The Justification of Complex Systems Analysis in Better Informing Project Decisions: A Study of the us Surface Transportation Board

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ABSTRACT

The complexity inherent in large-scale projects often challenges traditional project management approaches, particularly within the dynamic landscape of the United States Surface Transportation Board (STB). This study explores the application of Complex Systems Analysis (CSA) as a tool to better inform project decisions within this context. By examining the STB's handling of recent rail transportation decisions and operational metrics within the Chicago Railroad Region, this research highlights the significant interdependencies and emergent behaviors that characterize the system. Utilizing Ontonix software for complexity analysis, the study identifies key leverage points that contribute disproportionately to the overall system complexity. The findings reveal that the current complexity level is perilously close to the critical threshold, indicating a high risk of instability. This underscores the need for adopting more sophisticated project management approaches, such as CSA, to enhance system resilience and optimize decision-making processes. The study concludes with recommendations for integrating CSA into traditional management frameworks to mitigate risks and improve project outcomes in highly complex environments.

There are no relevant financial or non-financial competing interests to report.

INTRODUCTION

The landscape of project management has evolved significantly, with an increasing recognition of the complexity inherent in large-scale projects. Traditional project management methods used for effective straightforward and well-defined projects, often fall short in addressing the multifaceted and dynamic nature of modern projects. This shortfall is particularly pronounced in developing countries like United States of America (USA), where projects are influenced by a myriad of socio-economic, political, and environmental factors (Zodrow et al., 2017). Complex Systems Analysis (CSA) offers a promising solution. Rooted in systems theory, CSA provides a holistic framework for understanding and managing the interactions and interdependencies among various components of a project (Boers et al., 2021).

Unlike traditional approaches that often focus on linear cause-and-effect relationships, CSA considers the nonlinear and emergent behaviors that characterize complex systems. This perspective is crucial for anticipating potential challenges, optimizing resource allocation, and enhancing overall project resilience (Sbardella et al., 2017). In recent years, there has been a growing body of research and practical applications demonstrating the efficacy of CSA in various fields, including infrastructure development, healthcare, and environmental management (Napolitano et al., 2022). For instance, CSA has been used to model the spread of infectious diseases, manage natural resource conflicts, and optimize supply chains in volatile markets. These examples highlight the versatility and utility of CSA in addressing complex, real-world problems. Despite its potential, the adoption of CSA has been limited. This can be attributed to several factors, including a lack of awareness and understanding of CSA methodologies, inadequate data and analytical tools, and resistance to change from established project management practices. However, as US continues to pursue ambitious development goals, the need for more sophisticated and adaptive project management approaches becomes increasingly apparent.

The Surface Transportation Board (STB) still greatly shapes the goods transportation landscape of the United States. Acting as an independent federal organisation, the STB controls various aspects of surface transport with an eye towards the goods train industry (Roni et al., 2014). Recently the Board has experienced some significant challenges and made decisions impacting the sector (Surface, 2024). Among the most interesting recent incidents was the way the STB managed the proposed merger between Kansas City Southern and Canadian Pacific Railway (CPKC, 2024). The Board approved this merger in 2023, therefore creating the first single-line rail route linking Canada, the United States, and Mexico. Considered as a historic choice, this one may radically alter North American commodities transportation (United States Government Publishing Office, 2023).

Furthermore under close focus by the STB are issues with rail service reliability and quality. Aiming to increase transparency and accountability in the industry, the Board passed new rules in 2022 demanding Class I railroads to publish more complete performance statistics (Surface Transportation Board, 2022). This action responded to general worries about service interruptions and how they affected the supply chain. The STB's decision-making process now gives environmental concerns even more weight. Examining the possibility for modal changes from truck to rail transportation, a 2021 research commissioned by the Board underlined the environmental advantages of more rail use (Surface Transportation Board, 2021). This shows the increasing focus the transport industry is putting on sustainability.

The Board has also been debating problems of rail sector market competitiveness. The STB suggested new regulations in 2020 to boost rail industry competitiveness, including modifications to the rate review procedure and management of demurrage costs (Railway Age, 2020). These ideas generated a lot of discussion among shippers as well as within the sector. The STB struggles constantly to balance the interests of railroads, shippers, and the public as the scene of transportation changes. Policy projects and recent decisions show the Board's attempts to fit evolving industry dynamics and accomplish its responsibility to guarantee a fair, efficient, and competitive transportation system (Railway Age, 2020).

Although this paper mostly relies on current sources, the regulatory environment is dynamic and additional events might have happened since previous articles. Latest legal and business publications can be gotten on the official page for the most current information on STB operations and rulings. This action responded to general worries about service interruptions and how they affected the supply chain.The STB's decision-making process now gives environmental concerns even more weight. Examining the possibility for modal changes from truck to rail transportation, a 2021 research commissioned by the Board underlined the environmental advantages of more rail use (Surface Transportation Board, 2021). This shows the increasing focus the transport industry is putting on sustainability. The Board has also been debating problems of rail sector market competitiveness. The STB suggested new regulations in 2020 to boost rail industry competitiveness, including modifications to the rate review procedure and management of demurrage costs (Railway Age, 2020). These ideas generated a lot of discussion among shippers as well as within the sector. The STB struggles constantly to balance the interests of railroads, shippers, and the public as the scene of transportation changes. Policy projects and recent decisions show the Board's attempts to fit evolving industry dynamics and accomplish its responsibility to guarantee a fair, efficient, and competitive transportation system.

Effective project management is critical to the successful completion of large-scale projects, especially in US, where infrastructure, socio-economic conditions, and governance structures are highly complex and interconnected. However, traditional project management methodologies often fall short in addressing the multifaceted challenges and dynamic nature of such projects. As a result, decision-making processes can become fragmented, leading to project delays, cost overruns, and suboptimal outcomes. However, CSA is a relatively new and sophisticated approach that requires a deep understanding of systems theory, modelling techniques, and data analysis. Many project managers and stakeholders in US may not be familiar with these concepts, leading to resistance or reluctance to adopt CSA methodologies (Esomonu & Eleje, 2020). Successful application of CSA relies heavily on the availability of accurate and comprehensive data. In US, data collection and management practices are often inadequate, with issues such as incomplete data, lack of real-time information, and poor data quality. Additionally, the analytical tools and software required for CSA may not be readily accessible or affordable (Esomonu et al., 2020).

CSA needs to be integrated with traditional project management practices to be effective. However, this integration can be challenging due to differences in methodologies, terminologies, and frameworks. Project teams may find it difficult to reconcile CSA with established practices, leading to confusion and implementation difficulties. Implementing CSA requires significant resources, including skilled personnel, training, and technology infrastructure. In resource-constrained environments like US, securing the necessary funding and expertise can be a major hurdle (Campbell & Levin, 2008). Complex projects involve multiple stakeholders with diverse interests and objectives. Ensuring effective communication and collaboration among these stakeholders is crucial for the success of CSA. However, coordinating and aligning the efforts of various parties can be challenging, particularly in the context of political and organizational complexities. Adopting a new approach like CSA often encounters resistance from stakeholders who are accustomed to traditional methods. This resistance can stem from a lack of trust in new methodologies, fear of the unknown, or perceived threats to established power structures and practices.

These problems underscore the need for targeted efforts to raise awareness, build capacity, and develop infrastructure to support the adoption of CSA in project management. Addressing these challenges is essential to leveraging the full potential of CSA in enhancing decision-making processes and improving project outcomes in US.

LITERATURE REVIEW

The Essence of Complex Systems Analysis

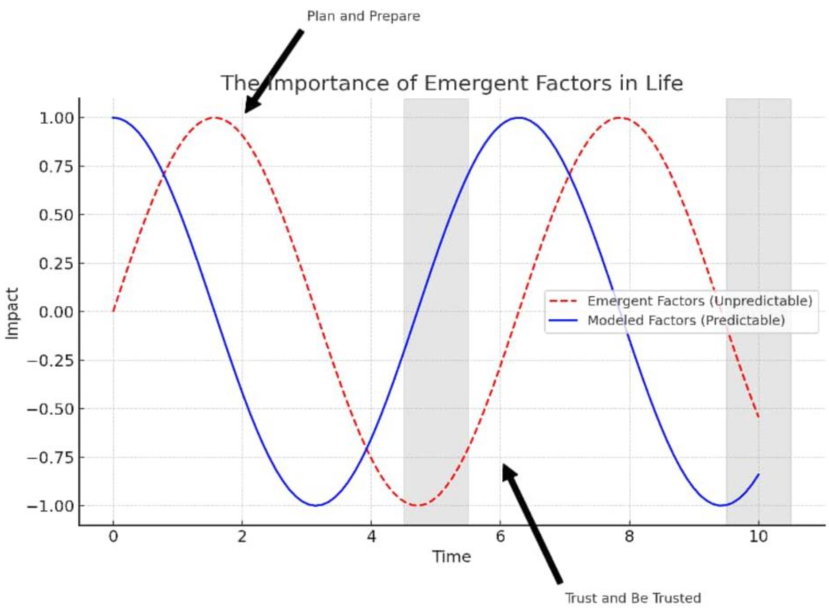

Figure 1:Complex system emergence (Author)

Life is full of complex dynamic systems and the most important things in life are often emergent. Complex systems are characterized by numerous interconnected components whose interactions produce emergent behaviors that are not easily predictable from the behavior of individual parts (Boers et al., 2021). Applied in strategic management and organisational studies, complexity theory and organizations also referred to as complexity strategy or complex adaptive organizations involve using the study of complex systems (Grobman, 2016). It is based on studies of uncertainty and non-linearity in the natural sciences Complexity theory stresses the interconnections and attendant feedback loops driving ongoing system change. It implies that systems are limited by order-generating laws even as they seem to be erratic.This translates to the interplay of various factors such as resources, stakeholders, timelines, and environmental conditions. CSA provides a framework for understanding these interactions, identifying potential points of failure, and developing strategies to enhance system resilience.

Requisite complexity as termed by Apanisile Samuel (2024) is the required level of complexity that a system can accommodate. This means that there is a highest point of complexity tolerance by every system for good functionality. Such that any further increase in complexity will only result to diminishing performance of such system.

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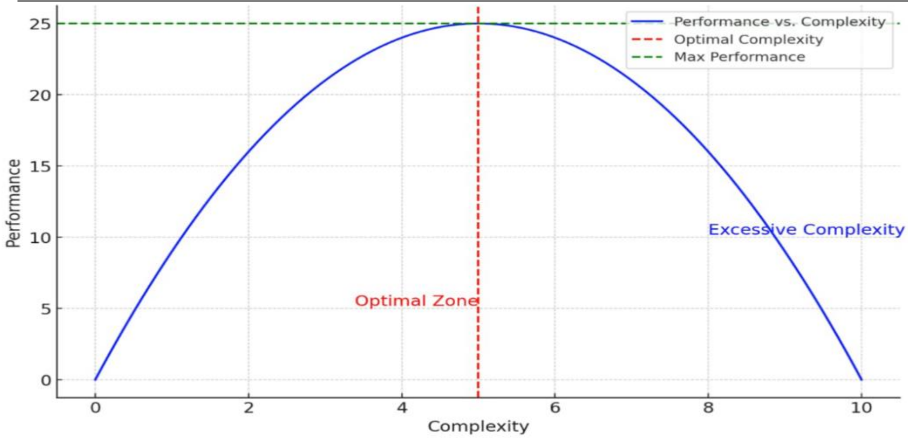

Figure 2: Relationship between system complexity and performance(Author)

Fig. 2 illustrates that complexity, which can be likened to energy, is needed for functionality and performance of a dynamic system. However, when complexity becomes excessive, by getting near to the critical threshold or surpassing it, system performance continue to reduce and can exhibit surprising fatal behavior as argued by (Marczyk & Deshpande, 2010).

Empirical Studies

Apanisile Samuel (2024) examines the impact of quantitative complexity analysis on the resilience of Nigerian banks. The descriptive research technique was chosen for the study due to its inherent ability to accurately observe and portray the researched events in their natural environment. The population of the research consists of all the Nigerian banks that were listed on the premium board of the Nigerian Exchange Group (NGX) between 2019 and 2022. At that time, there were four banks that were included on the list. Zenith Bank, First Bank of Nigeria, Access Bank, and United Bank for Africa are included in the list of banks. The investigation's sample size was determined using a purposive sampling approach. The four banks listed on the premium board of the NGX were selected based on their high capitalisation and adherence to global trading standards and strict corporate governance requirements set by the Nigerian Exchange. Therefore, the purposive sampling technique was employed. This research used the annual reports and financial statements of the selected banks from 2019 to 2022 as its data source. The gathered data was analysed using both descriptive statistics and inferential statistics. The selected banks' characteristics are examined using descriptive statistics, while inferential statistics are employed to analyse the quantitative intricacy and resilience of the chosen banks for various analyses, including Network analysis, Principal component analysis, Hierarchical clustering analysis, Capital adequacy ratio (CAR), Non-performing loans (NPL) ratio, Liquidity ratio, and Efficiency ratio. The financial data of all the banks was analysed using IBM SPSS to get insights on PCA (Principal Component Analysis) and HCA (Hierarchical Cluster Analysis). Subsequently, Ontonix QCM Software was used to investigate and analyse the financial data of all the banks, specifically focussing on Network Analysis. An Excel spreadsheet was used to analyse the financial data of the four banks in order to get insights into their Capital Adequacy Ratio (CAR), Non-Performing Loans (NPL), Liquidity Ratio, and Efficiency Ratio. The research found a significant correlation between increased resilience and greater degrees of quantitative complexity analysis in the financial structure and operations of the bank. This demonstrates that banks that frequently engage in quantitative complexity analysis of their financial structure and operations are more capable of withstanding adverse events or disruptions compared to those that do not. In the current business climate, characterised by brittleness, ambiguity, nonlinearity, and incomprehensibility (BANI), banks must strive to maintain the necessary level of complexity. The research suggests that enterprises and banks have challenges in developing effective future strategies due to BANI situations. Companies and banks need to be agile and successful in order to be competitive in a rapidly changing and unpredictable environment. For companies and banks to cultivate resilience, they must grasp the concept of necessary complexity, which refers to the optimal degree of complexity required to effectively handle and manage any problem or circumstance.

The concept of resilience as it relates to the building system of high-speed railway foundations on goaf sites is discussed in (Wang et al., 2022), and an assessment index system with 25 indicators is built. After that, the fuzzy comprehensive evaluation technique, entropy weight method, and ANP are used to build the resilience assessment model. This model is validated using the construction system of the Taijiao high-speed railway subgrade in the underlying goaf as an example. Based on the verification findings, the construction system has a rating of II (high resilience). The assessment outcome aligns with the real-world engineering scenario, and the assessment framework functions efficiently. A comprehensive process analysis approach founded on resilience theory is constructed, and it may serve as a theoretical foundation for safety management of high-speed railway construction projects.

Aiming to further the use of complexity theory and organizational-level studies in the psychology of sport literature, Niv Nachlieli & Natan Uriely (2023) offers a case-study using complexity theory's logic and vocabulary to justify a chronology of bad decision making at Hapoel Tel Aviv, a well-known football team in the Israeli Super League. The study links the financial crisis and the professional failure of the club between 2015 and 2017 to the inadequacy of owners, management, and active supporters in managing with complexity using a qualitative research approach. Particularly, the results draw attention to three poorly handled organizational contradictions known as the "order-disorder," the "love-hate," and the "strong-weak" paradoxes. The study shows how intricacy affects the psychological dynamics of decision-making in athletic teams.

Minami & Madnick (2007) conducted research spanning the occurrences and symptoms of accidents usually connected with human mistake. Rather, they concentrated on looking at the complex and little known organizational procedures and problems at higher levels that could be the root causes of mishaps. It was challenging as these causes typically include nonlinear dynamic events and show actions contradicting accepted human wisdom. Many times, such difficult issues are referred to be wicked difficulties. After careful review, a System Dynamics model was built to provide an analytical depiction of the intricate system, therefore facilitating extensive simulation and complexity analysis. These simulations show that strategic decisions considering the frequency of missions and the availability of troops will effectively control the work-rest cycle for deployed troops, so improving the evaluation of lessons learned from accidents and reducing Army combat and motor vehicle accidents.

Theoretical Framework

Model-Free Quantitative Complexity Theory

The emergence of Model-free Quantitative Complexity Theory (QCT) took place between the years 2000 and 2005, when it established the field of Quantitative Complexity Management (Marczyk, J. 2013). Jacek Marczyk created the first all-inclusive metric of complexity that integrates both structure and entropy, so establishing a connection between physics and information theory (Marczyk, J. 2010). Within this theoretical framework, the understanding of complexity has experienced a significant change in perspective. Complexity, like energy, is an intrinsic attribute of every system and may be determined by assessing the observable inputs and/or outputs of that system. It offers a methodical structure for examining the profound connections and dynamics inside these systems, providing valuable insights for scholars and decision-makers grappling with the challenges of complexity. The QCT differs from conventional approaches that link complexity to either entropy or structure. Instead, it combines both entropy and structure by examining the information flow topology among agents in a given system. The complexity function in the model-free QCT is constrained. When the system dynamics are close to the lowest threshold, their behaviour is mostly determined by their organisation, such as the movement of a watch, and tends to show predictability. At the critical complexity, which is the greatest limit, the driving force behind dynamics is entropy, which is a measure of disorder. As a result, the system's behaviour becomes random and unpredictable, as seen in phenomena such as turbulent flow. During the processing of real-time data streaming, the values experience constant variations. The QCT has been used in the banking sector for about a decade to assess possible hazards that banks and financial systems may encounter (Marczyk, J. 2013).

Complexity Theory

Theory of complexity has significant implications for the way companies are run and comprehended. Conventional management theories often depend on predictability and control as they assume that thorough planning and execution would help companies to be directed towards certain results. On the other hand, complexity theory contends that companies are more like living systems with erratic behaviour and continual change (Levy, 2020). Complexity theory studies dynamic, nonlinear, complex systems including feedback loops. Clearly, chaos theory is distinct from network theory; "complexity" is the general idea that spans both chaos and networks. Chaos theory is concerned with situations wherein the repetitive application of nonlinear deterministic functions may produce apparently random behaviour and complex patterns. Conversely, since the 1990s, network analysis which has become more entwined with complexity theory examines the properties of networks made of nodes, where the state of each node relies on its connections to other nodes (Levy, 2020).

METHOD

Research Design

The study uses a quantitative research methodology that specifically focusses on the investigation of complexity. The analysis of the Chicago Railroad Region's transport system involves the use of time series data and computer techniques to examine the interdependencies and interactions within the system. The main objective is to evaluate the intricacy of the system, pinpoint the major factors that contribute to it, and ascertain the system's stability and resilience. The Ontonix program (Marczyk & Deshpande, 2010) is used for doing complexity analysis, offering a methodical and data-centric approach to comprehending and controlling the complexity of a system.

Area of Study

The field of research pertains to the Railroad Region, with a special emphasis on the activities and statistics associated with the US Surface Transportation Board. The Chicago Railroad Region is a pivotal nexus in the transportation network of the United States, including many railroads and intermodal facilities. This location was selected based on its intricate nature and importance in the overall transportation system of the country, making it a perfect option for conducting a study of complexity.

Sample Size

The sample size for this study consists of the time series data collected for the Chicago Railroad Region over a period of four years, from 2021 to 2024. The dataset includes various operational metrics and variables related to railroad transportation. While the exact number of data points or variables is not specified, the study mentions the inclusion of 49 nodes (variables) and their respective contributions to the system's complexity. The sample is comprehensive enough to provide a detailed analysis of the system's complexity and stability.

Data Collection

The study begins with gathering time series data for the Chicago Railroad Region (EP724 data) from 2021 to 2024. This dataset includes a range of operational metrics and characteristics that are pertinent to the railway transportation system in the area.

Method of Data Analysis

The gathered data is analysed using Ontonix software (Marczyk & Deshpande, 2010), a specialised tool specifically developed for the purpose of complexity analysis. The program produces a System Complexity Map, which graphically illustrates the interrelationships and interactions among the many variables inside the system.

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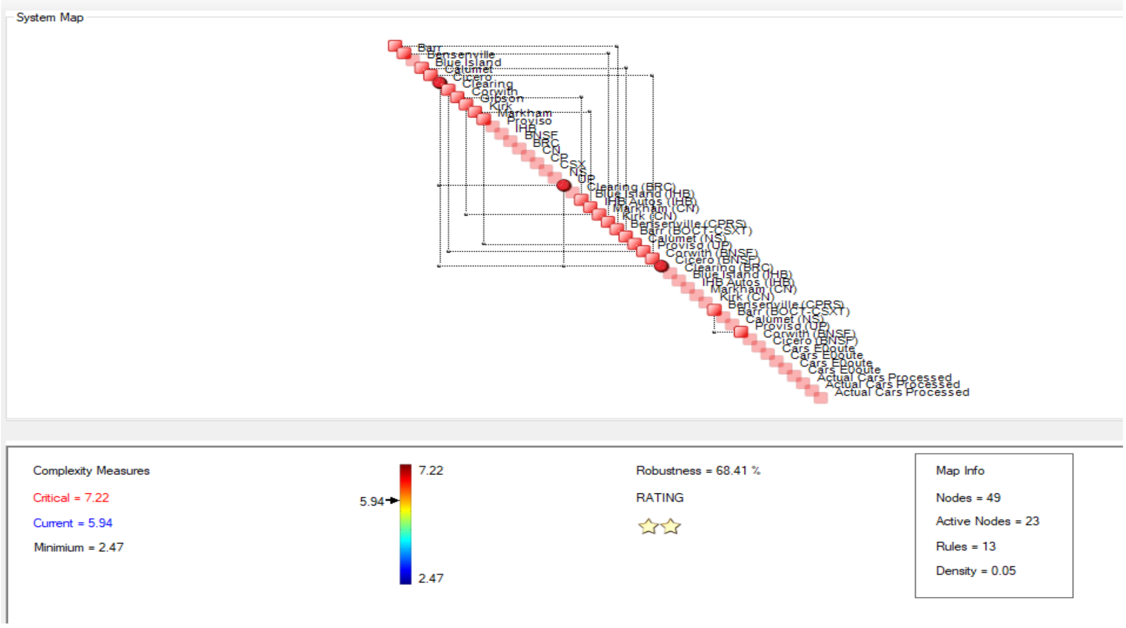
System Complexity Map of Chicago Railroad Region (EP724 Data) for the period of 2021 – 2024 (Via Ontonix Software):



From the above System Complexity Map

The complexity of the system: This is the Current Complexity Level of the System from the System Complexity Map and stands at: 5.94

Critical complexity of the system: When the Current System Complexity is closer to the Critical Complexity the system becomes unstable. The metric stands at **7.22**

Low requisite complexity: The Requisite complexity level stands at 68.41% because the system under study is too close to the Critical Complexity which signifies low capability to absorb shocks and thrive through it (Apanisile Temitope Samuel (2024). Hence the system is unstable and fragile.

As seen in the Complexity Profile below:

- **The dominant variables** which impact the most the system's behavior are Cicero (BNSF) with 53.52% contribution to the total complexity of the system. Followed by Cicero and UP which contributed 45.60% and 45.50% respectively to the total complexity of the business.

- **The leverage point** can be seen as the best "locations" in the system where management can start fixing problems by initiating projects that have the highest impact on the system behavior as a whole. The leverage point in this study based on the complexity profile is Cicero (BNSF)

- The remaining variables have little impact on the system's behavior hence decision or problem solving time should not be wasted on them.

Table 1: The system complexity profile for the Chicago Railroad Region in the transportation network of the United States. Chicago Railroad Region (EP724 Data) for the period of 2021 – 2024 (Via Ontonix Software)

No.	Variable Name	% Contribution to Total Complexity
31	Cicero (BNSF)	53.52
6	Cicero	45.60
20	UP	45.50

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1		0.00
2	Barr	0.00
3	Bensenville	0.00
4	Blue Island	0.00
5	Calumet	0.00
7	Clearing	0.00
8	Corwith	0.00
9	Gibson	0.00
10	Kirk	0.00
11	Markham	0.00
12	Proviso	0.00
13	IHB	0.00
14	BNSF	0.00
15	BRC	0.00
16	CN	0.00
17	CP	0.00
18	CSX	0.00
19	NS	0.00
21	Clearing (BRC)	0.00
22	Blue Island (IHB)	0.00
23	IHB Autos (IHB)	0.00
24	Markham (CN)	0.00
25	Kirk (CN)	0.00
26	Bensenville (CPRS)	0.00
27	Barr (BOCT-CSXT)	0.00
28	Calumet (NS)	0.00
29	Proviso (UP)	0.00
30	Corwith (BNSF)	0.00
32	Clearing (BRC)	0.00
33	Blue Island (IHB)	0.00
34	IHB Autos (IHB)	0.00

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35	Markham (CN)	0.00
36	Kirk (CN)	0.00
37	Bensenville (CPRS)	0.00
38	Barr (BOCT-CSXT)	0.00
39	Calumet (NS)	0.00
40	Proviso (UP)	0.00
41	Corwith (BNSF)	0.00
42	Cicero (BNSF)	0.00
43	Cars E0oute	0.00
44	Cars E0oute	0.00
45	Cars E0oute	0.00
46	Cars E0oute	0.00
47	Actual Cars Processed	0.00
48	Actual Cars Processed	0.00
49	Actual Cars Processed	0.00

The data that support the findings of this study are openly available in: https://www.stb.gov/reports-data/rail-service-data/#railroads-tab-content-1-

FINDINGS

The activities of the US Surface Transportation Board in the Chicago Railroad Region are characterised by a significant level of complexity. The present complexity level, quantified as 5.94, signifies that the system exhibits a high degree of interconnectivity with a multitude of interacting factors. The complexity of this system makes it challenging to manage and anticipate, which presents substantial obstacles for making good decisions and maintaining operational stability.

The system's close closeness to its critical complexity level of 7.22 is a significant cause for worry. When the organisation is operating at 68.41% of the critical threshold, it indicates that it is in a precarious position. Under these circumstances, even little disturbances have the potential to cause substantial disruptions or failures. The presence of fragility emphasises the immediate need for methods that might decrease complexity and improve the resilience of the system.

The study emphasises that the complexity is mostly influenced by a small number of crucial areas, including Cicero (BNSF), Cicero, and UP. The aforementioned knods are the primary contributors to the total complexity of the system, rendering them crucial areas of concentration for enhancing stability. Informing project decisions to tackling problems in these domains may greatly diminish the total intricacy and enhance the dependability of the system.

CONCLUSION

An examination of the activities of the US Surface Transportation Board (STB) in the Chicago Railroad Region demonstrates a significant level of interconnection and dependency within the transportation system. The current complexity level, quantified at 5.94, signifies a notable degree of intricacy, posing difficulties for efficient administration and decision-making. The system is now operating at 68.41% of its critical complexity level of 7.22, which is below the resilience threshold of 70% (Marczyk, J. 2013). The low level of required complexity indicates a fragility that indicates a greater probability of instability and operational disruptions. In order to mitigate this vulnerability, it is essential for the railroad administration to strategically prioritize the management of the three major factors outlined in the System Complexity Profile. By using this approach, the railroad system may bolster its resilience, so enhancing its capacity to withstand and prosper in the face of unforeseen problems, without the need for excessive deployment of resources.

RECOMMENDATION

In order to properly handle the complexities revealed in this research, it is advisable for the organization to use continuous monitoring systems that actively assess the levels of complexity in real-time. Anticipating possible problems before they worsen is of utmost importance for senior executives, board members, and those in positions such as managers or executives. By giving priority to the early identification of warning indicators, one may significantly impact the outcome, since it is frequently the decisive factor between success and failure. Utilizing complex systems analysis facilitates the swift detection of potential issues, enabling early and planned actions. To tackle the complexity, it is important to concentrate on the core underlying aspects, especially the most significant parts inside the system. By adopting this proactive strategy, the system's risks will be minimized, stability will be improved, and resilience will be strengthened. This will ultimately optimize the system's overall performance and ensure its capacity to adapt and succeed in the face of unexpected obstacles.

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