Simulations and Analyses of Packaging Recycling Based on System Dynamics

Lin Zhao [a], Qiaolun Gu [b]

School of Economics and Management, Tianjin University of Technology and Education, Tianjin 300222, China.

[a]18722220951@163.com, [b]tjguqiaolun@sohu.com

Abstract

In view of the problems of insufficient collection and low collection efficiency in traditional packaging recycling channels, this study constructs a system dynamic model of dual-channel packaging recycling by system dynamics methodology, and simulates Scenario 1(the traditional packaging recycling channel without intelligent collecting machines) and Scenario 2(the recycling channel with intelligent collecting machines). The simulation results indicate that Scenario 2 can achieve more collecting revenues and environmental benefits than Scenario 1. Although the collection cost is higher than that of Scenario 1, by increasing the collection frequency or reducing the purchasing unit price of the intelligent collecting machine, the net profits of Scenario 2 can be increased, and the incineration rate of packaging waste be greatly reduced compared to that of Scenario 1.

Keywords

Simulations and analyses, Packaging recycling, System dynamics.

1. Introduction

Along with the rapid development of the logistics industry and the packaging industry, the use of packaging is growing rapidly. If packaging waste cannot be recycled reasonably and efficiently, it will result in waste of resources and environmental pollution. According to statistics, only 5% of college students in colleges and universities will recycle express packaging, and 85% of college students will discard express packaging [1]. It can be seen that a large number of express packaging is not fully recycled. The National Development and Reform Commission issued the “2015 Circular Economy Promotion Plan” to promote and guide the innovation of recycling models, explore the mode and path of “Internet + recycling”, and actively support the development of new collecting methods such as intelligent collecting and automatic collecting machines. Linking the entire life cycle of packaging (production, transportation, consumption, disposal, recycling, and reuse) through the Internet of Things helps to form a complete packaging chain and supply chain from “cradle” to “cradle”. At this stage, packaging collecting mainly focuses on scattered waste collecting vendors and garbage collection channels, so only valuable packaging materials are collected and few intelligent collecting machines are used. However, Beijing INCOM Group has explored new channels in the field of intelligent packaging recycling. The company independently developed and mass-produced the first Internet reverse vending machine in China, and built an intelligent management platform which can be the source of recycling and controllable during the whole process. This channel can also be used to collect packaging waste by using Internet of Things, which is beneficial to shortening the collecting delay, reducing uncertainty and improving collecting efficiency. Based on this, this study constructs a two-channel packaging recycling system dynamics model, and discusses the related issues involved in

Scenario 1 (the traditional packaging recycling channel) and Scenario 2 (recycling channel through the intelligent collecting machine) to provide suggestions for collectors .

2. Literature Review

The existing research involves research on packaging recycling policies, recycling channels, recycling models, environmental awareness, and social values. Zhang Hui introduced the producer responsibility extension system, which made the government and producers stand together to realize the responsibility of producers, and established a system dynamics model of the package sharing collecting system, but only considered that the collecting behavior was affected by the collecting price[2]. Ren Wenjun applied the system dynamics method to establish a packaging waste recycling model in which social welfare is considered. The results show that when the government intervenes, the implementation of reasonable taxation and subsidy strategies can achieve optimal production, collecting and social welfare[3]. Zhou Yarong constructed a system dynamics model for campus express packaging collecting. Research shows that school participation and environmental awareness of college students are conducive to the collecting of campus express packaging.In order to solve the problem of imperfect recycling channels[1]. Jin Daxin used game theory to construct a cost-benefit model for industrial packaging products recycling[4]. He Tingting pointed out that the development of smart logistics has made it possible to optimize the packaging waste model. Smart Logistics can strengthen the classification and collection function of recycling mode, strengthen the collecting of household waste, improve the recovery rate of raw materials, and prevent waste of resources caused by low-level operation[5]. Tong Hefeng and Yang Yan studied the informal employment problem in the recycling process based on system dynamics. They believed that the government should gradually replace or rectify irregular garbage collection and improve the working conditions of garbage collectors[6]. Elina Dacea et al. established a system dynamics model with the impact of packaging tax in the packaging waste management structure and packaging ecological design. Research shows that packaging tax can reduce the total consumption of raw materials and the generation of subsequent waste[7]. Benjamin F. Hobbs et al., using the low-income urban community in Baltimore, Maryland, as a case study, proposed a system dynamics approach to study interventions and social norms that affect waste disposal behavior in residential areas. Interventions include: providing information, increasing street dustbin, strengthening family rules and financial incentives, and promoting residents' collection awareness. The study found that providing information can reduce garbage dumping behavior, while strengthening family rules does not work[8]. Shidi Miao et al. constructed a competitive recycling and remanufacturing model with the closed-loop supply chain through a case study of Midea Corp. and Gree Corp, explored the impact of two recycling modes on total revenue of the supply chain and market share. The simulation results showed that the total revenue of the supply chain would benefit from the increasing coverage points by the third party and the increasing environmental awareness of certain regions[9].

3. Model

3.1 Conceptual Model and Basic Hypotheses

The conceptual model of dual-channel packaging recycling under our study is shown as Fig. 1.

Scenario 1 represents the traditional recycling channel. Consumers throw waste packaging into the trash can. Collecting vendors collect waste packaging from the trash can. The collector pays the collecting price to the collecting vendors for packaging waste, and then put the packaging product into the market after reused. In Scenario 1 collection costs, reused costs, reused revenues, environmental benefits and net profits will be generated in the reverse supply chain. Scenario 2 represents the recycling channel of intelligent collecting machines, when the packaging life is over, consumers will actively put the packaging into the intelligent collecting machine and receive rebates from intelligent collecting machines while the packaging product will continue to enter the market after reused. In scenario 2 collection costs (rebates and equipment investment), reused costs, collecting revenues, environmental benefits and net profits will be generated. However, some of the waste will be incinerated in both channels.

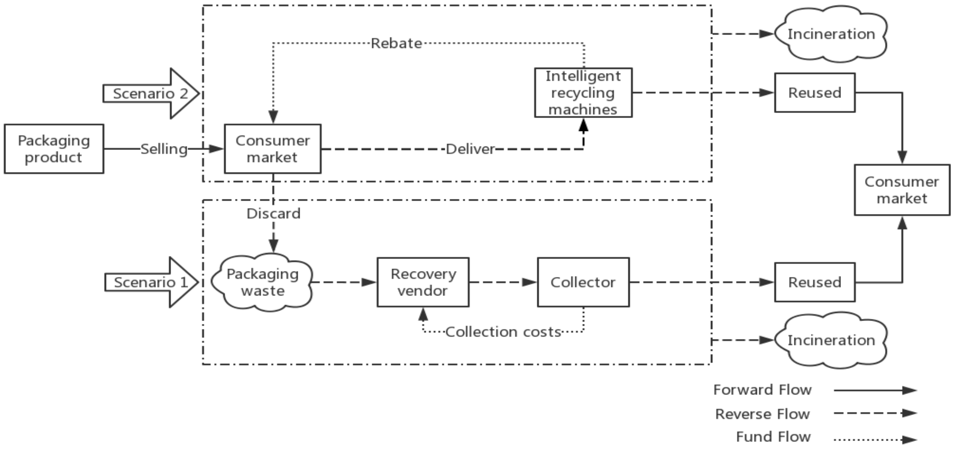

Fig. 1 Conceptual model of dual-channel packaging recycling

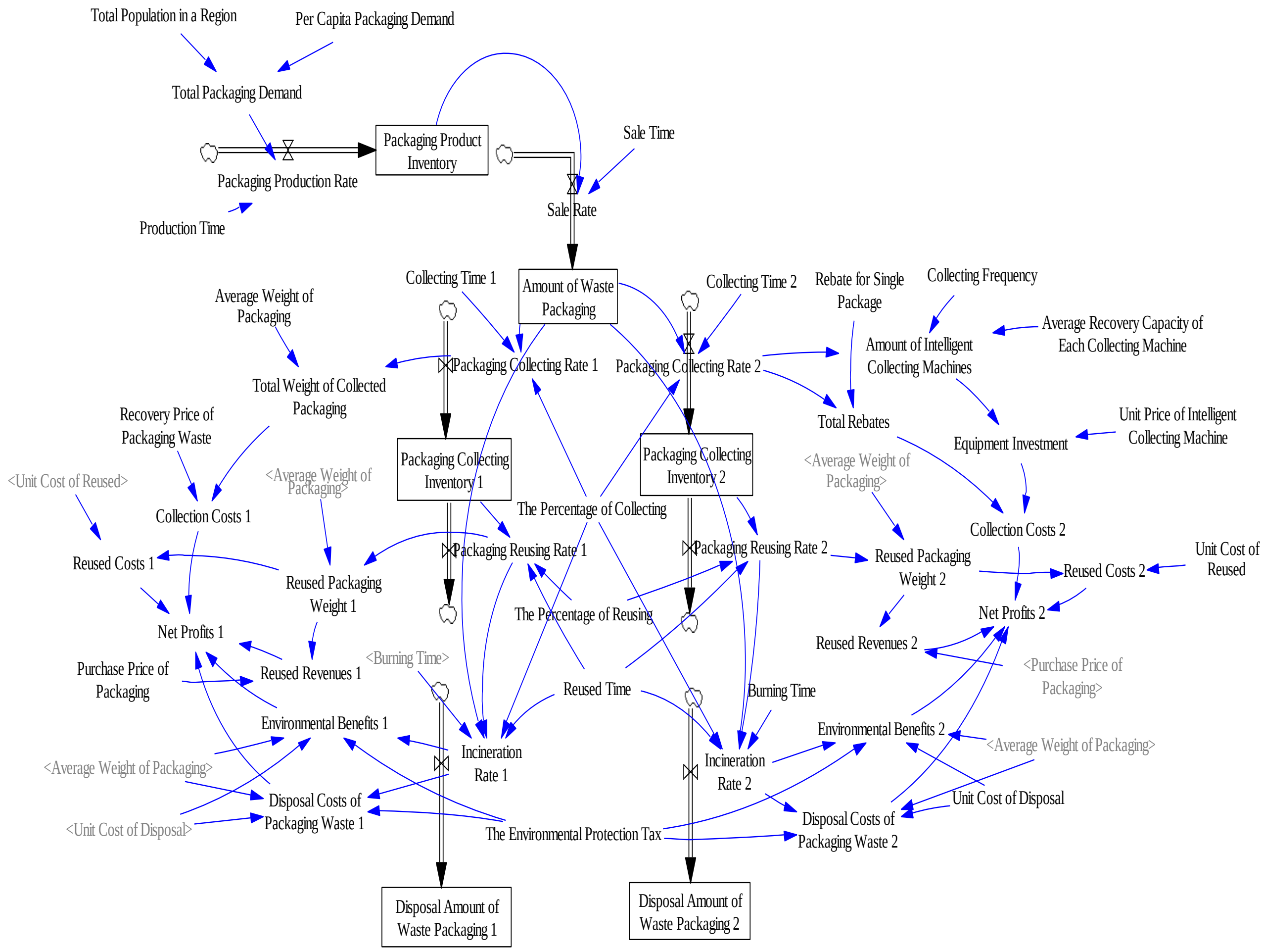

Fig. 2 Stock and flow diagram of the dual-channel packaging recycling system

This study is based on the following basic hypotheses.

(1) Consider the collecting of packaging waste (carton packaging) in a certain area, packaging reusing and waste disposal.

(2) The production capacity, collecting capacity, reusing capacity and waste disposal capacity of packaging are not limited, and the production rate of packaging can meet the demand of packaging.

(3) Consider the purchase cost of collecting equipment (the channel construction costs of intelligent collecting machines), collection costs, packaging waste disposal costs, collecting revenues, environmental benefits, net profits, while don't consider equipment depreciation, maintenance costs, management fee and transportation costs.

3.2 Stock-flow diagram

The system dynamics was created by Jay W. Forrester of the Massachusetts Institute of Technology in 1956. It is the science of analyzing and researching information feedback systems, and is a discipline that recognizes and solves system problems. Based on the system dynamics simulation software Vensim PLE, the system dynamics of the packaging recycling is constructed by the "DYNAMO" language (as shown in Fig. 2). The relationship between variables is represented by the Vensim equation. Scenario 1 represents the traditional recycling channel, and Scenario 2 represents intelligent collecting machine.

The following equations are attached to the above stock and flow diagram of the dual-channel packaging recycling to build the system dynamic model.

The key equations are shown below：

*Amount of Intelligent Collecting Machines=Packaging Collecting Rate 2/(Average Recovery Capacity of Each Collecting Machine*Collecting Frequency)*

Units: per unit/Day

Amount of Waste Packaging= INTEG (Sale Rate,0)

Units: piece

*Collection Costs 1=Recovery Price of Packaging Waste*Total Weight of Collected Packaging*

Units: yuan/Day

Collection Costs 2=Equipment Investment+Total Rebates

Units: yuan/Day

Disposal Amount of Waste Packaging 1= INTEG (Incineration Rate 1,0)

Units: piece

Disposal Amount of Waste Packaging 2= INTEG (Incineration Rate 2,0)

Units: piece

Disposal Costs of Packaging *Waste 1=IF THEN ELSE(Incineration Rate 1*Average Weight of Packaging*(Unit Cost of Disposal+The Environmental Protection Tax)>0, Incineration Rate 1*Average Weight of Packaging*(Unit Cost of Disposal+The Environmental Protection Tax) , 0)*

Units: yuan/Day

*Disposal Costs of Packaging Waste 2=IF THEN ELSE(Incineration Rate 2*Average Weight of Packaging*(Unit Cost of* Disposal+*The Environmental Protection Tax)>0 , Incineration Rate 2*Average Weight of Packaging*(Unit Cost of Disposal+The Environmental Protection Tax), 0)*

Units: yuan/Day

*Environmental Benefits 1=IF THEN ELSE(Incineration Rate 1*Average Weight of Packaging*(Unit* Cost *of Disposal+The Environmental Protection Tax)<=0, ABS(Incineration Rate 1*Average Weight of Packaging*(Unit Cost of Disposal+The Environmental Protection Tax)), 0)*

Units: yuan/Day

Environmental Benefits *2=IF THEN ELSE(Incineration Rate 2*Average Weight of Packaging*(Unit Cost of Disposal+The Environmental Protection Tax)<=0, ABS(Incineration Rate 2*Average Weight of Packaging*(Unit Cost of Disposal+The Environmental Protection Tax)) , 0)*

Units: yuan/Day

*Equipment Investment=Amount of Intelligent Collecting Machines*Unit Price of Intelligent Collecting Machine*

Units: yuan/Day

Incineration Rate 1=(Amount of Waste *Packaging*The Percentage of Collecting-Packaging Reusing Rate 1*Reused Time)/Burning Time*

Units: piece/Day

*Incineration Rate 2=(Amount of Waste Packaging*The Percentage of Collecting-Packaging Reusing Rate 2*Reused* Time*)/Burning Time*

Units: piece/Day

Net Profits 1=Reused Revenues *1-Collection Costs 1-Disposal Costs of Packaging Waste 1-Reused Costs 1+Environmental* Benefits *1*

Units: yuan/Day

Net Profits 2=Reused Revenues 2-Collection Costs 2-Disposal Costs of Packaging Waste 2-Reused Costs 2+Environmental Benefits 2

Units: yuan/Day

Packaging Collecting Inventory 1= INTEG (Packaging Collecting Rate 1-Packaging Reusing Rate 1,0)

Units: piece

Packaging Collecting Inventory 2= INTEG (Packaging Collecting Rate 2-Packaging Reusing Rate 2,0)

Units: piece

Packaging Collecting *Rate 1=Amount of Waste Packaging*The Percentage of Collecting/Collecting Time 1*

Units: piece/Day

*Packaging Collecting Rate 2=Amount of Waste Packaging*The Percentage of Collecting/Collecting Time 2*

Units: piece/Day

Packaging Product Inventory= *INTEG (Packaging Production Rate,0)*

Units: piece

Packaging Production Rate=Total Packaging Demand/Production Time

Units: piece/Day

*Packaging Reusing Rate 1=Packaging Collecting Inventory 1*The Percentage of Reusing/Reused Time*

Units: piece/Day

*Packaging Reusing Rate 2=Packaging Collecting Inventory 2*The Percentage of Reusing/Reused Time*

Units: piece/Day

Per Capita Packaging Demand=RANDOM NORMAL(1, 3 , 2 , 1 , 1)

Units: piece/per capita

Purchase Price of Packaging=RANDOM NORMAL(5000, 6000 , 5500, 200, 5000)

Units: yuan/ton

Recovery Price of Packaging Waste=RANDOM NORMAL(3000, 4000, 3500, 200 , 3000)

Units: yuan/ton

*Reused Costs 1=Reused Packaging Weight 1*Unit Cost of Reused*

Units: yuan/Day
*Reused Costs 2=Reused Packaging Weight 2*Unit Cost of Reused*
Units: yuan/Day
*Reused Packaging Weight 1=Packaging Reusing Rate 1*Average Weight of Packaging*
Units: ton/Day
*Reused Packaging Weight 2=Packaging Reusing Rate 2*Average Weight of Packaging*
Units: ton/Day
*Reused Revenues 1=Reused Packaging Weight 1*Purchase Price of Packaging*
Units: yuan/Day
*Reused Revenues 2=Reused Packaging Weight 2*Purchase Price of Packaging*
Units: yuan/Day
Sale Rate=Packaging Product Inventory/Sale Time
Units: piece/Day
*Total Packaging Demand=Per Capita Packaging Demand*Total Population in a Region*
Units: piece
*Total Rebates=Rebate for Single Package*Packaging Collecting Rate 2*
Units: yuan/Day
*Total Weight of Collected Packaging=Packaging Collecting Rate 1*Average Weight of Packaging*
Units: ton/Day

3.3 Setting the Major Parameters of the Model

The Simulation time length: initial time=0 days, final time=200 days, time step=1 day; the simulation cycle is 200 days, and a day is a step. In Scenario 1, vendors are responsible for recycling packaging, Collecting Time 1 is uncertain, therefore assume that Collecting Time 1 follows RANDOM NORMAL (1, 3, 2, 1, 1). In Scenario 2, recycling is through intelligent collecting equipments. Collecting Time 2 is fixed, therefore, the Collecting Time 2 is assumed to be 1 day. Production Time, Sale Time and Reused Time is assumed to be 3 days. In the literature [1], it is pointed out that the average packing weight is 0.3 KG per piece, therefore this study assume that the Average Weight of Packaging is 0.0003ton/piece. According to the literature, the rebate for single-piece packaging is set to 0.2yuan/piece. The other major parameter values involved in the stock and flow diagram are listed in table 1.

Table 1. Setting for parameter

Parameter	Value	Units
Production Time	3	Day
Sale Time	3	Day
Collecting Time 1	RANDOM NORMAL(1, 3, 2, 1,1)	Day
Collecting Time 2	1	Day
Reused Time	3	Day
Burning Time	1	Day
Rebate for Single Package	0.2	yuan/piece
Collecting Frequency	2	Dmnl
The Percentage of Collecting	0.5	Dmnl
The Percentage of Reusing	0.9	Dmnl
Average Weight of Packaging	0.0003	ton/piece

Average Recovery Capacity of Each Collecting Machine	1000	piece/per unit
Unit Price of Intelligent Collecting Machine	5000	yuan/per unit
Unit Cost of Reused	500	yuan/ton
Unit Cost of Disposal	1000	yuan/ton
The Environmental Protection Tax	1200	yuan/ton
Total Population in a Region	10000	per capita

4. Simulations and Analyses

Fig. 3((a),(b)) shows a comparison of waste packaging collecting rate and incineration rate betweent Scenario 1 and Scenario 2. In Scenario 2, the packaging collecting rate increases linearly due to the use of the intelligent collecting machine, and the collecting time and frequency are fixed. However, in Scenario 1, due to the uncertainty of the time of traditional collecting methods, the packaging collecting rate shows a trend of volatility growth. At the beginning of the simulation, the difference between collecting rates of the two scenarios is small while in the middle and late stages of the simulation time, the difference in packaging collecting rate is gradually growing. At the same time, in Scenario 2, when the simulation time is euqal to 200 days, the packaging collecting rate has a downward trend, while in Scenario 1, the collecting rate continues to grow. From the 30th day of simulation, the incineration rates of packaging waste in Scenario 1 and Scenario 2 began to decrease, and their difference became increasingly prominent. The downward trend of Scenario 2 was faster than Scenario 1, which indicated that Scenario 2 was more conducive to reducing the incineration of packaging waste, and thereby to reducing the disposal costs of packaging waste, saving resources and protecting the environment.

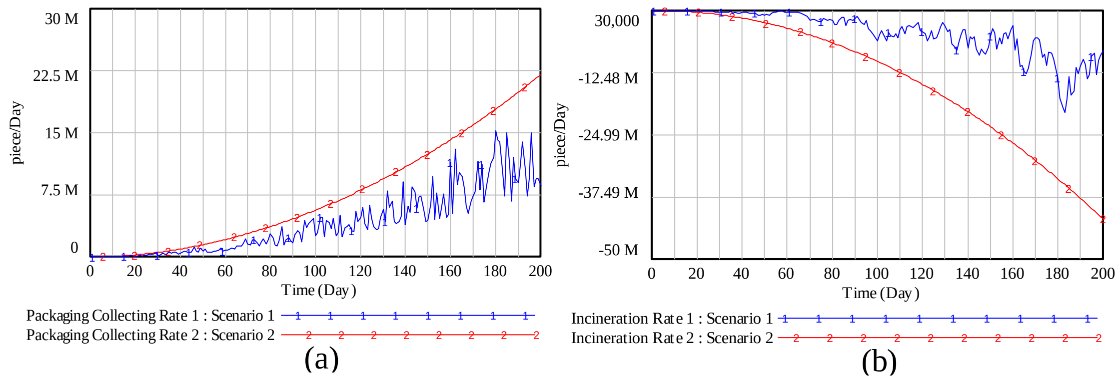

Fig. 3 Packaging collecting rate and incineration rate in Scenario 1 and Scenario 2

As can be seen from the analysis in Fig. 4((a),(b),(c),(d)), the collection costs in Scenario 2 shows a linear increase, while the collection costs of Scenario 1 remains at a lower level. This is because the unit price of the intelligent collecting machine is higher, and more equipment investment is required as the amount of packaging waste increases. However, from the perspective of income and environmental protection, the reused revenues and environmental benefits of Scenario 2 are much higher than Scenario 1 in the middle and late stages of the simulation, although the net profits of Scenario 2 has a negative growth due to excessive equipment investment. By increasing the frequency of collecting or lowering the unit price of the intelligent collecting machine, the net profits can be improved, which will continue to be discussed below.

Fig. 5 shows the effect of different collecting frequencies on net profits in Scenario 2 when the other conditions in Table 1 remain unchanged. In Scenario 2, when the collecting frequency of the intelligent collecting machine is 1 time and 2 times per day, the net profits show a downward trend, indicating that the collecting efficiency has not been fully utilized. When the collecting frequency is 3 times a day, the net profits of only a few days is higher than the net profits of Scenario 1. When the collecting frequency is 4 times a day, the net profits of Scenario 2 exceeds the net profits of Scenario 1. It shows that although the investment cost of the collecting machine is very high, the collector can increase the net profits by increasing the collecting frequency of the intelligent collecting machine.

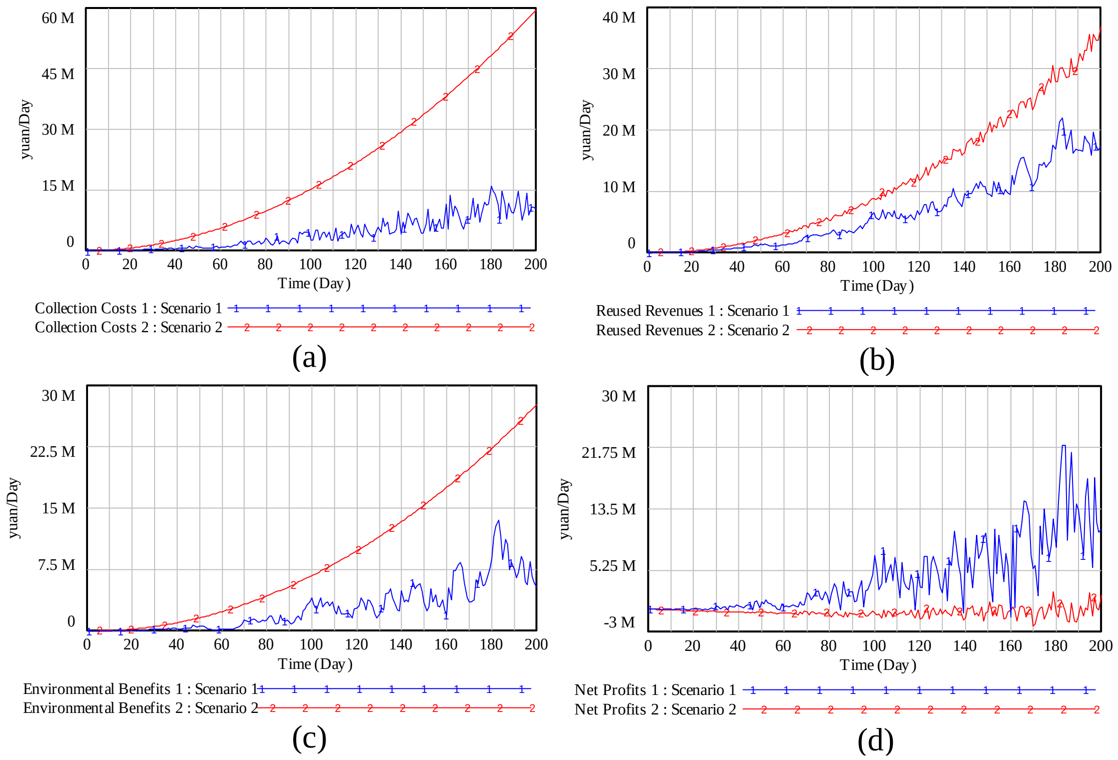

Fig. 4 Comparisons of collection costs, reused revenues, environmental benefits and net profits in Scenario 1 and Scenario 2

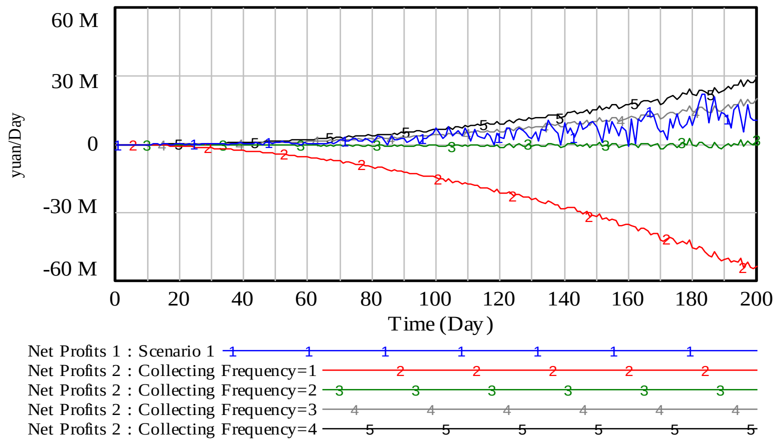

Fig. 5 Comparisons of the net profits of different collecting frequency of Scenario 2 and the net profits of Scenario 1

Fig. 6 shows the impact of unit prices of the intelligent collecting machine in Scenario 2 on net profits when the other conditions in Table 1 remain unchanged. When the unit price of the intelligent collecting machine is reduced, the net profits increase. When the unit price of the intelligent collecting machine is 3500 yuan/per unit, the net profit of Scenario 2 is already higher than that of Scenario 1 in most of the time. It shows that collectors can increase the net profits of packaging collecting by reducing the purchase price of the intelligent collecting machine.

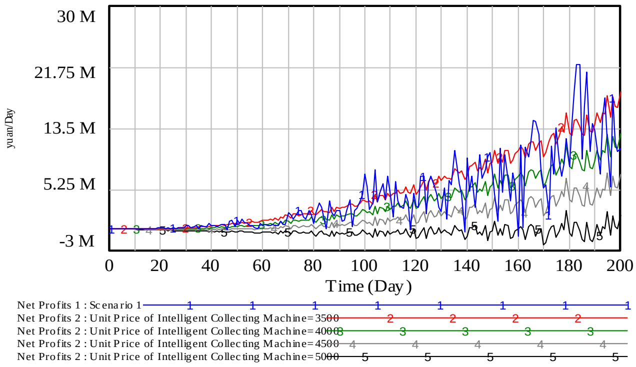

Fig. 6 Comparisons of the net profits between Scenario 2 and Scenario 1 as the unit price of the intelligent collecting machine changes

5. Conclusion

Based on the system dynamic model of dual-channel packaging recycling, the simulation results show that the collecting revenues and environmental benefits of Scenario 2 are higher than those of Scenario1, while the net profits of Scenario 2 are lower than those of Scenario 1. However, if the collector increases the collecting frequency or reduces the unit price of the intelligent collecting machine, the net profits of Scenario 2 can be improved.

Acknowledgements

This work was supported by Humanity and Social Science Planning Foundation of Ministry of Education of China [grant number:15YJA630018].

References

[1] Zhou Yarong. Research on Campus Express Package Recycling System Based on System Dynamics [J].China Logistics & Purchasing, 2017, (8):76-77.
[2] Zhang Hui. Packaging Recycling and Applied Research Based on Extended Producer Responsibility [D].(Ms, Qingdao University, China 2012)
[3] Ren Wenjun. Recycling of Packaging Waste based on Social Welfare [D]. (MS, Qingdao University, China 2013)
[4] Jin Daxin. Study on Recycling Cost and Channel Optimization of Industrial Packages [D]. (Ms, Chongqing University, China 2015)
[5] He Tingting, Xu Ying, Zhang Xuemei. Study on the Product Packaging Waste Recycling Pattern [J]. Logistics Engineering and Management,2015, 37(6):88-90.
[6] Tong Hefeng, Yang Yan. Employment of Municipal Solid Waste Sorting Collection in China Cities Based on System Dynamics Model [J]. Technology Intelligence Engineering, 2016, 2(5):104-111.
[7] Dace E, Bazbauers G, Berzina A, et al. System Dynamics Model for Analyzing Effects of Eco-design Policy on Packaging Waste Management System [J]. Resources Conservation & Recycling, 2014, 87(6):175-190.
[8] GUO H, HOBBS B F, LASATER M E, et al. System Dynamics-based Evaluation of Interventions to Promote Appropriate Waste Disposal Behaviors in Low-income Urban Areas: A Baltimore Case Study[J]. Waste Management, 2016, 56:547-560
[9] Miao S, Chen D, Wang T. System Dynamics Modelling of Remanufacturing and Recycling Mode Based on Closed-Loop Across-Chain Competition[J]. Discrete Dynamics in Nature and Society, 2017,(9):1-12.