Chaos, Solitons and Fractals 116 (2018) 95–105

Contents lists available at ScienceDirect

Chaos, Solitons and Fractals

Nonlinear Science, and Nonequilibrium and Complex Phenomena

journal homepage: www.elsevier.com/locate/chaos

# Longitudinal cooperative robust optimization model for sustainable supply chain management

Maozhu Jin[a], Lijun Song[b], Yanan Wang[a], Yucheng Zeng[a,*]

[a] Business School, Sichuan University, Chengdu, 610065, China
[b] College of Communication Engineering, Chengdu University of Information Technology, Chengdu, China

ARTICLE INFO

*Article history:*
Received 28 August 2018
Revised 8 September 2018
Accepted 8 September 2018

*Keywords:*
Robust optimization
Two-layer multi-slave programming
Vertical cooperation
Sustainable supply chain management
Low-carbon environment

ABSTRACT

This paper considers the trade-offs of two-tier supply chain enterprises in an uncertain environment, and can be formulated into a two-tiered multi-programming formula. The model we proposed considers green building alternatives' cost, duration and carbon emissions uncertainties simultaneously, making it more realistic comparing to models in previous literature. In this model, the interval number and expected value based on *Me* are adopted to handle the uncertain coefficients contained in the objective function and constraints, then a stochastic-based robust optimization method is developed to get a solution that can resist the uncertain environment. To solve the complex and non-linear bi-level multi-follower model, an interactive fuzzy programming technique combined an effective multi-objective algorithm, NSGA-II, is designed as the solution method. Finally, an applicant for a contractor of Urban Construction Group and its sub-contractors is given as an illustration that demonstrates the practicality and efficiency of the proposed model. The sensitivity analysis towards the change of important parameters is also provided.



## 1. Introduction

In the low-carbon environment, governments and enterprises are actively exploring solutions to reduce greenhouse gas emissions. There are 12 countries and regions in the world that require their companies to implement a carbon labeling system. More than 1, 000 well-known companies will “low carbon”. As a necessity in its supply chain, Wal-Mart, IBM, IKEA, etc. have required their suppliers to provide carbon labels. Low-carbon product certification can mobilize consumers to promote energy conservation and emission reduction. Through low-carbon product certification, the company's products are labeled with low-carbon products, consumers will be able to choose to buy, so as to promote the company's innovation in emission reduction technology, and strive to develop low-carbon products. The low-carbon product certification system also has a great impact on the upstream and downstream of the industrial chain of many industries. In the process of producing products, enterprises will propose corresponding emission reduction requirements for their upstream and downstream enterprises. Environmental issues are seen as an integral part of sustainability. Existing research indicates a complex relationship between economic and environmental outcomes of organizations [13]: There are enough studies to show that not all goals can be met, and often, further environmental actions require significant investment [3]. In recent years, some literature has proposed a trade-off between environmental and economic performance [7–9]. Therefore, it is of great practical significance to explore the cooperative emission reduction between upstream and downstream enterprises in the supply chain from the perspective of operation and management in a low-carbon environment.

## 2. Literature review

With the increasing competition in the global market, supply chain management has been highly valued by more and more companies. Some literature studies the impact of supply chain network design on its supply chain carbon emissions. Elhedhli and Merrick [5] introduced carbon emission constraints into supply chain network design, and built an overall cost minimization model with Lagrangian relaxation. The algorithm obtains the overall supply chain solution that meets the carbon emission constraints and has the lowest cost, and reduces the carbon emissions of the supply chain as a whole by rationally designing the vehicle scheduling in the supply chain network. Benjaafar et al.2012)explored joint emission reductions among firms within the same supply chain by establishing a cost minimization model under different carbon emission limitation policies (carbon tax, carbon neutrality and carbon capping and trading). The impact

* Corresponding author.
*E-mail address:* zengyucheng@scu.edu.cn (Y. Zeng).

https://doi.org/10.1016/j.chaos.2018.09.008
0960-0779/

of operating costs and carbon emissions, and proposed strategies to encourage upstream and downstream companies in the supply chain to seek cooperative emissions reduction. Jaber et al. [11] studied the joint emission reduction problem between manufacturers and retailers in a two-stage supply chain, by optimizing the manufacturer's product productivity and the coordination factor between manufacturers and retailers to achieve both inventory costs and emissions reductions. Minimize costs. However, this kind of literature does not consider the issue of cooperative emission reduction between upstream and downstream enterprises in the supply chain from the perspective of the game. Du et al. [4] further examined this supply chain that relies on carbon emission rights, and adopted the government's carbon emission limit as a variable parameter, introducing fairness preferences and total social welfare. By analyzing the Stackelberg game process of both sides of the supply chain, The impact of the government's carbon emission restriction policy on the operation of emission rights suppliers and emission rights demanders. However, this kind of literature does not consider the impact of emission reduction on product demand, nor does it involve the issue of upstream and downstream cooperation reduction in the supply chain under the dynamic framework.

The reminder structure of the paper is as follows: Section 2 presents a literature review of the vertical cooperation in the green building supply chain and related trade-offs. Section 3 describes the key issues between contractors and their subcontractors in a two-tier supply chain and identifies uncertain environments.Section 4 proposes a bi-level multi-follower programming model. Section 5 gives the techniques for handling uncertain coefficients of objectives and put forward to the robust mathematical model for the problem. Section 6 is devoted to the solution of the robust mathematical model and an interactive fuzzy programming combined with NSGA-II is applied. Section 7 presents the application of the method from a real case of the Urban Construction Group. The sensitive analysis is also included to demonstrate the effectiveness of the robust mathematical model. Section 8 contains the conclusion and the suggestion of future research directions.

## 3. Problem description

In this section, the relationship between the green contractor in the upstream and downstream of the supply chain and its multiple subcontractors is defined.The contractor needs the sub-contractors to be responsible for some parts of a green building project which should reach the corresponding low carbon standard. In order to achieve the carbon emission reduction target, the contractor will get some subsidies from external organizations (such as developer, authorities or industry foundation). Considering the economic and environmental performance, the contractor wants a scenario costing less but with a relatively low carbon emissions and good quality when the green building technologies are used. Meanwhile, the duration of the constructed projects also need to be short. Therefore, the contractor should design some incentive measures to induce the sub-contractors to meet his/her requirements. The implementation of the specific method is as follows: (1) the contractor set the limit value of the cost, duration and carbon emissions for every sub-contractor $i$; (2) If the cost of sub-contractor $i$ is less than the limit value of the cost, the sub-contractor will get reward provided by contractor; (3) Similarly, the rewards of duration and carbon emissions are similar to that of cost. Besides, the contractor will set the upper limit of carbon emission for each sub-contractor $i$ to ensure the overall project's carbon emissions reduction target scheme. Above all, the contractor's decision variables are the incentive intensities towards cost, duration and carbon emissions, and the goal of him/her is minimal the total cost of the contracted projects. To come up with a construction alternative with which the contractor is satisfied, the sub-contractors will put forward several alternatives and select appropriate ones to implement which can make the maximal income for them. It's worth noting that reducing duration will generate extra cost while bringing sub-contractors incomes from other projects (using the reduced duration to other project), so the sub-contractors also need decide a crash time.

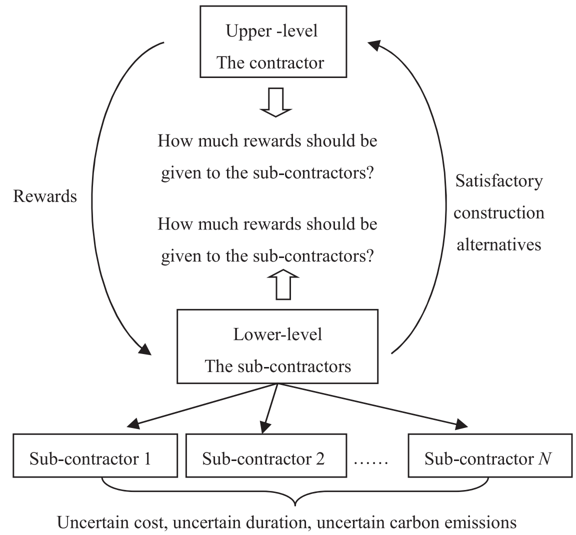


**Fig. 1.** Benefit trade-off problem between a contractor and multiple sub-contractors.

Considering the relationship between the contractor and his/her subcontractors, we can find that the contractor has the 'higher authority', while the sub-contractors are the "subordinate" which follows the contractors. That is, the relationship between the contractor and the sub-contractors considered in this paper can be regarded as hierarchical, the contractor make a decision first as a leader and the sub-contractors make the decision accordingly as the followers. The decisions they make effect each other's destination. This relationship is shown in detail in Fig. 1. Influenced by a variety of reasons, the duration of construction projects, especially large ones, cannot always be controlled. In addition, the green technologies have not been widely adopted, especially in the developing countries, so most construction companies are unfamiliar with them, leading to the precise green building duration is unknown before construction. Because total cost is closely related to the duration, and, the cost of green materials is also can't predicted accurately, so the costs are also uncertain parameters. Though the problem towards carbon emissions of the building process has been researched by many scholars from different angles, it is still difficult for project managers to evaluate the carbon emissions of a given project. In conclusion, the duration, cost and carbon emission are regarded as uncertain parameters.

## 4. Bi-level multi-follower programming model

In this section, a bi-level multi-follower programming model for the benefit trade off problem between the contractor and subcontractors is constructed. The description of the problem is given as follows.

### 4.1. Assumptions

(1) The contractor and sub-contractors are determined.

(2) The income of the sub-contractors consists of fixed income and rewards.