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REVIEW ARTICLE

TOP–THEORY–BUILDING THROUGH COMPUTATIONAL SIMULATION

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ABSTRACT

Lavelot presents a comprehensive and structured roadmap for the development of the Theory of Optimization for Projects (TOP) through the use of computational simulation models. This framework systematically guides the theory-building process by positioning simulation as a central methodology, complementing traditional approaches such as multiple case inductive studies. The study highlights the distinctive value of computational simulation in enabling creative experimentation, which is instrumental in generating innovative theoretical insights. Emphasising the pivotal role of simulation in advancing project management theory, the research advocates for the continued development of adaptable simulation models, the inclusion of a broader range of empirical case studies, and the promotion of interdisciplinary collaboration. These strategies aim to enhance the predictive accuracy and generalisability of project management theories across diverse industry contexts. Ultimately, this work establishes a strong foundation for the ongoing evolution of the TOP framework and makes a significant contribution to contemporary project management scholarship.

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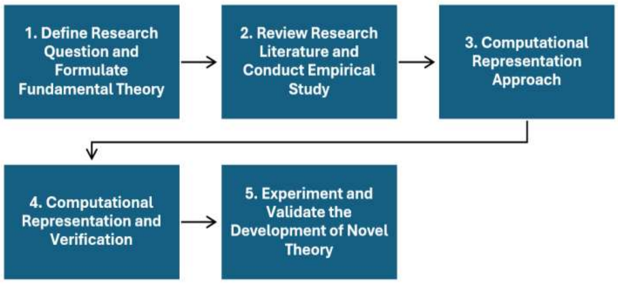
INTRODUCTION

Project management (PM) methods have evolved over time to address the increasingly complex and dynamic nature of project execution. However, the traditional project scheduling techniques, such as the Critical Path (CP) method and Program Evaluation and Review Technique (PERT), have remained relatively unchanged despite their widespread use. These conventional methods focus on determining the shortest path to complete a project within a specified timeline but fail to adequately address resource constraints and uncertainty. In contrast, the introduction of Critical Chain Project Management (CCPM) by Eliyahu M. Goldratt in 1990 presented a significant departure from these traditional approaches, offering an innovative methodology that emphasizes resource availability and task dependencies (Goldratt, 1997). The introduction of the Theory of Optimization for Projects (TOP) based on Theory Building and the CCRCS (Critical Chain Resource Scheduling) framework marks a significant advancement in project scheduling techniques. By addressing resource constraints, uncertainties, and optimization strategies, TOP offers a fresh approach to reducing project risks and improving scheduling efficiency (Tukel, 2006)(Lavelot, 2023a). This study aims to further explore the contributions of TOP as an optimization method and provide a comprehensive framework for its application in computational simulations, offering valuable insights for the field of project management (Figure 1). The use of computational simulation on TOP theory building is accompanied by evaluation guidelines to assess the effectiveness of simulation in the theory development process along the following lines.

1. Define Research Question and Formulate Fundamental Theory: Both quantitative and qualitative methods, including case studies have been extensively applied to address critical research questions and contribute to the advancement of theory and knowledge across a wide range of disciplines. These approaches begin with the identification of research questions that are informed by existing knowledge and literature (Hancock, 2017). The research process then progresses through the systematic collection and analysis of data, employing appropriate methods for each approach. Ultimately, the process concludes with the documentation of findings, offering answers that are grounded in thorough and methodologically sound analysis of the information gathered. Lavelot (2023a) identified questions centered around project scheduling and resource allocation from case study projects as inspiration for his research question(s). This step ensured the study addresses a meaningful issue. By focusing on the impact of resource limitations on project timelines, the research remains aligned with the overarching goal of theory development through computational simulation. Understanding the balancing act between resource constraints and project deadlines serves as the foundation for developing a computational simulation model.



TOP-Theory-Building Process by Lavelot

Figure 1. TOP Theory BuildingThrough Computational Simulation

Creswell discusses how researchers often begin with fundamental theoretical models to test relationships between variables, which are foundational for the development of more complex theories later on (Creswell, 2014). In the early stages of research, it is essential to select a basic theory that can effectively explain the impacts of resource allocation on project scheduling. This theory serves as the foundation for understanding how various factors influence project timelines and resource utilization. Theories such as Critical Path Analysis (CPA), resource bottleneck identification, and scheduling efficiency are valuable in this context. CPA helps identify the longest sequence of dependent tasks, determining the minimum project duration. Resource bottleneck identification focuses on highlighting constraints where resource limitations may cause delays, while scheduling efficiency examines how best to utilize available resources to meet project deadlines (Lavelot, 2023b). A fundamental, foundational theory with minimal constructs serves as the basis for computational representation. This step allows for easier operationalization and hypothesis testing through computational models. By simplifying the theory, the research can effectively test and refine the concepts.

2. Review Research Literature and Conduct Empirical Study: Hart (2018) discusses the importance of focusing on literature as a foundational step in the research process, highlighting how it helps shape the research question, provides context, and guides methodological decisions. Conduct a broad overview of existing research literature in project management, particularly focusing on theories such as PERT, CP, CCPM, and the CCRCS. Explore relevant case studies and project management (PM) theory underlying the aforementioned models. Summarize PM SRA (Scheduling Risk Analysis) to establish the theoretical and practical objectives of the research (Lavelot, 2023a). The literature review offers a comprehensive understanding of existing knowledge in PM theory and scheduling methodologies. By considering foundational theories like PERT, CPM, and CCPM, the research ensures its approach is rooted in established frameworks. The literature review also provides context for developing the research objectives and formulating relevant hypotheses. Yin's work provides comprehensive guidance on conducting case study research, an empirical approach offering step-by-step processes to collect, analyze, and report data for case studies. He states that *"[e]mpirical research advances only when accompanied by theory and logical inquiry"* (Yin, 2018). The experimental design employed, provides a systematic approach to addressing the research objectives. First, the design includes a careful examination of gaps identified in the literature, particularly those areas where existing knowledge is limited or ambiguous. These gaps will be addressed empirically through a tailored methodology that ensures the study's findings contribute new insights to the field. Additionally, a scoping review may be conducted to assess the feasibility and viability of the proposed research, providing an initial understanding of the scope of the project and helping to refine the study's parameters. In line with the research objectives, the process of theory development will be detailed, outlining how the research contributes to expanding or refining theoretical frameworks, particularly in relation to the TOP (Lavelot, 2023a). Finally, the study will include a validation phase, which will assess the results of applying TOP through the use of case studies. This validation study will offer a critical evaluation of the applicability and robustness of the theory when tested in real-world project management contexts. Empirical studies provide the necessary foundation for testing the theoretical concepts introduced in earlier steps. Identifying and addressing gaps in the literature ensures that the research contributes new insights. The validation process is crucial for determining the effectiveness of the proposed theory when applied to real-world case studies.

3. Computational Representation Approach: Once research literature and empirical study are formulated, and computation approach is determined to be the most suitable method for the research (e.g., define research question and formulate fundamental theory), the next critical step is to choose the appropriate simulation approach. This decision should be guided by the alignment between the research question, the assumptions, fundamental theory, with those inherent to the selected simulation method. The choice of computational simulation approach is pivotal, as it can influence the theoretical logic, type of research question, and underlying assumptions. Much like selecting a statistical technique (e.g., Ordinary least squares (OLS) regression versus event history analysis), which shapes theory-testing in empirical research, the choice of simulation method significantly impacts the outcomes of the study (Davis. & KM. Eisenhardt KM & Bingham, 2007). For formulating the TOP Theory building computational simulation, ProTrack V3 software was utilized to generate project simulations, with nine heterogeneous simulations being conducted, each containing 425 activities and incorporating three resource types to explore different project scenarios. This scheduling software provided a robust framework for modeling complex project schedules, which is crucial for capturing real-world variability. The heterogeneous simulations allow the analysis of a variety of project conditions, leading to diverse project outcomes and better insights into the impact of resource allocation on project scheduling (Lavelot, 2023b). By inputting realistic project parameters, the research enables detailed comparisons across different computational simulation scenarios. Recording the completion dates of simulations is critical for analyzing the effectiveness of resource allocation strategies.

4. Computational Representation and Verification: Vanhoucke, M. (2013), states that computational representation and verification refers to the process of ensuring that the computational models or simulations used in dynamic project scheduling accurately represent the real-world project processes and behaviors. This involves confirming that the

TOP-Theory-Building Process

Step	Activity
1.Define Research Question and Formulate Fundamental Theory	(1.1) Identify research questions based on existing literature (Hancock, 2017).
	(1.2) Focus on a meaningful issue (e.g., project scheduling and resource allocation) (Lavelot, A Methodology for the Present Acumen of Knowledge on TOP, 2023b).
	(1.3) Develop a fundamental theoretical framework (e.g., Critical Path Analysis, resource bottleneck identification) (Creswell, 2014).
	(1.4) Establish foundational constructs to guide computational modeling (Lavelot, A Methodology for the Present Acumen of Knowledge on TOP, 2023b).
2. Review Research Literature and Conduct Empirical Study	(2.1) Conduct a comprehensive literature review on project management theories (e.g., PERT, CPM, CCPM) (Hart, 2018).
	(2.2) Identify gaps in the literature and address them through empirical study (Yin, 2018).
	(2.3) Use case study methodology to contextualize and validate research (Yin, 2018).
	(2.4) Perform a scoping review to refine research scope and feasibility (Lavelot, Theory of optimisation for projects, 2023a).
3. Computational Representation Approach	(3.1) Select an appropriate computational simulation approach aligned with the research question (Davis. & KM. Eisenhardt KM & Bingham, 2007).
	(3.2) Utilize ProTrack V3 software to conduct project (Lavelot, Theory of optimisation for projects, 2023a).
	(3.3) Model heterogeneous project scenarios with realistic parameters.
	(3.4) Record computational simulation outcomes to analyze resource allocation impacts.
4. Computational Representation and Verification	(4.1) Ensure simulation models accurately represent real-world processes (Vanhoucke, 2013).
	(4.2) Conduct robustness checks and sensitivity analysis (50% critical index threshold) (Lavelot, A Methodology for the Present Acumen of Knowledge on TOP, 2023b).
	(4.3) Revise models or input parameters if discrepancies arise.
5. Experiment and Validate the development of Novel Theory	(5.1) Vary experimental conditions to observe impacts on project completion times.
	(5.2) Compare simulated outcomes with actual case study results.
	(5.3) Use correlation coefficients (Pearson, Spearman, Kendall) to validate accuracy (Lavelot, Theory of optimisation for projects, 2023a).
	(5.4) Present and discuss visual representations of correlation results.
	(5.5) Ensure empirical validation enhances the theory's applicability in project management contexts.

models reflect the correct relationships between tasks, resources, and timelines, and that the results generated by these models align with expected outcomes under varying conditions. Lavelot (2023a) embodied the theory of a real-world project into the software to test the theoretical construct of hypothesis for the research study. ProTrack V3 aided with the formulation of the computer algorithm. Verify that the computational simulation outcomes align with the expected project completion dates by conducting robustness checks, including sensitivity analysis with a 50% threshold for the critical index, and revise the model or input parameters if any discrepancies are observed played an important role in verification process. Verification of the computational simulation model was essential to ensure that the results are accurate and meaningful. Sensitivity analysis helps identify the key factors that influence project outcomes, ensuring that the model is robust and can handle a range of scenarios. Any discrepancies identified during verification was addressed through refinement of the model by Lavelot (2023a).

5. Experiment and Validate the Development of Novel Theory

A final step in TOP-theory-building using computational simulationthrough experimentation and validation. During the experiment phase, sensitivity thresholds and probabilities are varied to observe their impact on project completion times, and completion dates are recorded under different experimental conditions. These results are then compared with expected project deadlines to identify new patterns and relationships.

Experimentation is a critical step in theory development, as altering computational simulation parameters facilitates the discovery of new insights and relationships. By understanding how changes in resource allocation influence project outcomes, this empirical experimentation supports the refinement of the theory and contribute to the development of novel theoretical insights.

For validate computational simulation results using correlation coefficients to assess the accuracy of the model. The activities involve validating computational simulation results using correlation coefficients to assess the model's accuracy and comparing the simulated completion dates with actual case study outcomes. Three measurements validated the time sensitivity of tasks on the expected project time by correlation. These measurements were calculated by using Pearson's Product-Moment, Spearman's Rank and Kendall's Tau Rank Correlation. These correlations were used in the research study to display the degree of linear relationship between the task time and expected project time. A visual representation of the correlation results were presented and discussed (Lavelot, 2023b). This empirical validation ensures that the computational simulation accurately reflects real-world project behaviour, and by comparing simulated outcomes with actual data, the alignment between theoretical models and real project outcomes can be quantified. Such validation enhances confidence in the theory's applicability and its relevance in practical project management contexts.

CONCLUSION AND RECOMMENDATIONS

The development of the TOP through computational simulation offers a valuable framework for enhancing project scheduling and resource allocation practices. Lavelot's roadmap for TOP-theory-building using computational simulation successfully integrates various project management theories, including PERT, CPM, and CCPM, and applies them to real-world scenarios through empirical and computational validation. The ability of computational simulation to foster creative experimentation has proven essential in generating novel insights and refining project management theories, specifically in understanding the impact of resource constraints on project outcomes. The rigorous validation process, including sensitivity analysis and correlation testing, ensures the reliability and applicability of the TOP model in real-world project settings. The integration of empirical data, computational methods, and theoretical frameworks underscores the significance of computational simulation as a dynamic tool for theory development in project management. The research also demonstrates the importance of systematic verification, including the alignment of computational simulation results with expected outcomes, to ensure the accuracy and relevance of the theory. This work contributes to the growing body of knowledge in project management and lays a strong foundation for future research in this area. Based on the findings and methodology outlined in this study, the following recommendations are proposed for advancing the theory of project optimization and resource allocation:

Further Exploration of Simulation Models: Future research should continue to explore the potential of simulation methods in TOP-theory-building, particularly in the context of complex, dynamic project environments. Enhancing the simulation's adaptability to various project types can provide deeper insights into the impact of resource constraints across different industries.

Incorporation of Diverse Case Studies: Expanding the empirical foundation by including more diverse case studies across various sectors will help validate the TOP theory in broader contexts. This will enable the development of more generalized guidelines for project scheduling and resource optimization.

Ongoing Model Refinement: Given the critical role of sensitivity analysis in validating simulation results, researchers should continually refine simulation models based on emerging data and changing project conditions. Implementing adaptive feedback mechanisms will ensure that models stay relevant in dynamic project environments.

Interdisciplinary Collaboration: To further strengthen the theory of optimization, interdisciplinary collaboration with experts in fields such as operations research, systems engineering, and behavioural sciences can offer novel perspectives on project management challenges. This collaboration could help refine the assumptions and methods used in project simulations.

Broader Application of Correlation Techniques: The correlation-based validation approach used in this study provides a robust way to compare simulated results with real-world data. Future research should consider using additional statistical techniques and exploring advanced machine learning algorithms to enhance model validation and predictability.

By continuing to build on these findings, future research can significantly enhance project management practices, offering more effective tools for managing complex projects in various industries.

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