E-CARGO/RBC Research Guide

A Road Map for Researchers

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In addition to outlining the key components of the Environments – Classes, Agents, Roles, Groups, and Objects (E-CARGO) model and Role-Based Collaboration (RBC) methodology, this article aims to serve as a comprehensive research guide for scholars and researchers embarking on investigations within their research fields. By offering persuasive and illustrative arguments, the authors furnish valuable and pragmatic guidelines, equipping potential researchers with insights on selecting pertinent topics, crafting compelling scenarios, engaging in effective modeling practices, and designing rigorous experiments. The elucidation of these fundamental steps not only facilitates a clearer understanding of the intricate aspects of E-CARGO and RBC but also provides a road map for researchers to navigate the intricacies of conducting solid and insightful research within these frameworks.

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Introduction

Since the successful organization of the inaugural IEEE E-CARGO Summer School in 2023 (http://www.e-cargoschool.com/1/#/), numerous students and scholars have joined the ranks of researchers delving into E-CARGO/RBC [34], [52]. Recently, we have received substantial feedback from these research endeavors, revealing many intriguing questions and challenges. Recognizing the need to address these intricacies, this article aims to specifically discuss a series of crucial aspects related to conducting E-CARGO/RBC research, including topic selection, modeling skills, and verification experiment design. Given the expansive framework that E-CARGO/RBC provides, we believe that it serves as a comprehensive and interdisciplinary innovation platform for numerous master's and doctoral students in

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computer science, automation [19], systems engineering [4], industrial engineering [24], and management [27]. This encompasses interdisciplinary topics ranging from thesis, paper, and grant writing to expanding research perspectives and venturing into new domains, which follow the IEEE Systems, Man, and Cybernetics Society's mission [23] of "promoting the theory, practice, and interdisciplinary aspects of systems science and engineering, human-machine systems, and cybernetics."

Owing to the authors' experiences, this article is structured to offer readers a comprehensive research guide, addressing these aspects in distinct sections. The discussed challenges include how to understand E-CARGO/RBC from a high-level abstraction viewpoint, how to choose an interesting topic for research, how to compose an inspiring scenario, and how to design experiments to verify the proposed methods, which are all necessary parts of accomplishing good research.

To embark on E-CARGO research, a seamless integration of the E-CARGO model and RBC processes is imperative and highlights their indivisibility.

An Overview of the E-CARGO/RBC Framework

To embark on E-CARGO research, a seamless integration of the E-CARGO model and RBC processes is imperative and highlights their indivisibility. E-CARGO/RBC, when viewed at an abstract level, serves not only as a computational model and methodology but also as a systems engineering model and methodology.

E-CARGO unfolds as a nested (recursive) compositional model, while RBC manifests as a nested (recursive) procedural model. The combination of these two models yields a dynamic nested (recursive) model capable of modeling many complex systems. Beyond its modeling capabilities, the union of E-CARGO and RBC engenders a novel worldview and methodology, fostering a deeper understanding of the world. E-CARGO/RBC implies philosophical paradigms that abide by the thoughts of both Western and Eastern philosophies.

First, E-CARGO/RBC offers a framework that uses mathematical and computational modeling methods to investigate industrial and societal issues. Researchers can utilize the mathematical and computational tools provided by E-CARGO/RBC to explore real-world applications in industry and society. While seemingly composed of mathematical formulas or computer algorithms, these expressions encapsulate societal and industrial significance, which is the aim of the E-CARGO/RBC formalization. It is crucial to emphasize that every symbol or formula within the E-CARGO model holds concrete physical and societal meanings. For instance, our research project funded by the Natural Sciences and Engineering Research Council of Canada (NSERC), "Dynamic On-Demand Transit Services in Small Cities Based on the E-CARGO Model," utilizes E-CARGO/RBC to model the dynamic scheduling of buses in small city transit systems. The proposed scheduling scheme has been adopted by the public transit system in North Bay, ON, Canada.

Second, the E-CARGO model surpasses object and agent models, primarily due to its introduction of the role concept and the differentiation between objects and agents. Objects correspond to passive entities in the real world, representing "things," while roles correspond to "events" or "tasks" that must be undertaken by active entities. Agents, in turn, correspond to "people" or autonomous machines, including robots, serving as the active entities that perform tasks. The clarity in distinguishing roles from objects and agents helps avoid endless debates about whether agents are objects and vice versa. Objects are associated with events or tasks, and for agents to obtain a particular object, they must first assume a role, i.e., undertake an event or task.

Third, concerning the nesting and recursion within E-CARGO/RBC, each step in the RBC process can be understood as nesting the original RBC process description, offering flexibility controlled by researchers. For example, the role negotiation phase can be regarded as a task and described as an RBC process, implying the need for repeated role negotiation, agent assessment, role assignment, and role play. Various components within E-CARGO can be pairwise analyzed, such as <object, class>, <role, environment>, and <agent, team>. Each component can undergo nested or recursive analysis based on its corresponding physical and societal significance. Additionally, a particular object, role, or agent can be expressed through a complex E-CARGO model, while conversely, the system formed by E-CARGO can serve as an agent in another system.

For instance, in the context of a country as a collaboration system, "industry" can be considered a role. Numerous agents can play this role. Furthermore, "industry" itself constitutes a complex RBC dynamic system that operates under the supervision of the regulatory authorities, following the RBC process, including role (different industry branches) negotiation, agent evaluation, role assignment, and role-playing.

Through nested analyses, intriguing research questions can be unearthed, and breakthroughs can be identified. E-CARGO/RBC can be applied to various real-world scenarios, extracting research topics from these scenarios. Most of these topics are significant and possess originality. When addressing specific industrial issues directly, framing them within the RBC framework provides novel modeling perspectives, describing new practical scenarios. If a scenario differs from existing ones, it can be deemed an innovative contribution. A successful case is [22], where traditional cloud/service computing presumes computational resources to be infinite relative to demand. However, integrating E-CARGO/RBC necessitates the consideration of finite resource scenarios. This shift in perspective led to the introduction of scenarios for a private cloud with limited resources. Consequently, applying group role assignment (GRA) with conflicting agents on roles (GRACAR) directly addressed a previously unexplored issue. Another case involves service composition [20], [21], [22]. From the perspective of service providers with seemingly infinite resources, GRA with constraints (GRA+) modeling was deemed inappropriate. However, considering the limited resources from the users' perspective, this makes GRA+ modeling reasonable.

Fourth, the RBC process can be taken as an algorithm if each step of the process can be specified by an algorithm. For example, in a conventional multiagent system, each agent can incorporate an RBC as its process engine, and this incorporation makes each agent understand the overall situation of the whole system, which surpasses traditional multiagent systems that assume that agents have local views of the system. Combined with the blockchain [32] idea to remove centralization, RBC can also be applied to decentralized applications by duplicating the RBC process in a blockchain organization.

In summary, E-CARGO/RBC, as a unified framework, not only provides a platform for interdisciplinary

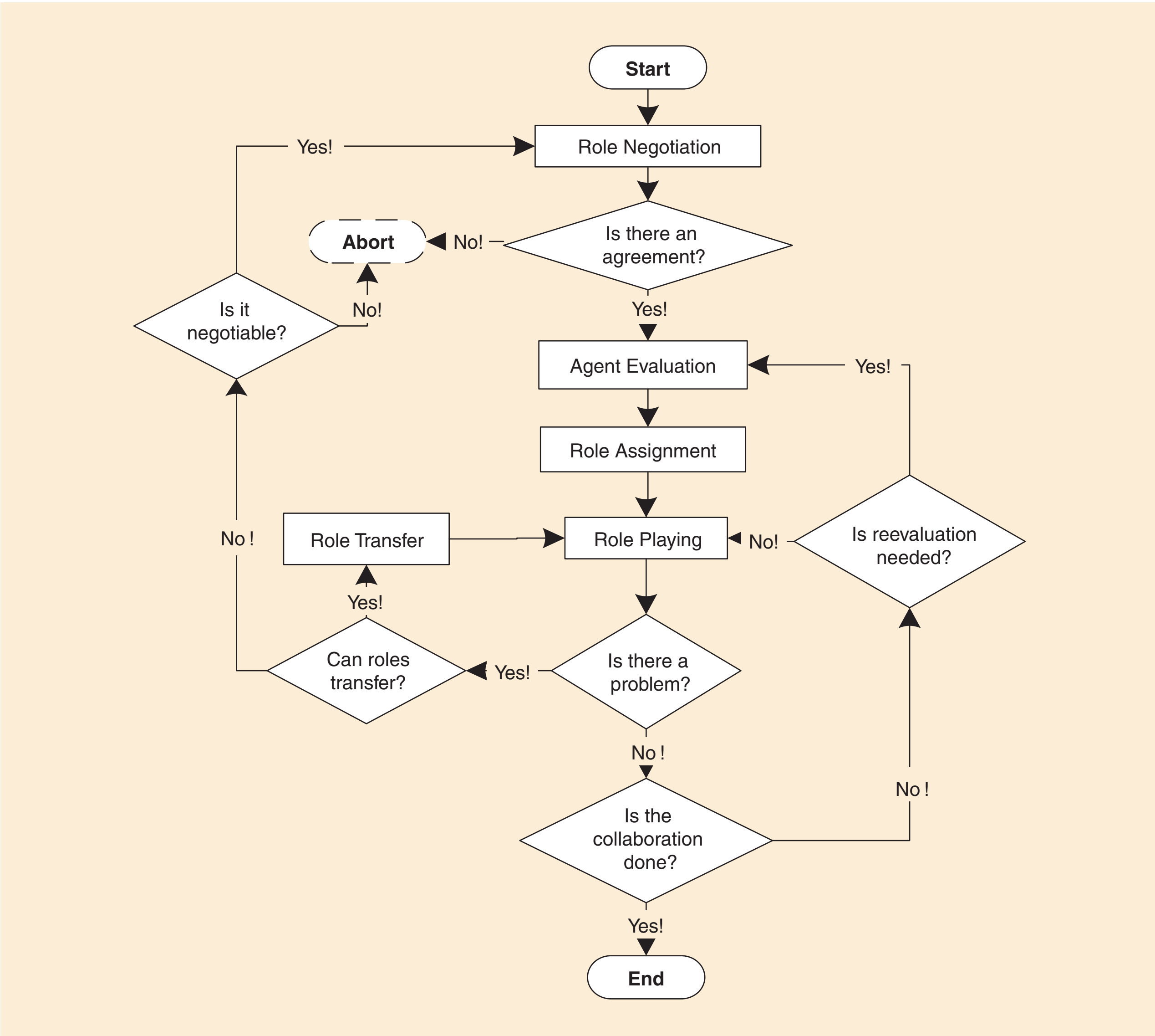

Figure 1. The original RBC process. (Source: Taken from [34] and [37].)

innovation but also serves as a powerful tool for investigating and addressing complex societal and industrial challenges. Its ability to bridge computational modeling and real-world applications underscores its significance in advancing both theoretical and practical domains. The following sections of this article aim to provide readers with a comprehensive research guide based on the authors' experiences, delving into the nuances of conducting research within the E-CARGO/RBC framework.

How to Choose a Research Topic

We can find research topics by reviewing the related diagrams, including the original RBC diagram (Figure 1) [34], [37]; the improved RBC diagram (Figure 2) [36]; the 3D E-CARGO diagram (Figure 3) [40]; and the E-CARGO/RBC integration diagram (Figure 4). Among these diagrams, the differences between the RBC process diagram (Figure 1) and its improvement diagram (Figure 2) suggest a topic selection approach, i.e., each RBC step can be refined,

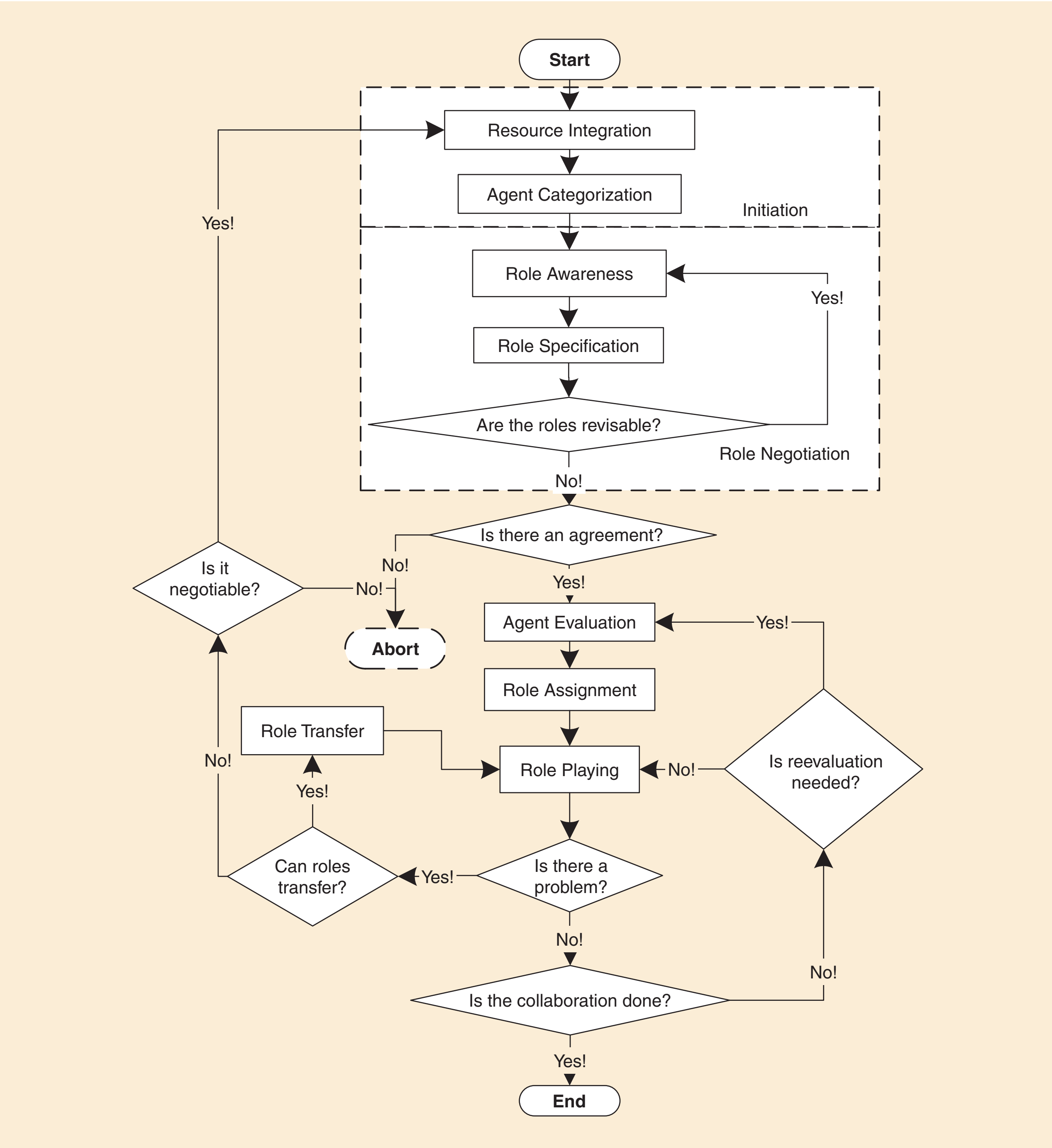

Figure 2. The detailed RBC process. (Source: Taken from [36].)

where Figure 2 revised and extended Figure 1 by refining role negotiation into more detailed processes to introduce new challenges in E-CARGO research, i.e., resource integration, agent categorization, role awareness, and role specification. The 3D E-CARGO diagram (Figure 3) implies numerous abstract problems, such as object-agent assignment, which addresses allocation problems in multiagent systems without considering roles, environmental construction issues in the E-CARGO environment, and problems involved in the role negotiation phase. The diagram also suggests the agent-environment assignment problem, an interesting new problem that can be correlated with the career choices of university graduates in the real world.

These new assignment problems differ from GRA problems [18], [53], especially in terms of their industrial (social) implications, requiring innovative approaches. Some of these problems can be addressed with popular machine learning methods, providing partial solutions, while also comparing and validating proposed role negotiation or agent assessment methods with GRA+ team performance. The E-CARGO/RBC integration diagram (Figure 4) directly illustrates the inseparability of E-CARGO and RBC through a Unified Modeling Language [5] class diagram. In terms of topic areas, we propose the following preferred directions.

Social Simulation

We can model existing social issues traditionally addressed through humanistic methods as computable and comparable optimization problems using E-CARGO. For example, our research project, "Social Simulation of Refugee Resettlement and Canadian Policy Making," funded by the Social Sciences and Humanities Research Council of Canada (SSHRC), utilizes modeling and optimization to replace previously manual tasks. This new method is not only precise and efficient but also provides new policy recommendations through simulation. All completed social simulation articles have followed this research path [5], [6], [9], [10], [11], [12], [13], [14], [39], [41], [42], [43]. For example, we have compared collectivism and individualism from the team performance perspective using weighted GRA and dynamic weighted GRA to simulate collectivism and the Best Agents for the Most Important Roles (BAMIR) algorithm and dynamic BAMIR to simulate individualism [39]. As a nontrivial side product of social simulation, visualization and animation are also interesting and challenging topics, i.e., how to present the simulation results in an easy-to-understand way [26].

Economics

Economics is a vast field attracting numerous researchers. Economics problems based on game theory can be redefined and delineated according to E-CARGO/RBC, potentially leading to breakthroughs. For instance, modeling multiplayer games within game theory is overly complex, and algorithms are generally impractical. Compared to the game models in game theory, E-CARGO/RBC presents an abstract scenario of a multiplayer game. Due to the abstraction at the role level, the formalized problem complexity is significantly reduced. Furthermore, this field presents numerous challenges and scenarios waiting for our understanding, modeling, and solution-seeking using E-CARGO/RBC. For example, we use GRA and dynamic GRA plus incentive factors to simulate social development from the viewpoint of earning income/making contributions [42]. We also discussed the Pareto

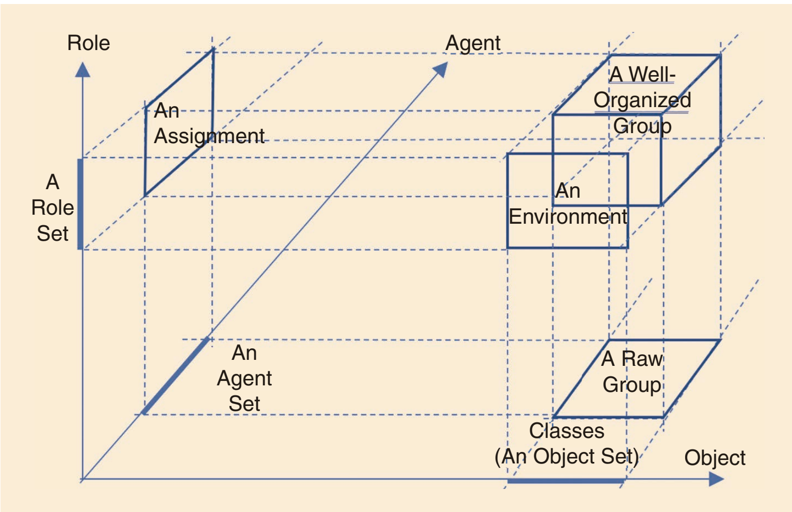

Figure 3. The 3d view of E-CARGO. (Source: Taken from [40].)

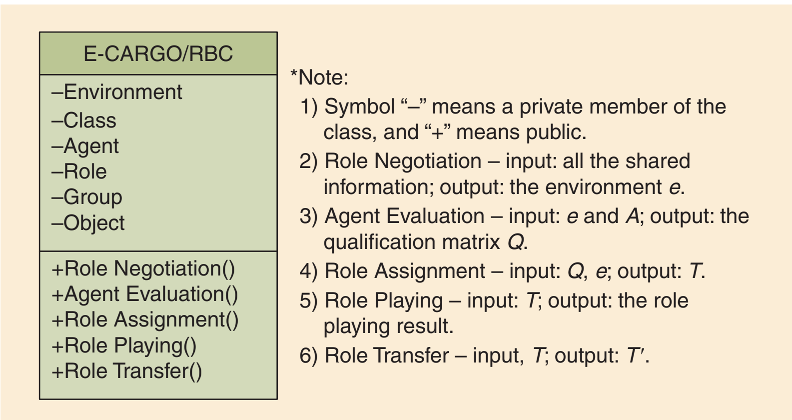

Figure 4. The integration of E-CARGO and RBC.

improvement from the GRA's perspective [41] to confirm that overproduction is driven by the requirement of Pareto improvement.

Logistics Management and Supply Chain

This is an extensive field that involves various complex issues, such as transportation optimization, demand forecasting, supply chain collaboration, and inventory management. These problems can be modeled and optimized using E-CARGO/RBC, which may lead to breakthroughs. For instance, when we address the issue of optimizing logistics transportation, our purpose is to minimize logistics costs and achieve efficient transportation as much as possible. By modeling the problem using E-CARGO/RBC, we can take the collaboration among roles into account to meet the requirements [28]. Also, when we encounter warehousing and supply issues caused by price fluctuations and uncertain demands, we typically rely on experience to devise solutions. However, we can precisely and effectively formalize such problems using E-CARGO/RBC [34]. What is more, supply chain collaboration involves information sharing and collaborative decision making among supply chains.

E-CARGO/RBC abstracts at the role level, simplifying unformalized complex problems into computable optimization problems.

Role-based modeling can formalize the collaborative relationships between supply chains more clearly, reducing the complexity of formalized problems and improving the overall performance of the supply chains [13]. Moreover, while traditional supply-demand forecasting methods rely on historical supply data and market trends, modeling with E-CARGO/RBC can take more factors into account, such as the supply correlation between products, and provide more accurate forecasting solutions. In addition, traditional logistics inventory management focuses on managing an individual company. Therefore, it can be difficult to address collaborative issues among multiple companies using conventional modeling methods. However, E-CARGO/RBC abstracts at the role level, simplifying unformalized complex problems into computable optimization problems [34]. This innovative method can propose accurate and efficient decision-making recommendations through simulations. Furthermore, using E-CARGO/RBC for research can provide new perspectives and solutions for these engineering problems.

Service Computing and Cloud Computing

Service composition optimization has always been one of the important research directions in the field of service computing. In recent years, composed cloud services (CSs) have provided an important infrastructure for many data-intensive or compute-intensive applications (DiCiAs). However, cloud computing environments are complex, uncontrollable, and changeable. For the sake of data and privacy security, the hybrid cloud integrating CSs from the private and public clouds has become a promising computing paradigm. Many enterprises and organizations have successfully harnessed the hybrid cloud for their DiCiAs. In a hybrid cloud, achieving CS composition optimization for a DiCiA consisting of multiple computation or storage tasks, with the consideration of quality of service (QoS) and cost, is still challenging.

With increasing CSs from a hybrid cloud integrated into DiCiAs, the complicated constraints about CSs add more difficulties for optimizing CS composition. The CS composition for DiCiAs is supposed to achieve the collaborative optimization of resource assignment in a hybrid cloud. The RBC theory provides us with a theoretical basis. A DiCiA in a hybrid cloud may be viewed as an RBC system [34]. Facing a limited number of CS resources, complex CS composition constraints, and uncertain QoS in the hybrid cloud, E-CARGO can help us clearly define such a type of CS composition problem and further explore its solution on this basis. For example, several works [20], [21], [22] have demonstrated the research paradigm of the CS composition optimization problem in a complex environment via E-CARGO. Moreover, with the continuous changes in the cloud computing environment and DiCiAs requirements, there should be more CS combination optimization problems that deserve further study.

Automation and Robot Teams

One of the most important ideas in automation is feedback. Feedback is involved in a dynamic process. During this process, the system adjusts commands in real time according to the current status to achieve system goals. The RBC Processes in Figures 1 and 2 illustrate this feedback idea clearly. For example, for the question "Is the collaboration done?", if the answer is no, the loop goes back, and an agent reevaluation is conducted [9], [10], [25], [28], [29], [52]. However, automation and RBC are also different. Control science mainly focuses on a single agent or a certain measurement index reaching a set of target values, while E-CARGO focuses more on how the group is organized. E-CARGO can achieve group optimization through collectivism. Therefore, combining E-CARGO/RBC with innovative control technologies is a promising way for research, where E-CARGO/RBC provides a high-level team management framework and the control technologies support the individual agent operations, i.e., role-playing. For example, work [1] is the first trial in this direction. Currently, unmanned aerial vehicles (UAVs) and robots have been widely used. In fields such as express delivery, agriculture, and combat, E-CARGO can be used to model, formalize, and optimize multi-UAV/robot collaboration scenarios.

Management

Management is a discipline that deals with the coordination and organization of various resources to achieve specific goals. It is a targeting area of E-CARGO/RBC. It involves various aspects, such as strategic planning, business administration, and human resource management. These issues can be analyzed and improved using E-CARGO/RBC, which may lead to innovations. For example, when we deal with the issue of strategic planning, our goal is to formulate and implement effective strategies that align with the vision and mission of the organization. By using RBC, we can model the roles and responsibilities of different stakeholders and evaluate the feasibility and effectiveness of different strategies [12], [13], [14], [15], [25], [28], [29], [36], [37], [38], [39], [40], [45], [46], [47], [48], [49], [50], [51], [52], [53]. Moreover, we can also use E-CARGO/RBC to simulate and test various scenarios and interventions that may affect business administration. Furthermore, RBC's strength lies in its ability to capture the nuanced capabilities and expectations associated with various positions. This proficiency translates into more precise and efficient solutions for personnel recruitment and training within the expansive domain of human resource management [44], [45]. For example, the early research on role transfer problems [50], [51] comes from team management requirements. In conclusion, the strategic integration of E-CARGO/RBC into research endeavors holds the promise of delivering fresh insights and innovative solutions to the complex challenges within the management landscape.

An exception needs to be highlighted. If you directly address specific industrial problems and model them using GRA [53] or GRA+ [3], [13], [37], [38], [40], [44], [45], [46], [48], it may be perceived by reviewers as traditional linear programming (LP) modeling. If the scenario remains unchanged, it might be considered an old problem, making it hard to present the significance of your work. Reviewers may also point out many existing solutions for comparison. Directly stating industrial problems and then using LP for modeling have been employed for decades and are the expertise of industrial engineering students and scholars. Finding all the references is very challenging. Thus, this path is not a preferred route for E-CARGO/RBC research.

Table 1. The required positions.

Position	Manager	Designer	Coder	Quality Assurance
Required number	1	2	3	2

The process of designing scenarios is akin to crafting a short story, complete with characters, locations, time frames, tasks, and requirements.

How to Compose Scenarios

A scenario clarifies the challenges. When a researcher presents the scenario well, they have a clear clue in the investigation. An informative scenario makes the readers and reviewers really understand the significance and creativity. It is an indispensable component for a high-quality article in conducting E-CARGO/RBC research because E-CARGO/RBC research mainly concentrates on solving problems that have not been well formulated. The scenario presents a new problem described in natural language, and the authors' work is to formalize it, provide solutions, and present related details in modeling and theory.

For young students and scholars with limited personal experiences, primarily focused on academic studies and school activities, exposure to real industrial and social scenes may be limited. In such cases, imagination becomes crucial. Suppose you were to manage a team—what challenges would you face? Envision the scenario of managing a workshop in a factory. You can also draw inspiration from movies, television shows, various collective project competitions you've participated in, and a variety of complex games you've played to create unique scenarios. For instance, several scenarios in the literature [25], [29] are inspired by watching NBA basketball games and playing the StarCraft game.

For example, scenarios like trailer management, waste bin management, and gas cylinder transportation, proposed by an industry alumnus of the authors, provide directly corresponding scenes for dynamic RBC systems. If we clarify the components and steps involved, we may find the correct input data and propose solutions. A solution does not have to be optimized. If the proposed solutions outperform humans' manual efforts, the clients will accept these solutions.

The process of designing scenarios is akin to crafting a short story, complete with characters, locations, time frames, tasks, and requirements. This short story should pose questions and highlight challenges but avoid providing answers. The people in this short story cannot solve the presented problems; instead, they must seek help from the authors of this scenario because the answers will be revealed throughout the entire research process, specifically in the main body of an article.

For example, the scenario design for GRACAR [37] is as follows. In company C, Anna, the chief executive officer (CEO), recently sealed a million-dollar contract. Turning her attention to the organizational aspects, she enlists the help of Brian, the human resources officer. Brian, tasked with assembling a team from the company's employees, formulates a position list (Table 1) and compiles a shortlist of potential candidates (Table 2). Initiating an evaluation process, Brian seeks input from branch officers for each conceivable position (Table 2).

During a meeting with Anna and the branch officers to finalize position assignments, concerns are raised based on historical experiences. It is highlighted that conflicts among employees have arisen due to various factors, including personal traits, working styles, emotional considerations, and political beliefs (Table 3). In essence, constructing an agile team within a single office must prioritize performance and minimize the impact of employee conflicts. Anna instructs Brian to appoint the most qualified candidates to positions while actively avoiding potential conflicts.

Acknowledging the complexity of this task, Brian cautions that finding a satisfactory solution may require considerable time. Fortunately, Anna, drawing on her experience as an administrator, understands the intricacies involved and does not impose an unrealistic timeframe.

From the aforementioned scenario, Anna and Brian actually follow the initial steps of RBC, and Brian encounters a problem of GRA that forces the consideration of additional constraints. The final optimized assignment, avoiding conflicts, is shown in Table 2 (expressed by bold numbers), i.e., a tuple set as {<Ada, Quality Assurance>, <Briden, Manager>, <Christine, Coder>, <Eddi, Designer>, <Frederick, Coder>, <Gregory, Coder>, <Jones, Quality Assurance>, and <Laden, Designer>}. The total sum of the assigned evaluation values is 6.95. This scenario clearly demonstrates the significance of the proposed problem. It appears that Gregory's assignment may not be the best use of his talents. However, it can be supported if we consider overall team performance.

This scenario includes the following essential parts:

- *Where:* This is Company C.
- *Who:* The individuals are Anna and Brian.
- *When:* This is a period after a contract is signed.
- *What:* The goal is to efficiently allocate roles to teams for optimal performance and resource utilization.
- *How:* Conflicts may arise due to overlapping role assignments, and adjustments need to be made to enhance overall team performance.

Table 2. The candidates and evaluations on positions.

Candidates \ Positions	Manager	Designer	Coder	Quality Assurance
Ada	0.69	0.57	0.27	**0.87**
Briden	**0.83**	0.38	0.01	0.52
Christine	0.78	0.08	**0.82**	0.83
Douglas	0.66	0.05	0.14	0.47
Eddi	0.71	**0.86**	0.39	0.51
Fredrick	0.88	0.79	**0.87**	0.64
Gregory	0.55	0.03	**0.88**	0.93
Hart	0.36	0.06	0.64	0.87
Israel	0.33	0.45	0.31	0.73
Jones	0.09	0.50	0.60	**0.95**
Kite	0.74	0.78	0.58	0.79
Ladden	0.18	**0.87**	0.30	0.12
Matthew	0.01	0.34	0.38	0.83

Bold numbers indicate assignments.

Table 3. The conflicts.

Candidates \ Conflicts	1	2	3	4	5
Ada	Hart				
Briden	Ladden				
Christine	Hart	Israel	Jones	Ladden	
Douglas	Fredrick	Gregory	Israel	Ladden	Matthew
Eddi	Jones				
Fredrick	Douglas	Israel			
Gregory	Douglas				
Hart	Ada	Christine			
Israel	Christine	Douglas	Fredrick	Kite	
Jones	Christine	Fredrick			
Kite	Israel				
Ladden	Briden	Christine	Douglas	Matthew	
Matthew	Douglas	Ladden			

Note: For example, Ada conflicts with Hart, and Hart conflicts with Ada and Christine.

Through such a scenario description, researchers can set the stage for exploring the capabilities and limitations of their proposed models or methodologies. The narrative created should intrigue readers, making them eager to delve into the research process to uncover solutions to the challenges presented in these imaginative scenarios.

How to Model With E-CARGO

Many researchers initially find the E-CARGO model comprehensible but struggle when it comes to specific problem modeling. Here are some guidelines to navigate the modeling process effectively.

Understand the Physical (Social) Meaning of Agents and Roles in E-CARGO

In E-CARGO/RBC/GRA, it is essential to define the physical or social meanings of agents and roles. Even in industrial scenarios where human involvement might not be apparent, we need to adhere to E-CARGO's "agents-roles-objects" principles (Figure 3). In GRA [48] or GRA+ [16], [17], [29], [31], [32], [38], [39], [42], we assign "tasks (roles)" to "people (agents)." If necessary, we may first need to associate "tasks (roles)–things (objects)," i.e., role-object assignment. To be discussed in the next guideline, "people (agents)–things (objects)" considering the association between people and things (objects) is not required when the other two kinds of assignments have been accomplished. This situation is reasonable and acceptable in common sense, i.e., objects are attached to agents due to the role-playing of agents. E-CARGO agents and roles may express different things in different scenarios. For example, in GRA and GRA+, agents are people, and roles are tasks or positions; in cooling storage defrost [28], agents are the working state of coolers, and roles are time slots; in exam scheduling [49], courses are agents, but <room, time slot>s are roles; and in employee training [30], <employee, time slot>s and courses or employees and <course, time slot>s can be agents and roles, respectively.

Embrace the "People (Agents)–Tasks (Roles)–Things (Objects)" Principles

From the examples of exam scheduling [49] and employee training [30], we encounter difficulties if we insist on using "agents" to mean "people." To avoid confusion in modeling, we suggest keeping in mind E-CARGO's fundamental principles of connecting people (autonomous agents), things (objects), and tasks (roles). Even in cases where tasks can be performed by machines, we may consider those machines as "agents." If difficulties persist, we may need to combine autonomous agents with time or space or even formalize new abstract assignment problems directly. As discussed in the first section regarding conceptual diagrams, agent-object assignments or role-object assignments are also potential problems to investigate. For example, role-object assignment is required when we need to specify roles in the step of role negotiation. We can confirm that, after role-object and role-agent assignments are resolved, agent-object assignment is accomplished. That is, no more agent-object assignment is needed anymore. Note that in modern economics, there are quite a few arguments about the relationships between people and objects, i.e., benefit distribution, equitable distributions, and fair or envy-free assignments [2]. From the E-CARGO/RBC theory, such kinds of arguments can be diminished if agent-role and role-object associations are well addressed.

Dynamism and Time-Space Considerations

Many industrial problems involve dynamic aspects, causing researchers to feel overwhelmed. In fact, by introducing the concepts of time and space and iteratively using GRA+ for modeling, we can ease the problem-solving in these applications. For example, adaptive collaboration [7], [8], [25], [31], [35], [52] was proposed based on the dynamic property of RBC. GRA+ focuses on demand (roles) and supply (agents) matching. If additional factors come into play, such as scheduling issues, involving agents, roles, time slots, and room (space), we can follow our successful practices of assignments by combining two or more entities like <role, time>, <role, space>, or <role, space, time> to roles and <agent, time>, <agent, space>, or <agent, space, time> to agents. With this method, we may need to consider conflicts introduced by combinations among agents or roles. That is why many solutions to GRA+ problem cases are significant, i.e., these solutions can be applied to such dynamic situations. Refer to the literature [17] for a GRA+ method under partial order relations; GRA+ can help solve assignment problems under temporal order constraints.

Practical Solutions

To be published, any model of a problem should be finally resolved in an acceptable time. Otherwise, even though we formalize a problem, we may not be able to confirm our contributions unless the problem is a highly significant and challenging issue and valuable enough to be known by other researchers for solutions, such as classical conjectures like the Goldbach conjecture [6].

The common way to deal with this issue is to decrease complexity dimensions. For example, if we formalize an optimization problem with a nonlinear objective, we may need to use equivalent logic and linear transformations to make the objective linear [48], or we can introduce heuristics to make the objective linear. In [48], we first use a product formula in the objective, then, we use an equivalent transformation to avoid the complex objective.

In summary, the key to effective E-CARGO modeling lies in understanding the nuances of your specific problem, adhering to the "agents-roles-objects" principle, and utilizing GRA+ to address the challenges that may arise in the assignment process. By adopting these strategies, researchers can successfully model a wide range of industrial scenarios, contributing to innovative and impactful solutions.

How to Design Verification Experiments

In the realm of problem-solving articles, the experimental phase is an indispensable component. E-CARGO research, primarily focused on real-world issues, goes beyond the exploration of existing solutions. It serves as a tool not only for refining current approaches but also for validating the practicality, rationality, and correctness of the proposed solutions. We emphasize a few key considerations in experiment design as follows.

> We may design experiments that facilitate a comparative analysis with existing solutions or methodologies, e.g., GRA, or a specific GRA+.

Real-World Relevance

We should ensure that the scenarios closely mirror real-world problems addressed by E-CARGO/RBC research. An experiment simulates solving a problem, which has inputs, processes, and outputs. The assumptions should be consistent with common sense. For example, the "How to Compose Scenarios" section presents a scenario that makes sense in most collaboration activities, i.e., two conflicting people working together degrade their performance. In design experiments, assumed data should be created to follow common sense, including abilities, time, and space constraints. For example, a person may work 8 h a day [2], a UAV needs to recharge after a few hours [12], there are at most two 3-h exams in a day [49], conflicting people cannot work on the same role [37], and cooperative people should work on the same role [48].

Comparative Analysis

We may design experiments that facilitate a comparative analysis with existing solutions or methodologies, e.g., GRA, or a specific GRA+. This not only validates the novelty of the proposed approach but also provides insights into its comparative advantages. For example, we have GRA as the ideal assignment result, which collects the group performance $\sigma_1 = \Sigma_{i=0}^{m-1}\Sigma_{j=0}^{n-1}Q[i,j]\times T[i,j]$, where i and j are indexes of agents and roles, respectively; m and n are the number of agents and roles, respectively; Q is the qualification matrix; and T is the assignment result obtained by GRA. However, all GRA+ problems occur in nonideal situations by introducing different constraints. Now, we can propose a new GRA+ problem, which obtains the group performance $\sigma_2 = \Sigma_{i=0}^{m-1}\Sigma_{j=0}^{n-1}Q[i,j]\times T'[i,j]$, where T' is the assignment result obtained by GRA+.

Note that normally, $\sigma_1 \geq \sigma_2$. Nonetheless, GRA is ideal and not real. We need to assume a reasonable degradation of individual performance in each role due to the unaddressed constraint introduced by the GRA+ formulation. Therefore, we can obtain Q'; then, the actual group performance of GRA is $\sigma_3 = \Sigma_{i=0}^{m-1}\Sigma_{j=0}^{n-1}Q'[i,j]\times T[i,j]$, which is normally smaller than σ_2, which is an optimized result under the newly introduced constraint. Finally, we may use $(\sigma_2-\sigma_3)/\sigma_3$ to express the improvement of the new GRA+ formulation. For example, [37] uses this comparison to demonstrate the improvement of GRACAR compared with GRA. Note that the GRA+ formulations also inform different social meanings related to teams, such as team performance σ discussed previously, role performance σ_r,and agent performance σ_a. Proposed new formulations can also be verified by comparing the newly obtained role or agent performance, i.e., σ'_r or σ'_a. with σ_r or σ_a.

Scalability or Performance Testing

We need to explore the scalability of the E-CARGO solutions to ensure their effectiveness across varying scales and complexities. This is critical for applications in dynamic and evolving environments. For example, to manage a midsized team, 200 agents are required. Ref. [37] used this scale to demonstrate the practicability of GRACAR. The experiments need to obtain solutions in a reasonable time for such a scale. If the problem scale is larger, we need to test if a solution can be acquired within an acceptable time. Note that we have many open source codes on GitHub (https://github.com/haibinnipissing/E-CARGO-Codes), which can be utilized for experiments and comparative analysis.

In the landscape of E-CARGO research, the design and execution of experiments play a pivotal role in advancing solutions to real-world challenges. By aligning experiments with practical scenarios, validating proposed solutions, and fostering collaboration, researchers can harness the full potential of E-CARGO in addressing complex issues and contributing meaningfully to the field.

Conclusion

E-CARGO/RBC serves as a robust research tool for engineers and researchers, especially in the scope of the IEEE Systems, Man, and Cybernetics Society, offering an innovative and significant platform for the exploration of interdisciplinary research. Research based on this tool has the potential to uncover numerous fascinating social and physical phenomena, providing a source of both enjoyment and intellectual stimulation. Early-stage researchers have already laid the groundwork for this initiative, releasing a lot of Java and Python code on GitHub, which is readily available for experimentation, comparison, and enhancement purposes.

We hope that this guide can help facilitate the swift generation of new research outcomes. The existing foundational work, coupled with ongoing contributions from the research community, positions E-CARGO/RBC as an evolving and dynamic tool. Researchers are encouraged to build upon this framework, fostering an environment of continual improvement and innovation.

This collaborative effort not only enhances the understanding of complex systems but also opens avenues for interdisciplinary exploration. By harnessing the power of E-CARGO/RBC, researchers can navigate through intricate landscapes, unraveling the intricacies of various domains. The potential for groundbreaking discoveries and the joy of exploration make E-CARGO/RBC a compelling choice for researchers to contribute significantly to their respective fields.

In conclusion, this article aims to inspire and guide researchers, providing a road map for utilizing E-CARGO/RBC effectively. As more researchers engage in this collaborative journey, the collective efforts are poised to yield impactful and transformative research outcomes.

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