Incorporating Game Theory in the Life Cycle Optimisation of Decentralized Supply Chains

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Abstract

Nowadays, supply chain optimisation is vital to the success of industrial concerns more than ever. Despite various research advances in supply chain optimisation, there are a number of research challenges. These include, but are not limited to, multiobjective challenges and multi-player challenges (Garcia and You, 2015). A very active research topic within the context of multiobjective supply chain design is sustainable supply chain design using the life cycle optimisation approach, which integrates life-cycle assessment (LCA) with supply chain optimisation to demonstrate the trade-off between economic and environmental performances (Yue et al., 2013, Gao and You, 2015). Meanwhile, most of the existing work still view the supply chain from a centralized perspective and integrate the various components of the supply chain into a monolithic model. The decision-maker is assumed to have full control of the entire system so that all the decisions can be implemented successfully. However, in practice the management of a supply chain is normally decentralized. Consequently, the optimal strategy obtained from a cooperative model can be practically unachievable (Von Stackelberg, 2010). Therefore, there is growing interest to investigate competition among the supply chain players and its impact on supply chain optimisation. Theories such as the leader-follower game can be employed to model such scenarios (Yue and You, 2014). The goal of this work is to propose such a modeling framework that can address the trade-off of multiple objectives within a non-cooperative supply chain.

In this work, we propose a leader-follower game-based life cycle optimisation framework, which incorporates the idea of leader-follower game theory and that of life cycle optimisation. A standard leader-follower game involves two players: a leader and a follower. The leader is recognized to have certain advantages enabling it to take actions first (e.g., the priority of customers in a buyer’s market), and then the followers reacts to the leader’s decisions rationally. With full knowledge of this supply chain, the leader senses more responsibility and cares about both its own profit and the overall environmental performance of this supply chain. Correspondingly, due to limited information about the
whole picture of supply chain, the follower only cares about its own profit. Both leader’s
decisions and follower’s involve design and operational decisions. The resulting problem is
formulated as a multiobjective bilevel MILP problem. In the first-stage problem (also known
as the leader’s problem), there are two objectives minimizing the leader’s total cost and the
overall GHG emission of this supply chain, respectively. In the second-stage problem (i.e.,
the follower’s problem), the objective is to maximize the follower’s profit. This problem is
extremely challenging to solve using off-the-shelf general-purpose solvers. Therefore, we
present a novel algorithm that can significantly improve the computational efficiency. A
general supply chain case study is considered to demonstrate the proposed modeling
framework and solution algorithm. In this case study, the distributors of final products are
considered as the leader in this supply chain, who will make design and operational
decisions ahead of the follower to optimize not only its total cost, but the overall GHG
emission as well. The suppliers and manufacturers are considered as the follower, who
makes decisions based on the leader’s move and solely cares about maximizing its own
profit. According to the optimisation results, the lowest cost achievable for the leader is
$4.7 billion. Correspondingly, the follower’s profit is $1.3 billion, and the overall GHG
emission is 24 million tons CO2-eq. On the contrary, the highest cost for the leader is $6.1
billion, with $1.5 billion profit for the follower. The corresponding GHG emission is 8 million
tons CO2-eq.