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Real-Time Measurement of Trust Dynamics in Global Virtual Teams

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Abstract. The escalating prevalence of Global Virtual Teams (GVTs) across diverse geographical landscapes underscores their indispensable role in our socio-technical and economic foundations. Increasingly, teams in strategic engineering projects are GVTs and must exhibit coordination and tradeoffs as transdisciplinary engineering (TE) partners. Extensive research has scrutinized the intricate challenges faced by virtual engineering teams. Researchers characterize these challenges as distance factors (geographical, temporal, and perceived), shedding light on associated hurdles concerning motivation, awareness, and the nuanced establishment of trust. Effective decision-making within teams relies on a foundation of trust. Within this context, trust is defined as the perception that team members will act benevolently, prioritizing collective interests over self-interest. Previous studies have demonstrated the pivotal influence of trust on team performance, particularly in sustaining collaborations. The challenge intensifies during the initial stages of projects within GVTs, where face-to-face social exchanges—historically relied upon for trust-building—are difficult or unattainable. Decades of research have yielded qualitative measurement techniques and supportive methodologies, with recent emphasis on computer-mediated communications encompassing face-to-face visuals, audio, and text messages. However, these techniques are commonly evaluated qualitatively at the conclusion of experiments, leaving a gap in understanding and measuring the dynamic nature of trust in global virtual teams. This research proposes an approach by prototyping measurements for real-time assessment of the trust phenomenon in GVTs. By outlining the subsequent steps for integrating these methods, the work aspires to contribute to the advancement of GVT research, offering practical insights to fortify trust in virtual teams and enhance collaborative efficacy in the digital era.

Keywords. Global Virtual Teams (GVTs), Trust Dynamics, Transdisciplinary Engineering (TE), Real-Time Measurements, Teamwork Experiments

Introduction

Trust, a cornerstone in collaborative efforts and transdisciplinary engineering projects, exhibits diverse definitions in various studies. Cummings and Bromily [1] define it as a belief in a team's good-faith effort, honesty, and avoidance of excessive advantage-taking. Pinjani and Palvia [2] simplify it as the "level of confidence" among team members, while Choi and Cho [3] detail interpersonal trustworthiness based on ability, benevolence, integrity, and goal congruence. This multiplicity of definitions converges on the perception that trust involves collaborators acting benevolently rather than in self-interest, honoring commitments in good faith. In the realm of collaboration, trust emerges as a pivotal variable crucial for all aspects. It influences team effectiveness,

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determining whether team members seek help, share feedback, and engage in issue discussions [4]. The positive correlation between team trust and performance, positions trust as the adhesive binding collaborations together [5-7]. In the context of global virtual teams (GVTs), trust encounters unique challenges due to the superficial nature of computer-mediated communication technologies [8-10]. The absence of contextual cues, such as facial expressions and tone of voice, renders interactions impersonal and less confident. Previous works showed that trust is particularly fragile in "swift trust" scenarios within GVTs [11-12], where unexpected disruptions across time, distance, organization, and culture are prevalent.

Establishing and maintaining trust in geographically dispersed collaborations proves intricate. Challenges include the absence of strong relationships common in co-located teams, difficulties in in-depth personal interactions, and the dependence of trust on the frequency of interactions, which tends to be less in virtual teams [13-14]. Lack of trust in virtual collaborations results in various detrimental effects, including corrosion of task coordination and cooperation [15], decreased eagerness to communicate [16], and an inability to systematically cope with unstructured tasks and uncertainty [17]. Moreover, trust issues lead to fewer team members willing to take initiative, a lack of empathy among teammates, lower feedback levels, and increased risk [18-19]. The initial stage of collaboration in projects is most susceptible to trust issues, with the lack of trust causing delays in progress and susceptibility to negative opportunistic behavior [20]. Social approaches, such as promoting early social exchanges and creating opportunities for non-work-related interactions, are identified as potential solutions, although these are more commonly facilitated face-to-face [21]. The impact of communication methods on trust is substantial. Face-to-face communication is deemed irreplaceable in building and repairing trust [22]. The absence of nonverbal cues, as observed in text-based communication, leads to delays in trust decisions and impedes the expression of trustworthiness. Video communication is highlighted for its positive influence in situations where collaborators are not familiar with each other. While technology, particularly computer-aided, plays a role in trust development, the irregular, unpredictable, and inequitable use of communication technologies hampers trust [23]. Therefore, research addressing trust in collaboration should consider measurement methods, coordination, and tradeoffs as transdisciplinary engineering (TE) partners, recognizing their profound influence on the dynamics of trust in GVTs.

1. Research Framework

1.1. Motivation and Challenges

The motivation behind this research stems from the increasing prevalence and significance of GVTs in contemporary organizational and transdisciplinary engineering team structures. An engineering team is a group of professionals who collaborate to design, develop, and deliver technical solutions. In this research, engineering teams are considered because it will be possible to define their projects as systems and thereby define the dynamics of these systems in a measurable way. This makes it doable to evaluate the system performance when influencing factors are altered. Consequently, it is envisioned to develop a comprehensive trust monitoring tool for team members. This tool would continuously assess trust dynamics in real-time, providing actionable insights to support team practices and enhance management strategies. As businesses expand

globally and seek to leverage diverse talent pools, the reliance on virtual teams has become indispensable [24-26]. GVTs offer advantages such as enhanced flexibility, access to specialized expertise, and cost-effectiveness. However, the effectiveness of GVTs is contingent upon the establishment and maintenance of trust among team members. Trust serves as the foundation for effective communication, collaboration, and decision-making within virtual teams, ultimately influencing team performance and organizational outcomes.

Extensive studies by Olson and Olson in 2000 and 2006 [27] delved into the complexities of remote work compared to co-located work. The research synthesized findings from over a decade of laboratory and field studies on synchronous collaborations. Ten challenges connected with trust and hindering distance work were identified, including issues related to awareness of colleagues, the motivational sense of others' presence, varying levels of technical competence and infrastructure, the nature of work, explicit management, and the balance between competition and cooperation [summarized in Table 1].

Table 1. Main Challenges Impacting Establishing and Maintaining a Trust in GVTs.

Team Interactions	
Trust	Awareness
	Motivation
	Level of knowledge and technical competence
	Level of technical infrastructure
	Nature of work
	Leadership
	Common ground
	Competitive and cooperative culture
	Alignment of incentives and common goals
	Team Dynamics

Understanding and addressing these challenges is crucial for the effective functioning of GVTs, emphasizing the intricate interplay between geographical distance and the dynamics of trust in collaborative work and transdisciplinary engineering coordination [28-31]. Even seemingly short distances, such as 30 meters, can significantly impact communication dynamics between collaborators. Geographical distance, often measured by the work needed for visits rather than physical proximity, presents notable challenges for GVTs.

1.2. Research Gap

Despite decades of active research, the study of trust in GVTs reveals a significant research gap. Most studies have adopted a "snapshot" view [32], assessing trust through questionnaires administered post-experiment (Figure 1). Trust has tried to be assessed in human-autonomy systems, but not human-human interactions. Existing research lacks a comprehensive understanding of the temporal dynamics of trust formation and evolution. With few exceptions, such as some studies [33–35], there is limited insight into how trust strengthens or weakens over time due to moment-to-moment interactions, but again with human-automation dependencies. Addressing this gap is crucial for a more nuanced understanding of trust in GVTs and its implications for human-human interactions within transdisciplinary engineering.

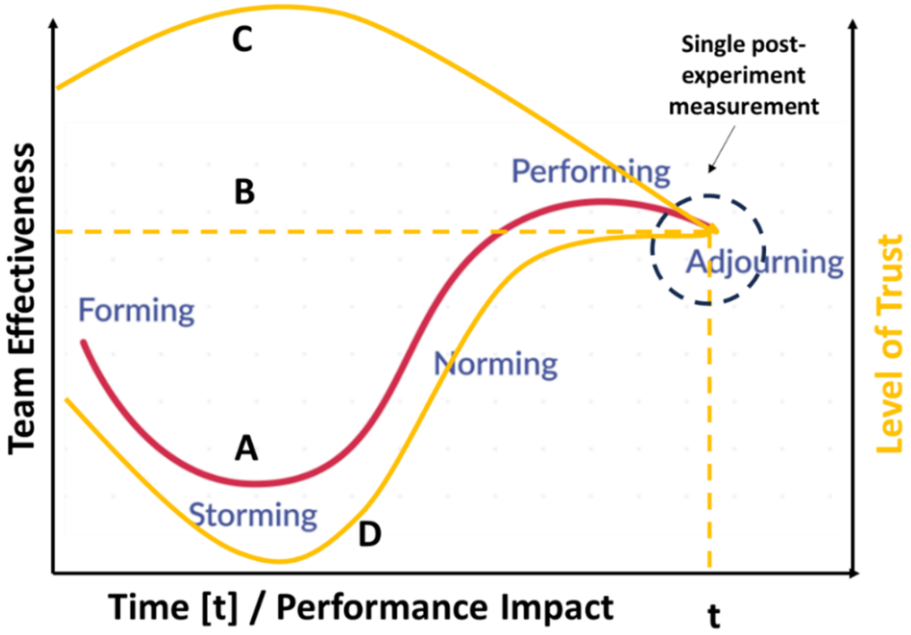

Figure 1. The static view (B) versus the example of dynamic view of trust (C, D). If taking a look at time t, all have the same trust level. However, their trust dynamics are fairly different.

Tuckman's Five-Stage Model of Team Development, also known as the "Forming, Storming, Norming, Performing, and Adjourning" model [36], focuses on the stages a team goes through in its journey toward high performance and efficiency. Trust dynamics play a significant role throughout these stages because: 1) It is inconsistent and can fluctuate during the team development stages (Fig. 1 C, D). 2) Open communication, conflict resolution, and collaboration are essential for trust development. 3) Trust established in later stages tends to be stronger and more resilient [37].

Understanding the interplay between trust dynamics and Tuckman's model is crucial for team leaders and members to navigate challenges, foster collaboration, and enhance overall team performance [28-31, 37]. Additionally, distance factors inherent in virtual collaboration, such as geographical dispersion, temporal differences, and perceived cultural barriers, further complicate the trust-building process within GVTs. Without real-time visibility into trust levels and dynamics, organizations may struggle to effectively address trust-related challenges and optimize team performance.

1.3. Research Aim

To address the challenges associated with trust measurement in GVTs, this research proposes an approach focused on real-time assessment of trust dynamics within virtual teams. The strategy involves the development and implementation of a comprehensive measurement system capable of capturing trust levels and fluctuations as they occur during team interactions. This real-time measurement approach integrates various data sources, including communication patterns, behavioral indicators, and sentiment analysis, to provide a holistic view of trust within GVTs. Key components of the strategy include the design and implementation of data collection protocols, the development of

analytical models and algorithms for real-time trust assessment, and the integration of feedback mechanisms to enable continuous improvement and refinement of the measurement system. Additionally, the strategy incorporates qualitative insights from team members through surveys, interviews, and focus groups to contextualize quantitative trust metrics and inform trust-building strategies. By employing this strategy, organizations can gain actionable insights into trust dynamics within GVTs, identify factors influencing trust formation and maintenance, and implement targeted interventions to strengthen trust and enhance team effectiveness. Ultimately, the proposed approach aims to contribute to the advancement of GVT research and provide practical tools and strategies for fostering trust and collaboration in virtual team environments.

1.4. Research Method Design

This work explores the developmental stages of trust according to the Tuckman's Model and System Dynamics [38] within GVTs, drawing on the framework proposed by Lewicki and Bunker [39]. The trust evolution unfolds in three sequential phases:

Calculus-Based Trust (CBT): In the initial stage, trust is rooted in a member's evaluation of outcomes and costs associated with maintaining group relationships. This phase involves a cost-benefit analysis.
Knowledge-Based Trust (KBT): As teams continue to work productively, calculus-based trust transforms into knowledge-based trust. This form of trust relies on members' understanding of each other's competencies, enabling predictions about one another's behaviors.
Identification-Based Trust (IBT): For teams working together effectively over time, knowledge-based trust evolves into identification-based trust. This deep level of trust is grounded in mutual identity and a willingness to act for each other's benefit.

The research method highlights the sequential iteration of these trust types over time. It introduces the concept of "swift trust," observed in work-oriented virtual teams, impacting early trust development and subsequently influencing later trust, communication, cohesiveness, and performance (Figure 2) integrated into the system dynamics framework.

Two streams of theorization concerning initial trust development are discussed. According to Lewicki and Bunker [39], as teams mature, trust progresses from CBT through KBT to IBT, with a direct, positive relationship between early and later trust. Initial trust plays a crucial role in determining individuals' willingness to trust others, shaped by observations of consistent positive behaviors among team members. Interpersonal interactions, as observed in studies like Jarvenpaa & Leidner [40], can strengthen or weaken trust, influencing a team's ability to manage uncertainty, risk, and points of vulnerability.

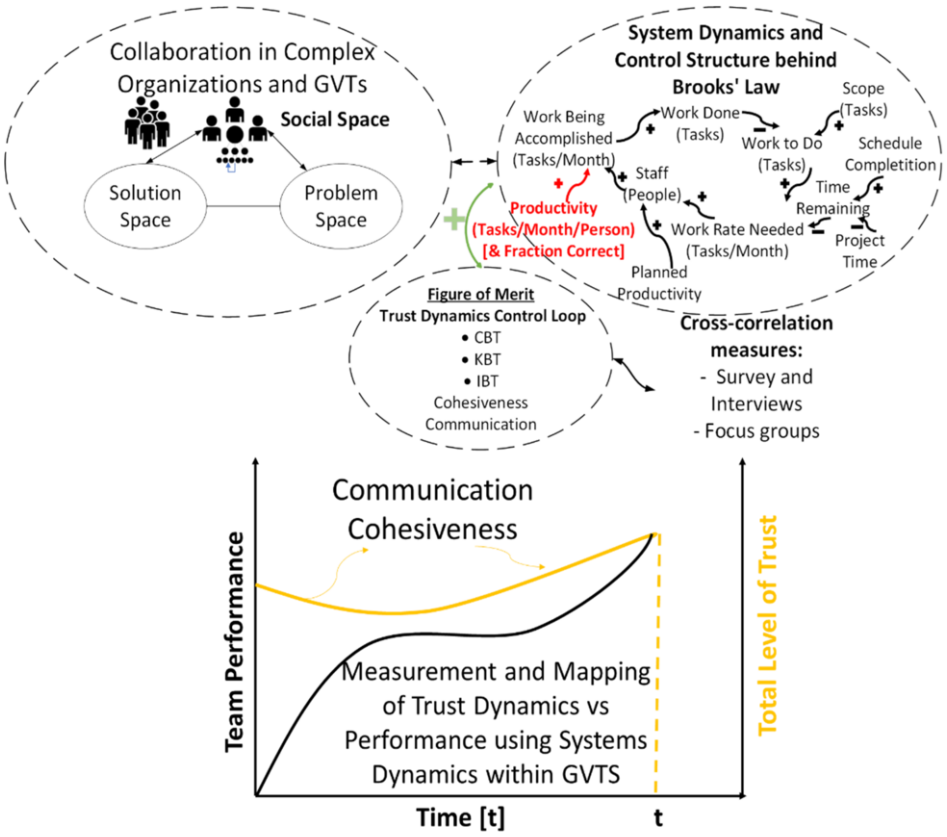

Figure 2. Methodology of measuring trust dynamics incorporated in the system dynamics framework within complex organizations and GVTs.

The conceptual framework delineates the components and processes involved in the real-time measurement of trust in GVTs. It identifies key variables, such as communication patterns, behavioral indicators, and sentiment analysis, that contribute to trust dynamics within virtual teams (Figure 2). The framework also highlights the role of distance factors, team processes, and organizational context in shaping trust development and maintenance. The work considers teams acting and interacting across solution, problem, and social spaces (Figure 2, Collaboration in Complex Organizations and GVTs). A team's behavior in the social space affects their awareness, exploration, and selection of solutions, which is their behavior as seen in the solution space. The outcome of their selection in the solution space is expressed in the problem space, and a decision on whether they are satisfied with the result or not is also affected by the social space. The system dynamics with a control structure is used to assess team productivity, and the trust dynamics control loop is added to in-situ measure and correlates its total level over time concerning the team performance. Table 2 summarizes the framework for measuring operationalizing trust concepts in the analysis of trust dynamics and cross-correlation with surveys.

Table 2. Main Challenges Impacting Establishing and Maintaining a Trust in GVTs.

Trust	Basis	Example
CBT	Individual assessments of what members can gain from the relationship	Fulfilled requirements and direct link to performance
KBT	Reflecting knowledge of others' competencies, group norms, and past actions.	Expressing thoughts other team members e.g., according to
IBT	Reflecting a high degree of identification with the team.	Expressing team behavior e.g., our team, tradition
Cohesiveness	Reflecting expressions of warmth, friendship, support, or intimacy with others.	Warm and supportive approach e.g., our team solve this problem
Communication	Measured by the number of messages related to previous messages, including reactive interactions.	Number of interactions and replies

The research design and methodology employed to implement the proposed framework consider the participant selection criteria, data collection methods (e.g., surveys, interviews, automated data collection tools), and analytical techniques (e.g., statistical analysis, machine learning algorithms) used to capture and analyze real-time trust dynamics within GVTs. The real-time measurement tools for assessing trust in GVTs include the design and deployment of the Vensim software application, communication tracking systems, and sentiment analysis algorithms capable of capturing trust-related data in real time. Vensim stands out for enabling dynamic analysis throughout the model-building process. It allows iteratively scrutinizing variables, exploring system loops, and refining models for robustness. With that and the presented methodology (Figure 2) it can be observed how the system responds to various inputs and conditions, providing crucial insights into system behavior. The tools are designed to integrate seamlessly with existing virtual team platforms and communication technologies to minimize disruption to team workflows. Then the data collection process and analysis procedures are employed to derive insights from real-time trust measurements. The different types of data (e.g., communication logs, survey responses, behavioral observations) are collected and the methods are used to analyze and interpret the data. Emphasis is placed on identifying patterns, trends, and correlations related to trust dynamics within GVTs. Vensim is a simulation software designed for enhancing the efficiency of real systems, including comprehensive model analysis capabilities with optimization and Monte Carlo simulation. Based on the findings from the real-time measurement of trust in GVTs, key insights into trust dynamics, including factors influencing trust formation, fluctuations in trust levels over time, and the impact of communication patterns on trust outcomes can be highlighted. The implications of the findings for virtual team effectiveness and organizational performance are also explored.

2. Theoretical System Model

2.1. Governing Equations

The system model and meticulously crafted framework have been developed by drawing upon insights from extensive research and experiential knowledge. It encapsulates the intricate dynamics underlying team performance (Figure 2), identifying key trans-engineering factors significantly influencing team effectiveness. Leveraging these insights, an equation (1) was meticulously constructed, synthesizing the interplay of these critical factors within the team ecosystem and system dynamics (Figure 2) and

incorporating trust level with a feedback loop (Figure 3). These factors, selected based on their empirical relevance and experiential significance, serve as the linchpin interactions within the system model. This rigorous approach ensures that the model encapsulates the nuanced complexities inherent in team dynamics, providing a robust foundation for further investigation and analysis in the realm of team performance optimization. Initially, the trust level built in the teams is computed based on the various parameters highlighted in Figure 3.

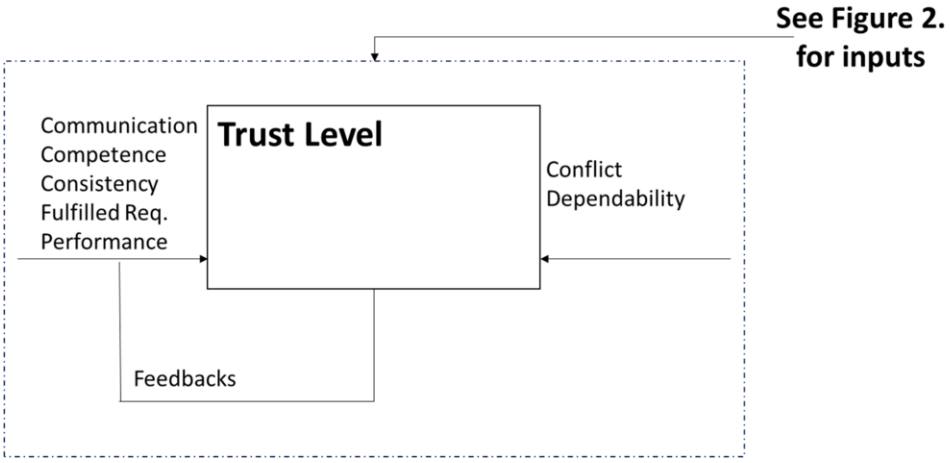

Figure 3. Quantitative framework for measuring trust level within complex organizations and GVTs (Fig. 2).

Using this approach, the trust level equation is derived as follows:

$$T_{\mathrm{L}} = \frac{C_1 * C_2 * C_3 * R * P}{(C_4 * D)} \tag{1}$$

Where T_{L} is a trust level. C_1, C_2 and C_3 are communication, competence and consistency, respectively. R is a fulfilled requirement and P is the performance. C_4 and D represent conflict and dependability, respectively.

Since the Team performance is based on the Trust Level, this value is then used to calculate Team Performance value as below.

$$T_{\mathrm{p}} = (T_{\mathrm{L}} * C_o * G_{Al}) + (L * M) \tag{2}$$

Where T_{p} is the team performance. C_o and G_{Al} are collaboration and goal alignment, respectively. L is the leadership and M is the motivation.

2.2. Cross-correlation survey measures

Before, during and after experiments, participants are required to complete a demographic survey, including age and gender information, along with a trust propensity survey that assesses their inclination towards trust in the team and recognition. Drawing upon the organizational trust model and our theoretical framework, a comprehensive

model for trust can be formulated, encompassing various underlying dimensions as identified in the literature and developed questionnaire methodologies [41-43]. Employing a deductive approach, an initial set of items is generated. These items undergo analysis based on criteria such as item difficulty, standard deviation, item-total correlation, internal consistency, and overlap with other items in content. Subsequently, the internal structure of the resulting questionnaire is examined in a second phase, aligning it with our model through exploratory factor analysis. The outcomes are expected to provide sufficient preliminary evidence supporting the proposed factor structure, indicating the viability of further exploration of the model. However, it is acknowledged that certain revisions may be necessary based on the results and feedback loop [Fig. 2-3]. The findings from the analysis will contribute valuable evidence for both the questionnaire's and the model's criterion validity, establishing a strong foundation for subsequent stages of the research. Moreover, our theoretical model will be cross-correlated with a survey linking team performance (measured by KPI points) to the level of trust, providing a comprehensive understanding of the dynamics at play in the team environment.

3. Prototyping and Integration

3.1. Preliminary model validation and findings

In order to facilitate computational analysis, distribution, Monte Carlo simulation, and generate a Pareto chart to elucidate the spectrum of performance possibilities, several assumptions have been instituted. These assumptions entail assigning specific values to the various parameters under consideration. Notably, values of 0.1, 0.6, and 1.0 are allocated to denote low, medium, and high levels, respectively, for the different parameters. Additionally, average values derived from extensive research are utilized in instances where data permits. These assigned values are deemed static for modeling, as their impact on the system diminishes compared to the variability exhibited by the factors under investigation. This standardized approach streamlines the computational process, enabling a focused exploration of the key determinants driving performance outcomes within the system. Partial derivatives of key variables are computed to analyze normalized sensitivities. Figure 4 shows the model outcomes by running various described scenarios. The Utopia point of this model suggests that the Team performance directly depends on the Trust level within the team. This means that when the Trust level is very high in a team, it automatically results in high team performance. A corollary can also be derived to give an impression that unless teams have high trust levels, they cannot perform well. However, in reality the dynamics of the teams are influenced by various factors and are not just dependent on trust levels

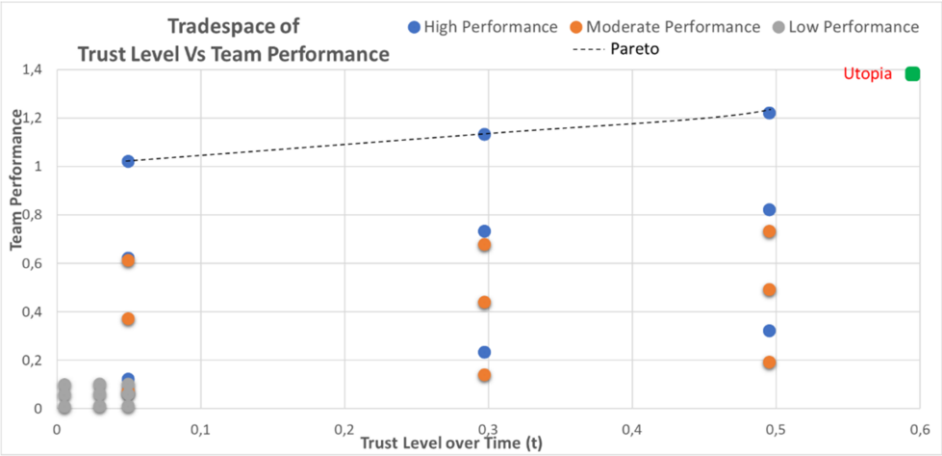

Figure 4. Developed trust dynamics model showing a tradespace of trust level vs team performance (for various teams) within complex organizations and GVTs.

The model's generation involves classifying teams into distinct categories based on their high, moderate, and low-performance levels (Figure4, Model 1-3, respectively). This thoughtful categorization, with parameters reflecting the anticipated characteristics corresponding to each performance tier, serves as foundational inputs for subsequent calculations and analyses. The model's output, as evidenced by graphical representations, reveals a discernible trend: higher levels of trust within the team correspond to enhanced performance outcomes. This empirical observation not only corroborates the initial assumption but also underscores the pivotal role of trust as a determinant factor influencing team effectiveness. This validation serves to fortify the model's utility in elucidating the multifaceted dynamics of team performance and underscores the significance of fostering trust within organizational contexts. By incorporating the data of the specific team structures into this model, it will be possible to measure the trust level and performance of the teams, and by comparing actual team performance against the utopian model, we can identify discrepancies and areas for targeted improvement. This can then be used to plan trainings and other strategies to increase the trust levels in the teams as will be fit.

4. Discussion, Limitations and Future Work

While the current analysis offers valuable insights based on select factors and their assigned values derived from research, integrating real-time surveys and observational data could substantially enhance the accuracy and granularity of performance computation and dependency parameters. By leveraging real-time data collection methodologies, such as surveys and direct observation, the dynamic fluctuations and nuances inherent in team performance dynamics can be captured. This empirical approach not only ensures the incorporation of up-to-date information but also enables a more precise assessment of the interplay between various factors and their impact on performance outcomes. The integration of real-time data acquisition methodologies promises to enrich our understanding and refinement of the underlying mechanisms governing team performance, facilitating more informed decision-making and strategy

formulation. An important limitation of this study is that the analysis was based on the research, previous results, and available surveys that are used to cross-correlate and validate the proposed model for measurements of trust dynamics. A dedicated study with a game and analysis of the impact of communication technologies within GVTs is part of a future study.

5. Conclusion

The increasing prevalence of Global Virtual Teams (GVTs) in strategic engineering projects underscores their crucial role in today's socio-technical and economic landscape. As transdisciplinary engineering (TE) partners, GVTs face intricate challenges related to distance factors, encompassing geographical, temporal, and perceived dimensions. These challenges significantly impact motivation, awareness, and the establishment of trust within teams, a key foundation for effective decision-making. This research proposes an innovative approach by introducing real-time measurements to prototype the assessment of trust dynamics in GVTs. The subsequent integration of these methods aims to address the existing gap in GVT research, offering practical insights to strengthen trust in virtual teams and enhance collaborative efficacy in the digital era. By taking this step, the study contributes to the advancement of GVT research, providing a valuable framework for real-time trust assessment in virtual teamwork experiments. However, it's important to note that this paper is a prototype and informs a Design of Experiment (DOE); the Vensim model by itself is not yet validated. Next steps involve refining the prototype based on feedback and conducting rigorous validation experiments. Additionally, exploring additional factors influencing trust dynamics in GVTs and further refining measurement methods is planned. The goal is to develop a robust and validated framework for real-time trust assessment in GVTs, contributing to the success of global collaborations in the digital age.

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