Prediction of Railway Cargo Carrying Capacity in China Based on System Dynamics

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Abstract

Prediction of cargo carrying capacity provides a base for planning railway networks, decision-making about the operations of railway freight companies, and development of transport scheme. The application of system dynamics assists in the predication of railway cargo carrying capacity. Through the analysis of the key factors that influence cargo carrying capacity in the railway freight system, the boundary for railway cargo carrying capacity system is determined; the system cause-effect relationship containing six feedback loops is determined; the system flow and simulation formula is constructed; the model for the development of system dynamics-based railway cargo carrying capacity is constructed. With the statistical data about railway freight in China from 1900 to 2009, simulation tests are conducted to verify the effectiveness of the application of system dynamics model in the prediction of railway freight. The railway cargo carrying capacity is predicted from the time from 2011 to 2015. In 2015, it is predicted to reach 5.40486 billion tons. The error analyses indicate that the maximum error of system prediction is 2.66%.

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Key words: railway, system dynamics model, prediction of cargo carrying capacity

1. Introduction

Prediction of cargo carrying capacity provides a base for the planning railway networks, decision-making about the operations of railway freight companies, and development of transport scheme. Railway transport system is a complicated feedback system that is featured with multiple variables, high orders, multiple circuits and non-linear quality. J·W·Forrest founded system dynamics theory in 1950s at reputed as the lab for the social and economic complex and even frequently applied in the prediction of carrying

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capacity (Gottschalk, P., 1981; Luo, D., Wang, D.J., 2007; Wang, Y.P., et al., 2005; Sun, D.C. and Li, J.H., 2005; Xu, Y.J., 2007; Wang, W.Q., et al., 1993; He, S.W., et al., 2003). System dynamics puts the accent on the system’s internal mechanism and structure, and stresses the relationship between units and information feedbacks. It also depicts the non-linear logic functions and delay factors inside the system. Therefore, the article applies the system dynamics theory for prediction as specified in the system structure prediction methodology.

2. System Analysis of Railway Cargo Carrying Capacity in China

System dynamics model for the development of railway cargo carrying capacity takes into account the relationship between railway and national economy, the railway fixed assets and railway transport demands, which makes up an overall structure. The complicated relationship between various factors is quantitatively depicted. GDP, the gross value of macro economy, is the motive power for freight service demands. The growing economy will undoubtedly drive the demands for freight service. The model will research on the problems with railway transport system against the background of different policy parameters and structural conditions, with a focus on the prediction of carrying capacity. The purpose of modelling is to predict the railway freight, and to highlight the research purpose, the most related factors will be selected from various influential factors to make up a closed railway carrying capacity system in consistency with the research purpose. Through qualitative analysis, it is preliminarily determined that the model will take the gross domestic product and fixed railway assets as the horizontal variable. For the model, the constants include enterprise indirect tax, composite depreciation rate, savings rate, renovation fund rate, depreciation rate, and investment proportion. Unit GDP cargo turnover, railway proportion, unit one hundred million Yuan for railway cargo carrying capacity, and expected GDP growth rate is the table functions, and others as auxiliary or exogenous variable.

3. Causal Relationship Analysis For Railway Carrying Capacity System in China

Causal feedback loop can be used to clearly explain the qualitative relationship between elements within the system. Therefore, the determination of a causal feedback loop is the key to the researches on system dynamics. According to the relationship between system boundaries, a general feedback loop for system dynamics model that reflects the railway freight development, the causal relationship Fig., is given below (Fig. 1). The causal chain, with a positive sign or a negative sign, suggests the characteristics of the influential factors. The negative sign tells that the variable the arrow points at will increase with the increasing variables of the arrow source, or decrease with the decreasing variables. The negative sign suggests the contrary relationship between variables. From the Fig., we can see the system is divided into three positive feedback loops and three negative feedback loops.

![Fig. 1: Feedback relationship of railway carrying capacity system](image)
From Fig. 1, we know that the system includes six major causal feedback loops. Feedback loop 1 is: railway investments → fixed railway assets → actual carrying capacity → railway transport stock → GDP → national revenue → accumulation → railway investments. Feedback loop 2 is: railway investments → fixed railway assets → depreciation → railway investments. Feedback loop 3 is: railway investments → fixed railway assets → actual carrying capacity → railway transport stock → railway investments. Feedback loop 4 is: railway transport stock → GDP → industrial production → railway carrying capacity changing with the industrial production → railway carrying capacity → expected carrying capacity → railway transport stock. Feedback loop 5 is: railway transport stock → GDP → output value of the primary industry → railway cargo carrying capacity changing with the output of the primary industry → railway cargo carrying capacity → expected carrying capacity → railway transport stock. Feedback loop 6 is: railway transport stock → GDP → general demands for freight → railway cargo turnover → expected carrying capacity → railway transport stock. The first three are positive feedback loops, and the latter three are negative feedback loops.

4. System Flow For Railway Carrying Capacity in China and Simulation Formula

Causal relationship chart simply depicts the basics of the system structure. On the causal relationship chain, it just reflects the tendency for increase or decrease of variables. It is a qualitative analysis, to specify the quantitative relationship between variables and changing rules. It is expected to depict the cumulative effects of dynamic performances that influence the feedback system. Therefore, a flow chart structure is to be constructed to describe the relationship between status and velocity and to prepare for modeling and analyses. Based on the causal relationship chart and analyses of feedback mechanism. To objectively understand and quantitatively analyze the internal development mechanism for railway freight system, construct the flow chart for development model (see Fig. 2).

The model will take the gross domestic product and fixed railway assets as the horizontal variable. For the model, the constants include enterprise indirect tax, composite depreciation rate, savings rate, renovation fund rate, depreciation rate, and investment proportion. Unit GDP cargo turnover, railway proportion, unit one hundred million Yuan for railway cargo carrying capacity, and expected GDP growth rate is the table functions, and others as auxiliary or exogenous variable.
Formula for the model is given below:

(1) GDP = \text{INTEG (GDP added value, GPD initial value)}, \text{Units: one-hundred-million Yuan};

(2) National revenue = GDP* (1-enterprise indirect tax-composite depreciation rate), \text{Units: one-hundred-million Yuan};

(3) Gross accumulation = national revenues * savings rate, \text{Units: one-hundred-million Yuan};

(4) Railway investments = investment proportion * gross accumulation, \text{Units: one-hundred-million Yuan};

(5) New investments in fixed assets = \text{SMOOTH (railway investments, 10)}, \text{Units: one-hundred-million Yuan};

(6) New fixed assets = new investments in fixed assets + updating and renovation of newly added assets, \text{Units: one-hundred-million Yuan};

(7) Fixed railway assets = \text{INTEG (newly added fixed assets-depreciation, initial value of fixed railway assets)}, \text{Units: one-hundred-million Yuan};

(8) Depreciation = railway fixed assets*depreciation rate, \text{Units: one-hundred-million Yuan};

(9) Renovation funds = depreciation*renovation fund rate, \text{Units: one-hundred-million Yuan};

(10) Newly added fixed assets for renovation = \text{SMOOTH (funds for renovation, 5)}, \text{Units: one-hundred-million Yuan};

(11) Actual carrying capacity = railway fixed assets*Unit one-hundred-million Yuan for completion of cargo turnover (time), \text{Units: one-hundred-million Yuan};

(12) Industrial production = industrial production proportion (time)*GDP, \text{Units: one-hundred-million Yuan};

(13) Industrial production proportion: the industrial production values from 1990 to 2007 will be compared to GDP data, and after an auto-regression analysis, the results will be taken as table function. The result is: x = 0.080229 + 0.809505x (-1), x(-1) being the value of the previous year. Units: not gauged;

(14) Railway freight = industrial production*Unit one-hundred-million Yuan for completion of railway cargo carrying capacity (time), \text{Units: one-hundred-million tons};

(15) Unit one-hundred-million Yuan railway cargo carrying capacity means the ratio of railway freight against industrial production. The railway freight from 1990 to 2007 will be compared to industrial production, and after an auto-regression analysis, the results will be taken as table function. The result is: y = (0.567846 + 0.780983y(-1))/10000, y(-1) being the value of the previous year. Units: one-hundred-million ton/one-hundred-million Yuan.

(16) General demands for cargo carrying capacity = GDP*unit GDP cargo turnover (time), \text{Units: one-hundred-million ton kilometers};

(17) Unit GDP cargo turnover: is the ratio of gross cargo turnover of the whole society against GDP. The gross cargo turnover of the whole society from 1990 to 2007 will be compared to GDP, and after an auto-regression analysis, the results will be taken as table function. The result is: z = 0.0703 + 0.796497z(-1), z(-1) being the value of the previous year. Units: one-hundred-million ton/one-hundred-million Yuan/one-hundred-million Yuan.

(18) Railway cargo turnover = railway proportion (time)*general demand for cargo transport, \text{Units: one-hundred-million kilometers};

(19) Railway proportion takes the proportion expected by the whole society in recent years as the table function, Units: not gauged;

(20) Expected carrying capacity = railway cargo turnover. Here, the expected carrying capacity means the overall transport capacity of the railway network. It not only reflects the performance of railway constructions, including the increased mileage and improved transport capacity, but also reflects the maximum transport service competence based on certain equipment and transport organizational method(He, S.W., et al, 2003). Units: one-hundred-million kilometers;
Transport stock rate = (expected carrying capacity - actual carrying capacity) / actual carrying capacity. Units: not gauged;

GDP growth rate = expected GDP growth rate (Time) * (1 - transport stock rate). Units: not gauged;

Expected GDP growth rate in stages, suppose 15% for 2005-2008, 10.5% for 2009 and 10% for 2010-2015;

GDP added value = GDP * GDP growth rate, Units: one-hundred-million Yuan;

Savings rate, in the report by The Financial Times one March 25th 2009, Zhou Xiaochuan: On Savings, Zhou points out that the savings rate in 2007 was 49.9%, and no major changes are expected in recent years. Therefore, 50% is applied for the model.

Investment proportion: based on previous data analysis, 4% is applied for the model.

Depreciation rate is calculated by the weighted average of non-housing fixed assets, 10.29%;

The renovation fund rate is around 8% in recent ten years. Therefore, 8% is applied for the model.

The composite depreciation rate is 10%, and enterprise indirect tax is 33%.

5. Prediction Results

Historical data applied in the model is indicated in Table 1. Besides, the initial value for GDP is RMB18321.74 billion Yuan in 2005, the initial value for fixed railway assets is RMB929.42 billion Yuan in 2005.

| Year | GDP/one-hundred-million Yuan | Cargo turnover /1,000,000,000 ton kilometers | Industrial production /1,000,000,000 Yuan | Railway carrying capacity /1,000,000,000 tons |
|------|-----------------------------|--------------------------------------------|------------------------------------------|---------------------------------------------|
| 1990 | 18667.8                     | 26107                                      | 6858.0                                   | 15.0681                                     |
| 1991 | 21781.5                     | 27986                                      | 8087.1                                   | 15.2893                                     |
| 1992 | 26923.5                     | 29218                                      | 10284.5                                  | 15.7627                                     |
| 1993 | 35333.9                     | 30647                                      | 14188.0                                  | 16.2794                                     |
| 1994 | 48197.9                     | 33436                                      | 19480.7                                  | 16.3216                                     |
| 1995 | 60793.7                     | 35909                                      | 24950.6                                  | 16.5982                                     |
| 1996 | 71176.6                     | 36590                                      | 29447.6                                  | 17.1024                                     |
| 1997 | 78973.0                     | 38385                                      | 32921.4                                  | 17.2149                                     |
| 1998 | 84402.3                     | 38089                                      | 34018.4                                  | 16.4309                                     |
| 1999 | 89677.1                     | 40568                                      | 35861.5                                  | 16.7554                                     |
| 2000 | 99214.6                     | 44321                                      | 40033.6                                  | 17.8581                                     |
| 2001 | 109655.2                    | 47710                                      | 43580.6                                  | 19.3189                                     |
| 2002 | 120332.7                    | 50686                                      | 47431.3                                  | 20.4956                                     |
| 2003 | 135822.8                    | 53859                                      | 54945.5                                  | 22.4248                                     |
| 2004 | 159878.3                    | 69445                                      | 65210.0                                  | 24.9017                                     |
| 2005 | 183217.4                    | 80258                                      | 77230.8                                  | 26.9296                                     |
| 2006 | 211923.5                    | 88840                                      | 91310.9                                  | 28.8224                                     |
| 2007 | 249529.9                    | 101419                                     | 107367.2                                 | 31.4237                                     |
| 2008 | 300670                       | 105512.9                                   | 117567.1                                 | 33.1                                         |
| 2009 | 335353                       | 121211.3                                   | 127325.2                                 | 33.3                                         |

Data source: from the statistical reports by STATS from 1991 to 2010
The time range for simulation model is 2005~2015. For simulation results, refer to Table 2.
Table 2: Simulation Results

| Year | Actual railway freight /1,000,000,000 tons | Predicted value of railway freight / 1,000,000,000 tons | Error /% |
|------|------------------------------------------|--------------------------------------------------|---------|
| 2003 | 22.4248                                  | 22.4434                                           | 0.08    |
| 2004 | 24.9017                                  | 24.8387                                           | 0.25    |
| 2005 | 26.9296                                  | 26.9838                                           | 0.20    |
| 2006 | 28.8224                                  | 28.9314                                           | 0.38    |
| 2007 | 31.4237                                  | 31.4206                                           | 0.01    |
| 2008 | 33.1                                     | 33.1819                                           | 0.25    |
| 2009 | 33.3                                     | 33.3332                                           | 0.10    |
| 2010 | 36.3                                     | 35.3347                                           | 2.66    |
| 2011 | —                                        | 38.4123                                           | —       |
| 2012 | —                                        | 43.4665                                           | —       |
| 2013 | —                                        | 47.0487                                           | —       |
| 2014 | —                                        | 50.5414                                           | —       |
| 2015 | —                                        | 54.0486                                           | —       |

From table 2, the freight from 2011 to 2015 is predicted. It is expected to reach 5.40486 billion tons in 2015. The maximum error expected is 2.66%. As the investment proportion and renovation fund rate is a constant for the model. The actual railway investments and renovation funds each year are always changing, which result in increasing errors. The railway contributions are calculated by the absorption rate and refer to some data. Therefore, the accuracy is to be improved. The industrial production proportion and unit one-hundred-million Yuan for completion of railway freight and other auxiliary variables will show some error in the predictions and then applied as table functions in the model. Therefore, the error will also rise.

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