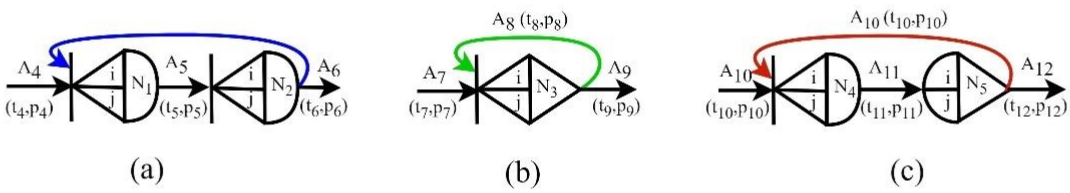


Fig 3: Representation of Loop (a) Recurrence loop (b) Self loop (c) Feedback loop

Computation Procedure

The stages in the analysis of a GERT network include the following stages. The first step in the GERT implementation process is creating a work breakdown structure (WBS) by methodically breaking down the process into more easily comprehended sections and hierarchically representing the tasks within the WBS. Subsequently, the initial description of the system or situation is transformed into a network model. Then, all pertinent data necessary to delineate each branch of the network are collected. The network is later reduced to obtain a one branch equivalent equation between the source and sink nodes. The subsequent step involves the conversion of the equivalent equation into performance measures. These measures comprise the probability of node realisation and the moment generating function of the duration attributed to the equivalent network.

An extension of the flow graph theory based derivation technique is developed to allow for the study of a network with nodes and edges representing durations defined by random variables. The principle of the '*w*' generating function is derived to understand the network's statistical attributes contingent on implementing unique network components that may be utilised to establish the 'w' function and moment generating function (MGF). MGF transmits characteristics (such as temporal variables) from one associated arc to the succeeding arc [39]. The time transfer across the associated GERT vertices is relatively determined by multiplying the probability of realising that arc with MGF ($M_i(s)$). The transfer function ($W_i(s)$) expresses the probability p_i that the activity '*i*' will be performed in time duration'*t*' as shown in Equation 1.

$$W_i(s) = p_i exp(s.t_i) = p_i e^{st_i} \quad (1)$$

Evolution & Modification

Several studies on the GERT technique combine the GERT methodology with mathematical programming models to establish appropriate solutions to problems driven by contingencies [40]. Among the mathematical programming models are network optimisation, dynamic programming, and stochastic programming [41]. It is used to accurately measure critical parameters, even when dealing with highly complicated situations. Stochastic processes can be used to evaluate GERT networks, providing more insight into the structure and requiring less computational effort [42]. It is later extended to develop the procedure for computing the branch parameters of the network models to analyse reliability problems [43], sensitivity issues [44], and time cost analysis [45]. Subsequently, efforts occurred to obtain analytical solutions for GERT networks that comprised INCLUSIVE OR and AND nodes. A simulation software, GASP II, evolved to incorporate all three categories of input nodes.

The characterisation and review procedures for many tests were exemplified and accomplished parametric conditions by employing GERT simulations (GERTS) [46], in addition to elaborating the precise details of node attributes and network modelling [47]. Furthermore, GERTS is improved to accommodate the costs (GERTS IIIZ), resources (GERTS IIIR), and Q nodes (GERTS IIIQ) parameters [48]. The GERTS IIIZ methodology permits the inclusion of initial expenses and variable costs for network operations [49]. The GERTS IIIR model implemented the concepts of resources, which mandated that the commencement of an activity is contingent on the availability of the resources required by the indicated activity. GERTS IIIQ incorporated the implementation of transaction flow and Q nodes, which involve the queuing of transactions for operations [50].

An analysis of the restrictions present in the resource handling operations of air cargo employed the stochastic network method of GEPT IIIQ, primarily focused on the relationship between the GERTS IIIQ network model and building standards [51]. The expansion of facility boundaries enables identifying and removing obstacles in functioning operational procedures. Hogg et al. [52] developed GERTS QR, a revised version of the GERTS model, that can manage queueing systems with resource constraints and is competent in accommodating varied labour categories. Also, a specific approach known as R GERT was devised to compute significant metrics in GERT networks subject to resource limitations. Subsequently, Kurihara et al. [53] described a technique for maximising a network for resource apportionment that could be made up of AND, OR, and Exclusive OR nodes. Neumann provides a summary of the time based study of GERT networks. Furthermore, the issue concerning the allocation of resources on a project is conceived as a nonlinear programming problem, and it is addressed by applying iterative techniques such as the gradient method and the Monte Carlo simulation. The effectiveness of the recommended technique is demonstrated through numerical experiments.

A.A.B. Pritsker[54] concurrently formulated GASP IV, a simulation language to model the queueing and inventory systems, which later evolved into Queueing Graphical Evaluation and Review Technique (Q GERT based on GERT IIIQ) [55] and SMOOTH (a network simulation language based on GERT IIIZ that is capable of analysing models of a combined continuous discrete nature) [56] GERT IIIZ later evolved into the Generalized Reliability Analysis Simulation Program (GRASP), Partitive Analytical Forecasting (PAF), and Precedence GERT (P GERT). GRASP addresses various challenges where failures and repair occurrences are simulated by the probabilities of the system's components [57]. The PAF approach uses logical circuits to describe the creation and development of competent techniques and create probability associated estimates of technology development duration and expenditures [58], and P GERT addresses complex queueing issues [59].

Projects often involve multiple variables and a high degree of complexity, significantly affecting the project's eventual outcomes. Consequently, project management inevitably involves a considerable level of uncertainty. To manage uncertainty in project management, project managers can use various tools and techniques, including mathematical modelling. Mathematical techniques, including Fuzzy Set Theory, Grey System Theory, and Vague Set Theory, are utilised in combination with GERT methodology to depict and evaluate uncertainty in quantitative terms.

Fuzzy set Theory Based GERT (F GERT)

Zadeh[60]originally proposed Fuzzy Set Theory (FST) as a means of representing and analysing problems in reality that involve incomplete information, imprecision, and inherent uncertainties arising from the use of natural languages by humans [61]. It is a model based on data with fuzzy relationships, indicators, and occurrences [62-63]. The Fuzzy based Graphical Evaluation and Review Technique (F GERT) is a project management tool that integrates the principles of FST for modelling and investigating projects that involve ambiguous and imprecise data. Initially, Itakura and Nishikawa [64] proposed STOCNETIC, a FST incorporated stochastic network technique (GERT), and detailed the comprehensive framework for modelling and analysing complex projects in which the estimates of time may exhibit imprecision or uncertainty. A mathematical approach to constructing a fuzzy set involves assigning a numerical value to each possible member of the universe of discourse, which reflects their degree of membership in the fuzzy set. The grade assigned indicates the extent to which the given set resembles the concept represented by the fuzzy set. The degree of relation between the fuzzy sets can be expressed through the membership function, which may indicate a higher or lower degree of membership [65]. In contrast to classical set theory, where the membership of a set's elements is stated in binary terms, the membership function of a fuzzy set can be valued within the range of [0,1] [66]. The fuzzy numbers may be expressed as triangular fuzzy numbers [67-70] or trapezoidal fuzzy numbers [71-73].

Grey System Theory Based GERT (G GERT)

Ju Long [74] established the Grey System Theory (GST) as an alternative approach to address uncertainty. The term "grey" can be perceived as an intermediary state between an entirely black framework and one entirely white. In a black system, there is a complete absence of information, while in a white system, there is a complete availability of information [75]. The GST emphasises the analysis of data that is characterised by inadequate sample sizes and inadequate reliability, which may include incomplete or redundant information. The primary objective of an ambiguous system is to acquire maximum information to generate a comprehensive response, relying on inadequate and incomplete information [76]. A grey number is an indeterminate number that takes its possible value within an interval or a general set of numbers. A grey number is represented as a pair of values: a central value that best estimates the quantity being measured and a range that represents the uncertainty associated with that estimate. A grey number is denoted as (x, δ, α), where x is the central value, δ is the grey deviation or the range of uncertainty, and α is the accuracy degree or the degree of confidence in the central value. The grey deviation can be further divided into two parts: the lower grey deviation (δ_L) and the upper grey deviation (δ_U).The lower and upper deviations represent the lower and upper bounds of the range of uncertainty. So, a grey number can also be represented as $(x, \delta_L, \delta_U, \alpha)$ [77]. Grey systems incorporate fundamental principles of grey numbers to implement grey sets, which involve interpreting the characteristic function values of a given set as grey numbers [78].

Ruan et al. [79] proposed the Grey Graphical Evaluation Review Technique (G GERT), which integrates GST and GERT methodologies. G GERT aims to model and analyse complex systems that may have unreliable, ambiguous, or insufficient information [80]. The G GERT network incorporates grey information to account for the uncertain nature of activity parameters in stochastic networks. The simulation algorithm is evaluated utilising the principle of signal flow graph analysis. Furthermore, an analysis is conducted on developing the moment generating function within a GERT network featuring grey variables, accompanied by a comprehensive study of its primary characteristics [81].

Vague System Theory Based GERT (V GERT)

The mathematical theory of Vague Set Theory is an extension of FST that integrates the assumption of vagueness. Gau and Buehrer[82] developed the concept of vague sets as a generalisation of a fuzzy set. The vague sets are characterised by an indeterminate or uncertain element membership, represented by a certain degree of vagueness or imprecision. The membership function in vague set theory is a bivariate function that considers the level of membership of an element in a set and the degree of vagueness associated with the set within the universe of discourse [83]. The grade of membership of an element 'm' in a vague set is represented by a vague value $[\alpha_m, 1 - \beta_m]$ in [0,1]. $\alpha_m$denotes the degree of truth, β_m denotes the degree of false, $1 - \alpha_m - \beta_m$ denotes the unknown values, where $0 \leq \alpha_m \leq 1 - \beta_m \leq 1$, and $\alpha_m + \beta_m \leq 1$(Shyi-Ming Chen, 1995). Wang et al. (Wang et al., 2011) introduced Vague set theory based GERT (V GERT) to address the ambiguity involved in the re entry challenges in wafer manufacturing using GERT. This approach employs vague set theory to address the ambiguity problem. Umasankar and Thiagarasu[84] comprehensively review the literature on decision making using vague sets across various domains.

3. Methodology

An investigation into the use of GERT is carried out by a thorough assessment of the literature. The review includes a structured approach that encompasses the following steps. Initially, a comprehensive exploration of research publications is conducted on the Web of Science platform, encompassing journal articles and conference proceedings. The search is conducted by combining keywords derived from the practical implementations of GERT and its related concepts. Subsequently, the redundant entries are removed. Following that, a thorough analysis of the abstract and the complete text of the article is conducted to obtain a comprehensive understanding of its main points. Subsequently, articles that do not specifically relate to the research topic are eliminated from the study. The literature is classified according to the different areas of application. Subsequently, informetric and critical analyses of the literature are performed based on predetermined subcategories.

The authors extracted data from the acclaimed bibliographic database Web of Science Core Collection, which also has several sub databases, in August 2023. The search combines the terms 'GERT' or 'Graphical Evaluation and Review Technique' with the eight essential key elements or concepts identified in prior research listed in Table~\ref{pub}.

One of the inherent limitations associated with utilising these terminologies is the incorporation of studies that are not specifically focused on GERT but include the broader field of graphical modelling. The WoS database search for 'TS (Topic Search) = 'GERT' OR TS = 'Graphical Evaluation and review technique' yielded 579 items in total. The results were subjected to filtration using a more specific set of search terms, specifically AK (Author Keywords), AB (Abstract), and KP (Keyword Plus) for the keywords listed in Table 2 and the application of Boolean operators, resulting in a cumulative count of 351 appropriate outcomes.

To obtain a comprehensive comprehension of the research's scope, the authors conducted a meticulous examination of the complete manuscript. Following the exclusion of published research that did not align with the specified objectives and redundant entries, 96 journal articles, 10 book chapters, and 39 conference papers were identified. The 145 articles are collected for 25 years, from 1997 to 2023. The researchers also used VOSviewer software, often used in bibliometric, scientometric, and informetric studies, to conduct an informetric analysis of 145 scholarly articles to examine patterns in the literature, find prominent journals and researchers, measure the frequency of words, and look at the distribution of publications from previous years.

Table 2: List of Web of Science (WoS) publication keyword searches along with GERT

Keyword	No. of Publication in WoS
Stochastic	102
Project scheduling	88
Simulation	75
Optimisation	41
Uncertainty & Risk Analysis	74
Project control	35
Decision making	35
Complex System	47

Informetric Perspective of GERT

The fundamental goal of informetric analysis is to acquire a deeper understanding of the structure, growth, and influence of scientific research and the process of scholarly communication. To analyse the bibliographic data, researchers employ a diverse variety of metrics and statistical methods. Some of these methodologies include publication counts, citation analysis, cocitation analysis, and the dispersion of literature [85].

Published Scientific Literature in WoS

The authors present the results of a study into the number of scientific articles published on GERT during the span of investigation from 1997 to 2023 to shed light on the research productivity and impact as well as detect patterns. Figure 4 demonstrates the number of scientific articles published on GERT from 1997 to 2023, with the polynomial trend line of publications. The graph illustrates the fluctuations in publication volume over a period extending from 1997 to 2023. However, the polynomial curve demonstrates a consistent upward trend in publications over time, suggesting increased interest and research activity. A minimal convex curve suggests the field of study continues to develop and attract the interest of researchers without experiencing abrupt or significant changes in the rate of publication.

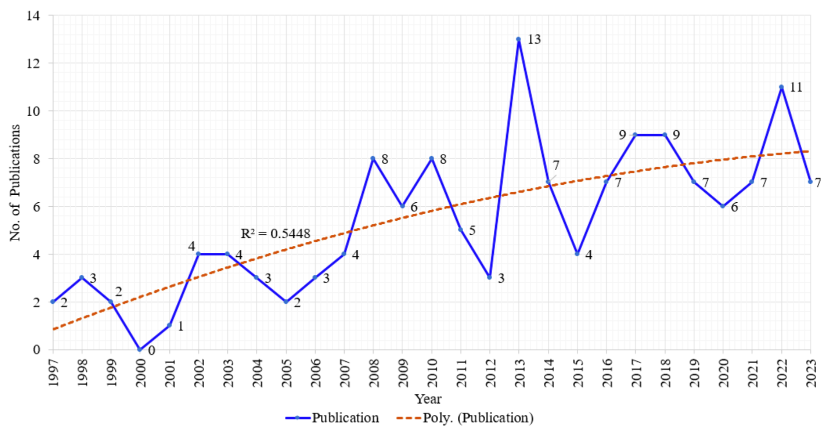


Fig 4: Number of Published articles in WoS

It is essential to ascertain the nations that exhibit the highest levels of productivity. Table~\ref{countries} demonstrates the publication statistics from 1997 to 2023, indicating that institutions in the People's Republic of China contributed 71 articles, institutions in India contributed 13 articles, and institutions in Russia contributed 9 articles. The bibliographic coupling analysis was conducted for countries to elucidate the robustness of the connections between nations, as determined by the availability of shared references in their respective articles. The total link strength denotes the combined strength of bibliographic coupling between a cluster of documents about a specific country and all other documents within the dataset. The data presented in Table 3 indicates that the People's Republic of China, the United States of America, and Belgium engage in academic relationships with various countries, regardless of their number of publications or citations.

Table 3: Distribution of countries

Country	No. of Publications	Total Citations	Norm. citations	Total Link Strength
People's Republic of China	71	427	66.35	1150
USA	8	178	16.62	692
Belgium	3	18	4.11	342
India	13	112	16.04	326
Poland	7	51	5.62	270
Taiwan	5	45	7.24	242
Canada	3	112	10.49	242
Turkey	3	44	9.60	207
England	3	33	4.94	164
Japan	8	77	7.89	152
Russia	9	8	1.67	109
Germany	3	11	3.36	83
Iran	3	18	1.86	73

Although the quantity of publications serves as a crucial starting point, it is imperative to supplement this metric with other metrics, such as citation analysis, to thoroughly assess the research's effectiveness and influence.

Citation Analysis

The authors employed the Vosviewer software to perform a citation analysis to investigate the citation patterns observed in academic publications. The Web of Science (WoS) dataset, including details on publications, authors, affiliations, abstracts, keywords, and citation references, served to construct a new map. After the data was imported, the analysis settings were adjusted to incorporate the citation analysis and LinLog/Modularity normalisation method. Normalisation is used in citation analysis and bibliometrics to account for variances in citation practices between study domains and time frames. The ‘Norm. Citations’ value of an article is its citations divided by the average of the citations of the dataset. This normalisation makes comparing publications' citation counts easier regardless of their total citations. Higher normalisation values imply that a publication's citation count is higher than typical or expected in the analysis context.

The network visualisation of the citation relationships obtained from Vosviewer is depicted in Figure 5. The network comprises nodes that symbolise the publication, with links connecting nodes to indicate citation connections. The quantification of a scholarly article's citation count serves as a fundamental metric for assessing its importance and the extent to which fellow researchers have cited it. The degree of citation a publication receives is directly proportional to its perceived influence and value within the respective academic discipline. Table 4 presents the top fifteen cited articles along with the normalised citation counts.

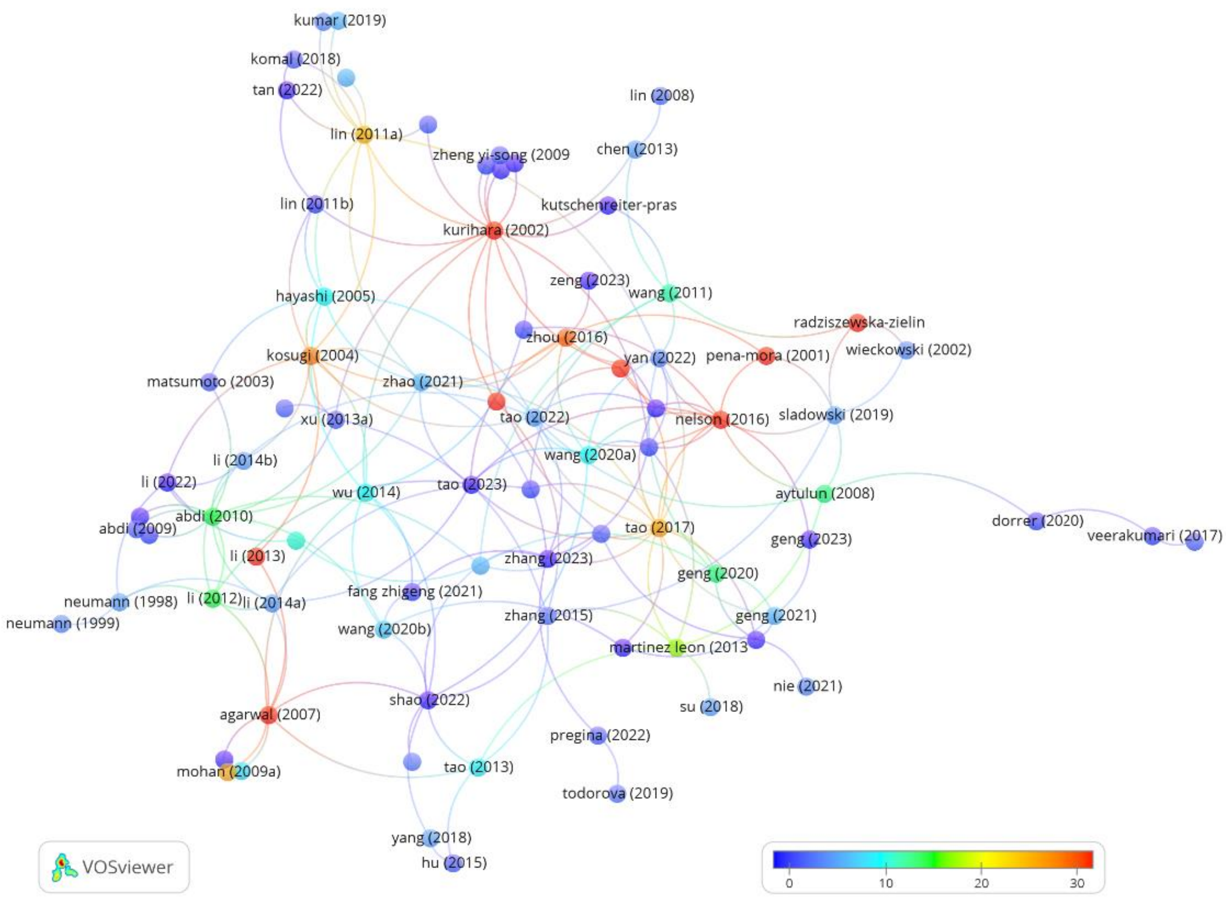


Fig 5: Citation Analysis

Table 4: Citation Analysis Top 15 citations

S.No.	Article	Pub. year	No. of Citations	Norm. Citations
1	Pena Mora and Li [86]	2001	94	1.96
2	Wu et al [87]	2010	75	6.45
3	Xu et al [88]	2014	41	3.04
4	Agarwal et al [89]	2007	35	3.41
5	Kurihara and Nishiuchi[90]	2002	35	2.69
6	RadziszewskaZielina et al [73]	2017	33	1.90
7	Li et al [91]	2013	32	5.62
8	Nelson et al. [92]	2016	31	3.10
9	Zhou et al. [13]	2016	28	2.80
10	Kosugi et al [93]	2004	27	2.53
11	Tao et al [94]	2017	25	1.44
12	Mohan et al [95]	2009	25	4.05
13	Lin et al. [96]	2011	24	3.16
14	Martínez León et al [97]	2013	17	2.99
15	Abdi et al [98]	2010	14	1.20

The normalisation process prioritises the recognition of publications or authors who have demonstrated significant impact within their respective disciplines, irrespective of their initial citation counts, which may have been relatively low. This feature emphasises noteworthy articles that may be excluded from a traditional citation ranking. Table 5 showcases the top fifteen articles that have a significant impact on the progress of the GERT application, as determined by their normalised citation counts

Table 5: Citation Analysis Top 15 Normalised Citation Counts

S.No.	Article	Pub. year	No. of Citations	Norm. Citations
1	Aytulun and Guneri [39]	2008	13	6.50
2	Wu et al. [87]	2010	75	6.45
3	Li et al. [91]	2013	32	5.62
4	Mohan et al. [95]	2009	25	4.05
5	Agarwal et al. [89]	2007	35	3.41
6	Tao et al.[99]	2022	5	3.24
7	Lin et al. (Li et al., 2013)	2011	24	3.16
8	Xu et al. [88]	2014	41	3.04
9	Nelson et al. [92]	2016	31	3.10
10	Li and Liu [100]	2012	14	3.00
11	Martínez León et al. [97]	2013	17	2.99
12	Zhou et al. [13]	2016	28	2.80
13	Kurihara and Nishiuchi[90]	2002	35	2.69
14	Yan et al. [101]	2022	4	2.59
15	Kosugi et al. [93]	2004	27	2.53

Moreover, the authors employ cocitation analysis as an empirical approach to examine the interconnections among research papers cited collectively by other research publications. The analysis of citation patterns enables the identification of clusters of interconnected or frequently referenced scholarly works, thereby illustrating the conceptual framework of GERT. The minimum number of citations for a cited reference was fixed as 10, and 12 articles met the threshold among 2751 cited references with LinLog/Modularity normalisation. The twelve articles were organised into three distinct clusters. Cluster 1 consists of three fundamental articles that served as the foundation for the concept, providing a detailed explanation of its basic principles, including to develop novel advancements. Cluster 3 consists of six articles that have combined various other applications, such as incorporating the Monte Carlo simulation method modelling of complex projectsand fuzzy logic [102] as depicted in the Figure 6.

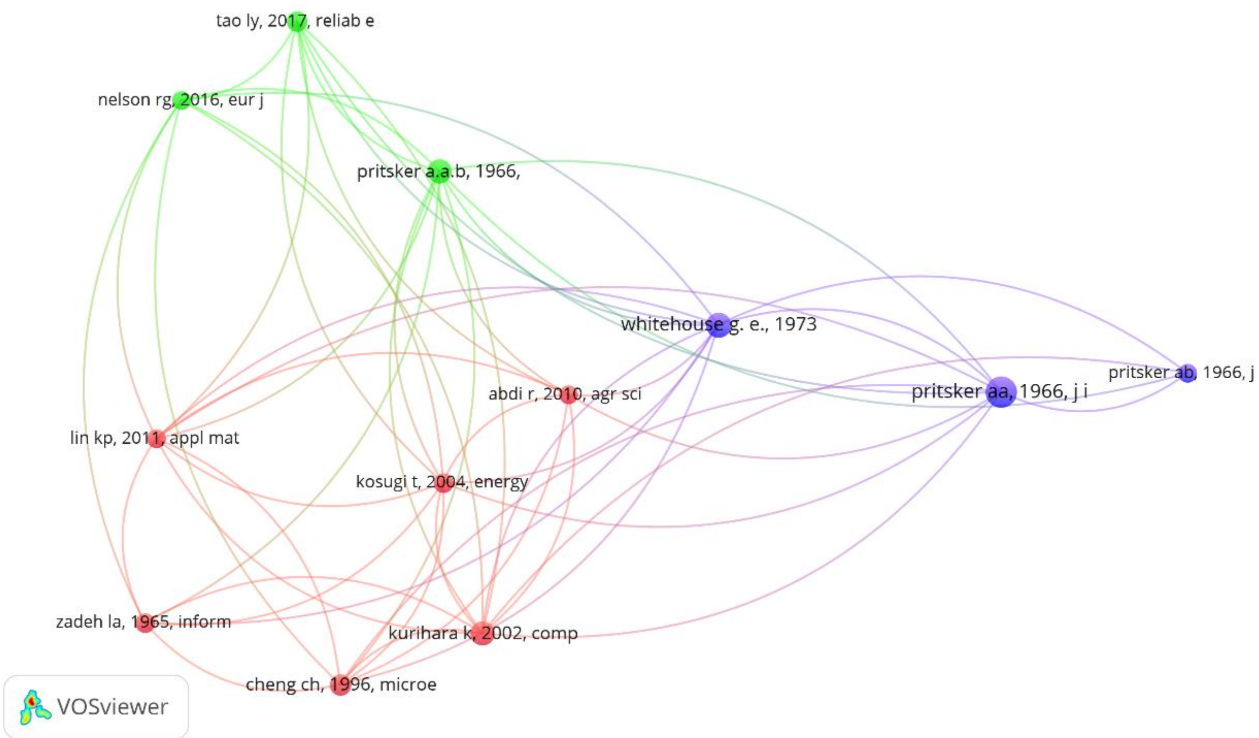


Fig 6: Cocitation Analysis

The most active authors who worked on GERT between 1997 and 2023 are listed in Table 6. Zhigeng Fang, Sifeng Liu, and Liangyan Tao contributed to most publications, while the research articles by Sifeng Liu, ManjuAgarwal, and Pooja Mohan gained more citations than other investigations.

Table 6: Top 10 researchers working on GERT

Author	No. of Articles	Total No. of Citation	Norm. Citations	Avg. Citations
Liu, Sifeng	12	80	13.76	6.67
Fang, Zhigeng	16	59	13.23	3.69
Tao, Liangyan	7	47	10.57	6.71
Agarwal, Manju	4	68	8.77	17.00
Mohan, Pooja	4	68	8.77	17.00
Gao, Su	4	23	5.55	5.75
Kosugi, Takanobu	4	40	4.86	10.00
Kosugi, Takanobu	4	40	4.86	10.00
Zhang, Na	4	12	4.63	3.00
Li, Chong	4	24	3.76	6.00

Dispersion of Literature

Another essential component of informetric analysis is the assessment of literature dispersion, which can offer valuable insights into the diversity of research and improvements in scholarly publishing. The authors intend to use Bradford's Law of Scatter to examine the distribution of publications among various academic journals. Bradford's Law of Scattering is an empirical observation for bibliometric analysis that describes the pattern of distribution of scientific literature across various journals within a specific research domain [19].

Initially, academic papers on GERT are compiled into a dataset. The journals are arranged according to their publication frequency. The journals are put into three groups with an equivalent number of publications in each group. Typically, the division is based on the idea that a small number of core journals (a_1) will account for a substantial amount of the publications (zone 1: Core Journal), followed by a larger number of journals with fewer publications (a_2) (zone 2: Relevant Journals), and a list of journals with minimal publications (a_3) (zone 3: Peripheral Journals). The relationship between the number of journals in the above zones is defined in Equation 2.

$$a_1 : a_2 : a_3 = 1 : n : n^2 \quad (2)$$

Finally, the Bradford Constant (n), the ratio of the number of journals in the second zone to the number of journals in the core zone, is computed. A greater value of the Bradford constant signifies an increased concentration of core journals (Zone 1) responsible for publishing a substantial proportion of the overall publications within the field. It implies that the distribution of research effort is dominated by a relatively limited number of core journals, whereas many journals (Zone 2) publish fewer articles overall.

According to Bradford's Law of Scattering, the 68 journals were divided into three zones to assess the algebraic interpretation, and Bradford’s multiplier factor is computed. In the present study, 11: 26 : 31 = 1 : 2.36 ; 1.19 does not adhere to Bradford's distribution. Table 7 summarises the computational results for journal dispersion in Bradford's zones.

Table 7: Journal Dispersion in Bradford's Zones

Bradford’s Zones	No. of Journals	% of Journals	No. of articles published	% of articles published	Bradford’s Multiplier
1 (Core)	11	16.18	33	34.38	
2 (Relevant)	26	38.24	32	33.33	2.36
3 (Peripheral)	31	45.59	31	32.29	1.19
Total	68	100.00	96	100.00	1.78*

* Mean value of the Bradford multiplier

Subsequently, the formulation is adjusted by applying Bradford'sMultiplier, $11: 11 \times 1.78: 11 \times 1.78^2 \approx 1: n: n^2$ leading to a ratio of $11: 19.58: 34.85$. Nonetheless, it is important to note that a 4% margin of error is identified in the computation. The Leimkuhler model is applied to achieve a more precise distribution of citations across the three zones while minimising the percentage error [103-104].The Bradford Multiplier can be determined by applying the formula shown in Equation 3. Table 8 summaries the Journal Dispersion in Bradford's Zones applying the Leimkuhler model.

$$k = (e^{y} y_m)^{1/p} \quad (3)$$

Where, e^{y} is Euler's number ($e^{y} = 1.781$), y_m is the number of items in the most productivity sources ($y_m = 5$), p is the number of zones ($p = 3$)

Table 8: Journal Dispersion in Bradford's Zones applying Leimkuhler model

Bradford's Zones	No. of Journals	No. of articles published	% of articles published	Bradford's Multiplier
1 (Core)	9.23	29	30.21	
2 (Relevant)	19.14	27	28.13	2.07
3 (Peripheral)	39.66	40	41.66	2.07
Total	68.03	96	100.00	2.07*

* Mean value of the Bradford multiplier

Table 8 reveals that the algebraic interpretation of Bradford's Law ($a_1: a_2: a_3 = 1 : n : n^2$), is applied with negligible error of 0.05%. However, in our analysis, we have observed that the number of publications within each zone does not adhere to the expected one third distribution of the total publications. The dispersion of journals in the study on GERT in Bradford's zones applying the Leimkuhler model is depicted in Figure 7.

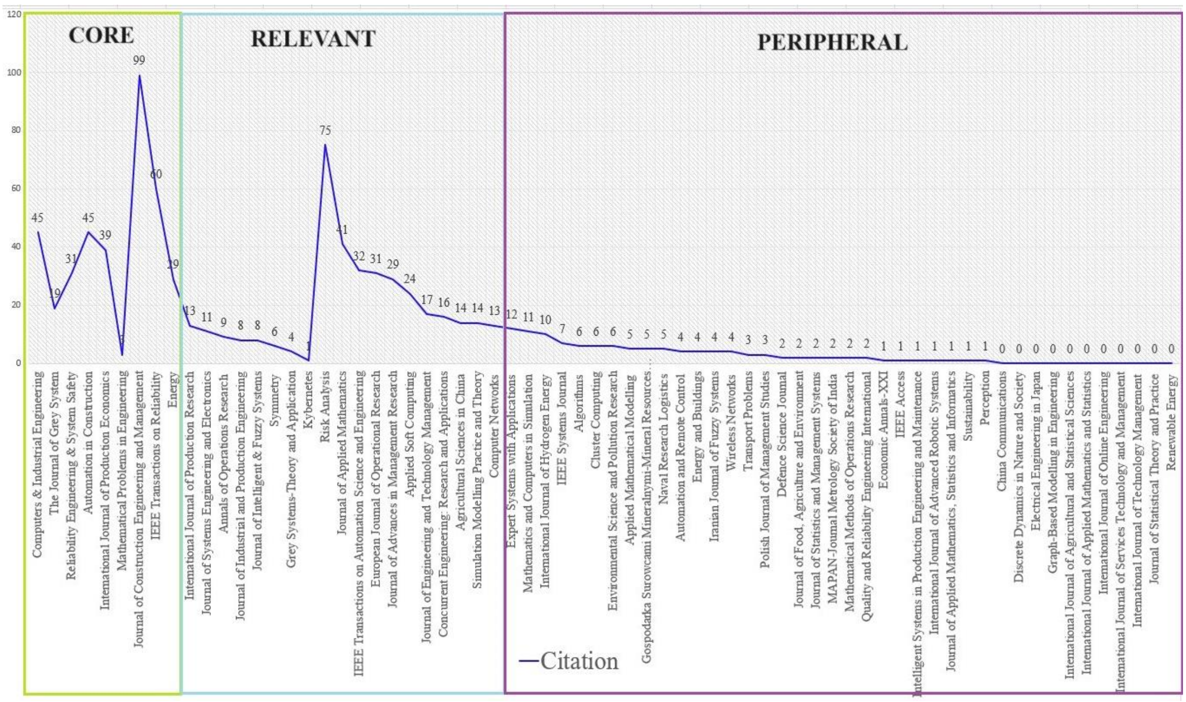


Fig 7: Journal Dispersion in Bradford's Zones applying Leimkuhler model

Keyword Analysis

Analysis of the cooccurrence of keywords is an additional valuable element within the field of informetrics, which serves as a complementary quantitative approach in the examination of scientific publications. The authors adopt Vosviewer to analyse the cooccurrence of keywords provided by the authors (author keywords). The 531 keywords provided by the authors were grouped into 35 clusters as shown in Figure 8. In addition, certain terms, such as 'GERT', 'Graphical Evaluation and Review Technique', and 'GERT network', were intentionally excluded from the list of keywords to avoid any potential bias in the results. Simulation, uncertainty, reliability, optimisation, risk, management, information, schedule risk, cost, and stochastic networks are among the frequently appearing keywords provided by the author.

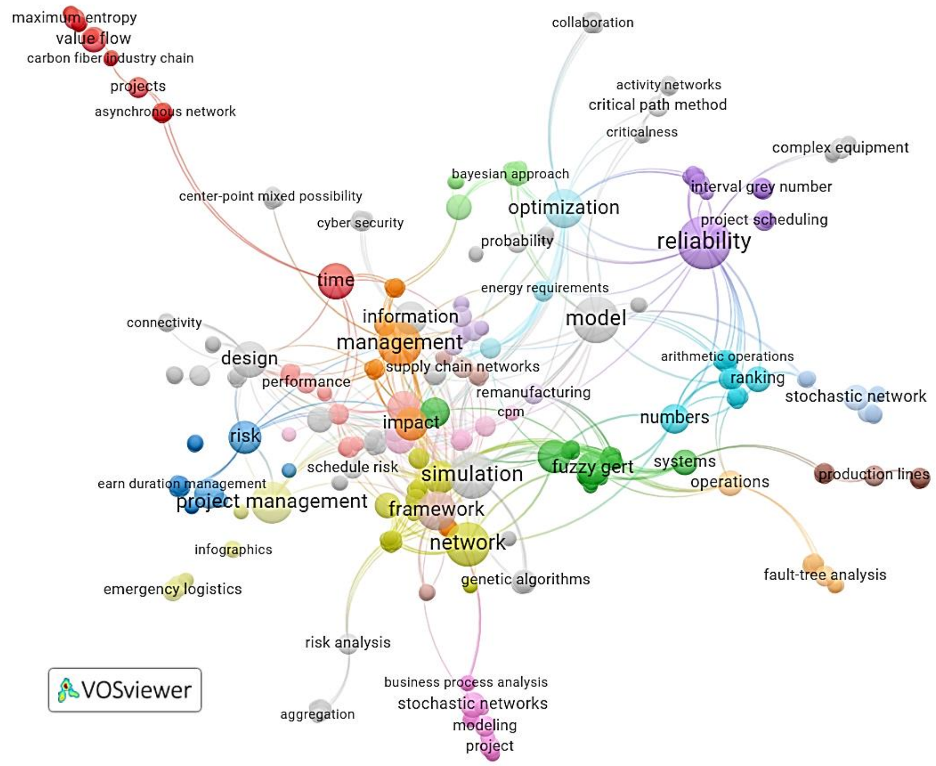


Fig 8: Keywords provided by the author

4. Discussion

The researchers conducted an extensive analysis of 149 scholarly articles on GERT as a tool for project management published between 1997 and 2023. Consequently, the 149 journal articles were classified into distinct categories that corresponded to the various dimensions within the field of project management, including project scheduling& forecasting, risk analysis, resource allocation, cost estimation & budgeting, performance evaluation, decision making, optimisation, sensitivity analysis, and reliability analysis.

The GERT plays a multifaceted role in the realms of project scheduling and forecasting, offering a powerful and flexible tool that caters to the complex nature of modern projects. In scheduling, GERT stands out by adeptly managing complex projects characterised by interdependencies, uncertainties, conditional branches, and multiple possible outcomes [105]. Unlike traditional scheduling methods like the Critical Path Method (CPM), GERT allows for conditional branching, where task sequencing can be influenced by specific conditions or events [106-107], a critical feature for projects with complex dependencies, as it mirrors real world scenarios more accurately [108-109]. Moreover, GERT introduces a vital dimension of uncertainty management [110] enabling the incorporation of probability distributions for task durations. GERT is especially beneficial when dealing with projects subject to variable conditions, estimating their completion time and costs [111].

In the context of forecasting, GERT extends its utility by facilitating scenario analysis. It empowers organisations to explore multiple "what if" scenarios, assess potential outcomes, and make data driven decisions [112-113]. This capability is indispensable for business forecasting, allowing companies to navigate uncertainties and develop contingency plans [8] effectively. GERT's risk analysis feature is equally relevant in forecasting, as it helps identify and mitigate risks and uncertainties that can impact future performance. It is an invaluable tool for depicting complex network structures and is utilised in the simulation, modelling, and analysis of mechanized agricultural production systems.

GERT's role in scheduling and forecasting is further enhanced by its visual representation of project schedules and potential scenarios, making it easier for project teams and organisations to communicate and collaborate. The tool excels in managing projects with varying complexities, and its ability to identify multiple critical paths ensures that project managers and forecasters have a comprehensive view of project dynamics [114]. This versatility positions GERT as an asset for organisations seeking to effectively manage the intricacies of modern projects and make informed forecasts in an environment marked by uncertainty and complexity [115].

Several research studies have been conducted on scheduling complex systems using GERT, providing a rigorous and systematic framework for project planning such as Fuzzy GERT [116] and Grey GERT .The enhanced planning process can lead to a notable improvement in productivity and efficiency, thereby fostering competitiveness [117]. Integrating Q GERT into the transmission process is a robust solution for satellite networks to manage their energy needs, especially in uncertain scenarios [118]. The Q GERT framework surpasses existing algorithms, attaining higher reliability and energy efficacy in satellite networks and providing promising solutions to facilitate the implementation of real time services.

Risk analysis has also been a major focus where GERT has been utilised to assess schedule risks and evaluate uncertainties in research and development, concurrent engineering environments, and new product development processes [28]. A scientific model using GERT, Monte Carlo simulation, and probability distribution theory evaluates cost and schedule risks in complex product system research and development projects. Furthermore, analytical and regression methods are used to examine simulation outcomes. Modified GERT approaches and simulation based models have been proposed to address the challenges associated with risk analysis in scheduling by incorporating Bayesian network techniques to adapt the parameters of the SIGN GERT model, such as probability and time. From the concurrent engineering environment perspective, the GERT method analyses the numerous risks and challenges associated with product development.

The approach considers various operational factors, including reliability and combat capability [119]. It precisely analyses optimal resource allocation by employing the moment generating function's exceptional analytical attributes. Developing a logistics support process model with GERT is an effective approach, especially when dealing with the complex and unpredictable nature of aviation logistics for aircraft carriers [120].

GERT offers an analytical perspective, demonstrating potential solutions to problems that may arise during the emergency transportation of products and supplies to increase the effectiveness and the rate of emergency rescue efforts [121]. The GERT model's computability presents numerous opportunities for applying this model in warning systems for emergencies and critical decision making [122]. GERT is used for modelling and solving complex system problems, including agricultural mechanisation projects with resource allocation and simulation [123].

Strategic Integration of GERT in Construction Scheduling

GERT is extensively studied and utilised as a methodological approach for scheduling complex systems. Research studies have demonstrated its effectiveness in addressing potential issues during project planning, improving productivity and efficiency, and enhancing competitiveness. In the context of agricultural production systems, GERT has been employed to depict complex network structures and has proven valuable in the simulation, modelling, and analysis of mechanised agricultural projects. In the reengineering field, GERT has been used to precisely determine probabilities and durations of specific processes within remanufacturing systems. It has also been combined with other techniques, such as the Analog to Digital Converter model and Bayesian theorem, to improve joint operation system effectiveness evaluation. GERT has been proposed as a potential solution for scheduling difficulties encountered in critical chain projects. By integrating critical chain and multilevel GERT, challenges associated with optimisation at each level can be addressed effectively. In construction projects, GERT has been recognised as a suitable solution for managing uncertain incidents, repetitive activities, and multiple outcomes. Stochastic networks and fuzzy logic, in the form of interval sets, have been suggested to estimate reconstruction parameters like necessity, duration, and cost. The Grey GERT framework has also been introduced to estimate coupled probabilities, timing, and costs in various applications. It is also evident that researchers commonly prioritise a select number of influential academic journals as the primary outlets for disseminating their research, resulting in a more concentrated distribution pattern. In terms of optimisation, the strategy considers several operational criteria, including dependability and combat capability. A precise evaluation of the operational efficacy is provided by this method, which makes use of the powerful analytical capabilities possessed by the moment generating function. GERT has various applications in diverse fields, including project management, aerospace and defense, manufacturing, supply chain management, risk analysis, nuclear and chemical engineering, healthcare, emergency management, environmental engineering, financial risk management, and transportation logistics. GERT's unique ability to model and analyse complex systems under conditions of uncertainty, incorporating probabilistic estimates and decision points, makes it a valuable tool for enhancing decision making, optimising resource allocation, and managing risks in scenarios where traditional deterministic approaches are inadequate. The strategic integration of GERT in construction scheduling serves as a potent solution to the industry's complex challenges. Its ability to model dependencies, manage uncertainties, adapt to dynamic environments, analyse, and mitigate risks, and optimize resource coordination makes it an asset for project managers seeking precision and efficiency in their scheduling endeavours. GERT's impact extends beyond mere methodology; it becomes a strategic enabler for successful project completion in the intricate landscape of construction.

5. Limitations

The GERT methodology presents distinctive attributes requiring specialised training for project managers and their teams. Comprehending GERT's conditional branches and probabilistic modelling often represents a formidable learning curve. In academic contexts and professional training programs, this underscores the necessity for comprehensive educational modules that delve into the intricacies of GERT. Aspiring project managers must have a deep understanding of effectively harnessing GERT. The distinctive features of this technique, while powerful, can be unwieldy in simpler projects, adding extra complexity. GERT is most effective in projects characterised by significant intricacies, conditional interdependencies, and inherent unpredictability. Here, academic institutions and project management educators are crucial in imparting knowledge regarding project complexity assessment. GERT is an appropriate tool for project managers, aligning its application with the intricacies of the project at hand.

Moreover, GERT's reliance on historical data to establish probabilities and conditional relationships highlights the importance of data driven decision making in project management. When historical data is unavailable, individuals must seek alternative methods or adjustments to obtain the necessary data. This underscores the importance of robust data collection techniques and the need for adaptability in project management when using GERT.

Recommendations

The appropriateness of GERT, Fuzzy GERT, Grey GERT, and Vague GERT is contingent upon the distinct characteristics of the project and the nature of uncertainty or imprecision inherent in the data. Each model possesses unique strengths and is well suited for various scenarios. The selection of the suitable model (GERT, Fuzzy GERT, Grey GERT, or Vague GERT) depends on the features of uncertainty or imprecision within the project data. GERT could be sufficient for project analysis and management if the data associated with the project are well defined and adhere to predictable criteria. The Fuzzy GERT is an approach that is more suitable when uncertainties indicate uncertainty or imprecision and can be effectively expressed using combinations of ambiguous numbers. Grey GERT has proven to be a useful method for controlling uncertainty in projects that are limited by inadequate or just partially available data. If the project data is characterised by a lack of definition or clarity, the Vague GERT model can be considered appropriate.

6. Conclusion

Graphical Evaluation and Review Technique (GERT) has proven to be a valuable and effective methodological approach for project planning, scheduling, and management in various domains. The numerous research studies conducted on GERT have demonstrated its versatility and applicability in complex systems, including agricultural production, reengineering, construction, and joint operation systems. GERT provides a systematic and rigorous framework for depicting complex network structures, allowing for precise analysis and optimisation of project schedules. By forming a network of activities and events, GERT helps identify critical paths, potential issues, and dependencies, improving productivity and efficiency. In agricultural production systems, GERT has been successfully employed to model and analyse mechanised projects, aiding in the timely execution of operations and enhancing the system's overall productivity. In reengineering projects, GERT has facilitated the precise determination of probabilities and durations of specific processes, contributing to the effective evaluation and control of complex systems.

The uncertainty or imprecision in the project data determines the model (GERT, Fuzzy GERT, Grey GERT, or Vague GERT). GERT can analyse and manage project data if it is established. Fuzzy GERT is better at representing uncertainties with unclear numbers. Grey GERT successfully manages uncertainty in projects with limited data. The Vague GERT model may be appropriate if project data is vague. When selecting an appropriate model, project managers can manage uncertainty and make informed decisions by considering project data attributes.

Moreover, GERT has proven useful in construction projects, particularly in dealing with uncertain incidents and multiple outcomes, providing reliable estimates for reconstruction parameters. Overall, GERT's extensive research and applications underscore its significance as a powerful tool for modelling, scheduling, planning, controlling, and analysing various projects. Its ability to handle uncertainties and complexities makes it an asset for decision makers and project managers across different industries. Implementing the GERT method can improve project outcomes, better resource management, and increase competitiveness in today's dynamic and challenging environments.

Future Scope

Although the GERT has demonstrated its efficacy across multiple industries, its implementation in construction scheduling remains restricted. Construction projects rely more on traditional project management methods like the Critical Path Method (CPM) or the Program Evaluation and Review Technique (PERT), which provide simpler, deterministic scheduling and resource allocation models. However, in specific cases of large, complex construction projects with a high degree of uncertainty and complex interactions between activities, GERT may be considered for a more accurate representation of the project's dynamics and potential risks.

Additionally, there is a lack of comprehensive research exploring the benefits and limitations of GERT in the context of construction scheduling [124]. The shortage of scholarly investigation regarding the utilisation of GERT in the scheduling of construction projects presents a valuable opportunity to enhance our understanding of its implementation and make meaningful contributions to the field of construction project management.

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