

MODELING COOPERATION AMONG BUILDING COMPANIES VIA AXELROD ITERATED PRISONER'S DILEMMA TOURNAMENTS FOR ACHIEVING SUSTAINABLE LONG-TERM PERFORMANCE

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Анотація

Запропоновано використання турнірів Аксельрода на основі повторюваної дилеми в'язня як імітаційного середовища для аналізу кооперативної поведінки будівельних компаній. Метою є виявлення стратегічних закономірностей, які забезпечують довгострокову економічну ефективність і стабільні партнерські відносини під час реалізації серії будівельних проєктів. Результати імітаційних експериментів свідчать, що стратегії, засновані на взаємності, у довгострокових взаємодіях зазвичай перевершують суто егоїстичні стратегії. Будівельним компаніям доцільно укладати угоди про співпрацю, які стимулюють кооперацію, одночасно зберігаючи механізми підзвітності та реагування на опортуністичну поведінку.

Ключові слова: будівельна компанія, кооперативна поведінка, турніри Аксельрода, партнерство.

Abstract

The use of Axelrod Iterated Prisoner's Dilemma tournaments as a simulation framework for analyzing cooperative behavior among building companies is proposed. The objective is to identify strategic patterns that support long-term economic performance and stable partnerships for multiple projects. Simulation experiments indicate that strategies based on reciprocity generally outperform purely selfish strategies in long-term interactions. Building companies should establish collaboration agreements that encourage cooperation while preserving mechanisms for accountability and response to opportunistic behavior.

Keywords: building company, cooperative behavior, Axelrod tournaments, partnership.

Introduction

The construction industry is characterized by complex interactions among multiple stakeholders, including construction contractors, material suppliers, transportation providers, equipment owners, and subcontractors. Although each company aims to maximize its own profit, many construction projects require various forms of cooperation such as resource sharing, logistics support, coordinated scheduling, and information exchange. Such cooperation may improve project efficiency and reduce costs. However, individual firms often face incentives to prioritize their own interests at the expense of partners [1, 2].

This conflict between collective and individual interests can be represented as a socio-economic dilemma [3, 4]. While cooperation (alternatively referred to as compliance) may generate greater long-term benefits for all participating companies, unilateral defection (alternatively referred to as defiance) may provide higher immediate gains for a particular firm [5, 6]. Consequently, understanding the conditions under which cooperation emerges and remains stable is an important problem for sustainable construction management.

This study proposes the use of Axelrod Iterated Prisoner's Dilemma tournaments [7, 8] as a simulation framework for analyzing cooperative behavior among building companies. The objective is to identify strategic patterns that support long-term economic performance and stable partnerships in multi-project construction environments, including healthy recycling [1, 2, 9, 10].

Methods

The proposed model represents each participating company as an autonomous agent employing a predefined behavioral strategy [7, 11, 12]. Agents interact repeatedly during a sequence of construction projects. In every interaction, a company chooses either to cooperate or to defect with respect to a partner company. Cooperative actions may include sharing transportation resources, lending construction equipment, exchanging technical information, coordinating deliveries, or temporarily allocating excess materials to project part-

ners. Defective actions generally correspond to withholding resources, refusing assistance, exploiting shared information for unilateral gain, or pursuing purely self-interested decisions [4, 6, 13, 14].

An illustrative scenario consists of two cement manufacturers and three construction contractors participating in several consecutive projects. The manufacturers possess production capacities and distribution capabilities, whereas the contractors differ in machinery availability, workforce productivity, and logistics efficiency. Cooperation between these firms may plausibly reduce project delays and operational expenses, while defection may provide temporary advantages to individual participants.

To investigate the effects of strategic behavior, a tournament environment inspired by Axelrod framework [7] is employed. Various strategies are introduced, including unconditional cooperation, unconditional defection, reciprocal cooperation, retaliatory behavior, and forgiveness-oriented strategies. During the tournament, each strategy interacts repeatedly with all other strategies. The accumulated economic outcomes are interpreted as indicators of long-term business performance.

Formally, given a set of N admissible strategies $\{s_i\}_{i=1}^N$ for every agent and a period T of the virtual Axelrod tournament, the goal is to run each of those strategies through the tournament, denoted by A , and determine a strategy $s^* \in \{s_i\}_{i=1}^N$ such that maximizes the expected performance for every agent. So, tournament A factually returns the most efficient strategy

$$s^* = A(\{s_i\}_{i=1}^N, T, \mathbf{P}; K, M) \text{ by } s^* \in \{s_i\}_{i=1}^N, \quad (1)$$

where $\mathbf{P}$ is a payoff matrix, K and M are the numbers of turns and repetitions, respectively, serving for tournament statistically stable results. Strategy (1) can be used during period T in real interactions among building companies, but not necessarily that exact period. This approach is a simple yet very effective in simultaneously analyzing three dimensions:

1. Individual profitability of participating companies.
2. Collective profitability of the construction network.
3. Stability of cooperation over multiple projects.

In fact, the Axelrod tournament results are used to identify behavioral patterns associated with sustainable economic outcomes. And strategy (1) may outperform some other strategies just for little. Then a subset

$$S^* = A(\{s_i\}_{i=1}^N, T, \mathbf{P}; K, M) \text{ by } S^* \subset \{s_i\}_{i=1}^N \quad (2)$$

is determined, where each element of subset (2) is an efficient strategy s^* applicable to the cooperation meta-strategy for the building companies.

Results

Simulation experiments indicate that strategies based on reciprocity generally outperform purely selfish strategies in long-term interactions. While persistent defection may generate short-term benefits (Fig. 1), its effectiveness decreases when interactions are repeated and reputation effects accumulate (Fig. 2). Reciprocal strategies successfully discourage opportunistic behavior while preserving opportunities for mutually beneficial cooperation [15, 16]. In environments involving multiple projects and repeated partnerships, these strategies tend to produce higher cumulative profits than unconditional defection, but this also depends on the period of real interactions, not the virtual interaction period in formulae (1) and (2).

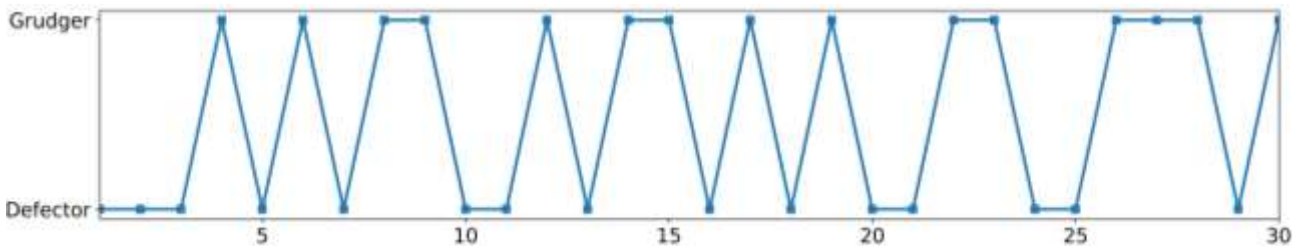


Fig. 1. A tournament result, where two strategies appear to be both efficient throughout a month of interactions (these two strategies, namely Grudger and Defector, can be applied with either equal probabilities or by the exact sequence, but not longer than a few months)

The results further suggest that moderate levels of cooperation can improve the overall performance of the construction network. Companies possessing complementary resources, such as transportation assets,

machinery, or material inventories, benefit from coordinated resource utilization. Such cooperation reduces idle capacity and improves project execution efficiency.

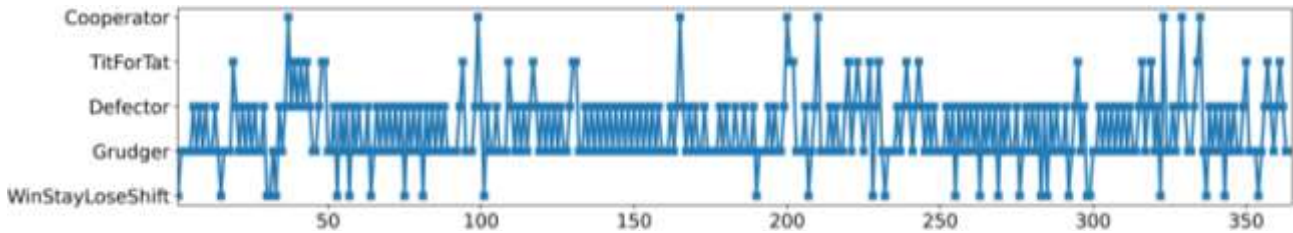


Fig. 2. A tournament result, where five strategies appear to be efficient throughout a year of interactions, but Grudger and Defector significantly dominate; here, their respective relative frequencies are 0.46 and 0.37, which are re-normalized to 0.55 and 0.45, respectively, whereupon Grudger and Defector are to be applied randomly at those probabilistic rates

The simulations also demonstrate that excessive vulnerability to exploitation may reduce the effectiveness of cooperative behavior (the example of such reduction is shown in Fig. 2, where direct cooperation is hardly survivable). Consequently, the most successful strategies are neither fully cooperative nor fully competitive; instead, they balance willingness to cooperate with the ability to respond to non-cooperative actions [3, 17].

Discussion

The findings support the view that long-term sustainability in construction networks depends on strategic reciprocity rather than unconditional cooperation. Repeated interactions create incentives for firms to maintain trustworthy relationships because future opportunities may outweigh immediate gains from opportunistic conduct [18, 19].

The Axelrod tournament framework provides a useful decision-support tool for evaluating partnership policies among construction companies. Managers may use such models to examine the consequences of different cooperation mechanisms before implementing them in practice.

From a practical perspective, the model, formalized by (1) and (2), suggests that construction firms should establish collaboration agreements that encourage cooperation while preserving mechanisms for accountability and response to opportunistic behavior. Such arrangements may include transparent performance monitoring, contractual incentives, and information-sharing protocols, which are not directly modeled by Iterated Prisoner's Dilemma tournaments. Moreover, the tournament results heavily depend on the choice of its parameters, like number of turns K and number of repetitions M in (1) and (2). Furthermore, setting payoff matrix $\mathbf{P}$ therein is fundamental. This is a nontrivial task, which is commonly solved in an iterative, trial-and-update manner.

Future research may extend the proposed framework by incorporating heterogeneous project sizes, stochastic market conditions, evolving strategies, coalition formation, and dynamic partner selection mechanisms. These extensions would increase the realism of the model and enhance its applicability to real-world construction ecosystems.

Conclusions

Axelrod Iterated Prisoner's Dilemma tournaments provide an effective conceptual framework for studying cooperation among building companies involved in repeated construction projects. The results indicate that reciprocal cooperative strategies can generate superior long-term economic performance compared with purely self-interested behavior. Short-term performance rationalization is possible as well, but it is practically implausible because construction projects are rarely accomplished in a few months. The study demonstrates that sustainable cooperation emerges when companies can benefit from repeated interactions, reputation effects, and complementary resource utilization. Consequently, strategic cooperation may become a significant factor in improving both individual profitability and overall efficiency within construction industry networks.

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