Study on the Material Stock of Transportation Construction Associated with the Development of Infrastructure in China

中国における交通インフラ建設に伴うマテリアルストックに関する研究

Tao HUANG*, Feng SHI, Jinling FEI, Hiroki TANIKAWA and Hidefumi IMURA

Abstract: Unprecedented infrastructure construction, particularly in the transportation sector, has recently taken in China. This study estimated the material stock of transportation construction in China from 1993 to 2007. The results indicated that the steel, cement, and sand and gravel stocks of the railway system increased 1.5, 2.1 and 1.6 times, respectively, between 1993 and 2007, but the wood stock decreased. The steel and cement stocks of the highway system increased 18 and 2.8 times, respectively. Steel recycling is thus becoming an important factor for transportation construction in China.

Key Words: Transportation Construction, Material intensity, Material stock

要旨：近年、中国は莫大なインフラ整備、特に鉄道や高速道路などの交通部門のインフラ整備を行っている。そこで本研究は、中国の交通インフラとして鉄道及び道路に着目し、1993年から2007年までのマテリアルストックを計算した。その結果、鉄道および道路の鋼鉄、セメント、砂及び砂利のストック量が明らかとなった。鉄道施設については、木材ストックは減少し、鉄鋼ストックは1.5倍、セメントのストックは2.1倍、砂利石材のストックは1.6倍に増加した。一方、道路施設については、鉄鋼ストックが18倍、セメントは2.8倍に増加したことが明らかになった。

キーワード：交通インフラ、マテリアル強度、マテリアルストック

INTRODUCTION

Unprecedented infrastructure construction, especially in the transportation sector, is taking place in China. Since the adoption of reforms and open-door policies in 1978, the length of China’s operational railways has increased from 51,700 km in 1978 to about 78,000 km in 2007, and highway length has also increased from 890,200 km to 1,962,200 km. Large amounts of construction material have been required for the development and maintenance of the railway and highway system, which have already had severe environmental impacts. Appraisals of material stock are useful for the early recognition of environmental problems, for investment planning in the mining, production, and waste management sectors, and for government policy formulation.

Bergsdal et al. (2007) introduced a stock dynamic approach to forecast national resource demand and construction and demolition (C&D) waste generation. Hashimoto et al. (2009) clarified the relationship between stock and flow for two stock types: non-potential wastes and secondary resources (missing stock or dissipated stock). Tanikawa et al. (2009) analyzed material accumulation over time in urban settings using four-dimensional geographic information systems (GIS) data. However, these data were based on the material intensity of construction. Similar data are not available for China. There has been little research on the material stock of transportation construction in China.

The objectives of this study are to calculate the material intensity and characterize the material stock of railway and highway construction in China from 1993 to 2007. The resulting information is pertinent for stakeholders in China’s infrastructure, and will facilitate the planning and implementa
ntation of appropriate measures for life-cycle management of the transportation infrastructure.

1 METHOD

1.1 Material intensity

Figure 1 illustrates the flow diagram for the calculation of the material intensity of the railway system. First, China's railway system is divided into single and double track railway. Steel consumption per kilometer of railway is then calculated according to track type. The railway system incorporates concrete and wooden sleepers. The steel, cement, and sand and gravel contents of each concrete sleeper can be obtained according to the ratios of materials employed in their construction. Gravel consumption can also be determined by volume per kilometer of ballast bed. Finally, the material intensity of single and double track railway lengths can be obtained according to the weight of the rails, the number of sleepers, and the volume of ballast beds.

Figure 2 is the flow diagram for the calculation of the material intensity of the highway system. The highway system uses cement and asphalt concrete paving materials. Several classes of highways are also distinguished by their subgrade structures, which result in different material intensity. The material intensity of each class highway can thus be determined according to structure and material consumption. This study did not include unpaved roads in the material intensity analysis.

1.2 Material stock

The regional material stock of transportation infrastructure may be estimated using the follow equation:

\[ MS_{i,j}(t) = A_{i,j}(t) \times I_{i,j}(t) \]

where \( MS_{i,j}(t) \) is the amount of material \( i \) stocked in structure \( j \) in year \( t \), and \( A_{i,j}(t) \) is the total amount of physical data for structure \( j \) in year \( t \). This variable describes the size of a structure, such as railway length or highway area. \( I_{i,j}(t) \) is the intensity of material \( i \) in structure \( j \) in year \( t \). In other words, the intensity of a given material is the stocking rate of material \( i \) per stock in structure \( j \).

2 RESULTS AND DISCUSSION

2.1 Material intensity of the railway system

In China's railway system, steel consumption is concentrated in rails and concrete sleepers. Several types of rails are used for different routes (Table 1), but rails weighing 60 kg/m accounted for more than 80% of rail use in 2007 (HCTC, 2008). Table 1 shows the steel consumption of rails for each class of railway.

The steel content of each type of concrete sleeper can be obtained using the detailed structure parameters described by Wang and Xie (2008) and the result is shown in Table 2. The material composition of the concrete sleepers can be determined using the ratio of materials in each concrete mixture (Yang and Li, 1999) and the result is also shown in Table 2.

The structure of ballast beds vary with railway types. Figure 3 shows cross-sections of single- and double-track railways (Ministry of Transportation...
Table 1 The rail and sleeper of different railway

<table>
<thead>
<tr>
<th>Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Reference</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Code for design of railway line (GB 90-85)</td>
</tr>
<tr>
<td>Number of sleeper / km</td>
<td>1840</td>
<td>1790</td>
<td>1790</td>
<td>1880</td>
<td>1690</td>
<td>1640</td>
<td></td>
</tr>
<tr>
<td>Rail (kg)</td>
<td>75</td>
<td>60</td>
<td>60</td>
<td>50</td>
<td>43</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Type of sleeper</td>
<td>II</td>
<td>II</td>
<td>II</td>
<td>II</td>
<td>II</td>
<td>II</td>
<td></td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>III</td>
<td>II</td>
<td>II</td>
<td>II</td>
<td>II</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 The composition of different concrete (kg)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>6.0</td>
<td>6.4</td>
<td>7.5</td>
</tr>
<tr>
<td>Cement</td>
<td>39.5</td>
<td>43.3</td>
<td>45.3</td>
</tr>
<tr>
<td>Sand and gravel</td>
<td>172</td>
<td>172</td>
<td>186</td>
</tr>
</tbody>
</table>

Note: S and J denote steel wire and steel bar respectively.

Figure 3 The cross section profile of single and double track railway

The material intensity results for China's railway system are shown in Table 4. These results show a pronounced increase in sand and gravel intensity after 2005 compared with the value from 1999 to 2005. No other changes in material intensities were observed.

2.2 Material intensity of the highway system

China's highways are composed of cushion layer, base layer, and surface layer. The cushion layer is typically paved with brushed stone, and its depth is determined by the class of highway and local hydrogeological conditions. More than 10 kinds of materials can be used in the highway base layers (Liu, 2007). Given this range of variation in depth and materials, it is impossible to determine the material consumption of the cushion and base layers for a given highway. Because the steel, cement and asphalt concrete are mainly concentrated in surface layer, we based our calculation of material intensity on these materials for each class of highway.

For highways with asphalt pavement, the structure and depth of the surface layer differs by class of highway according to a unified standard (Ministry of Transportation of China, 2006). We determined the average structure and depth of the surface layer for asphalt-paved highways using the specifications and investigations of paved highways in China (Yang, 2004; Zhang, 1999) (Table 5).
Table 4 The material intensity of railway (tons/km)

<table>
<thead>
<tr>
<th>Material</th>
<th>Single track railway</th>
<th>Double track railway</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Extr.-heav.</td>
<td>Heavy</td>
</tr>
<tr>
<td>Wood sleeper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>140</td>
<td>120</td>
</tr>
<tr>
<td>1999-2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete sleeper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>2550</td>
<td>2562</td>
</tr>
<tr>
<td>1999-2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete sleeper</td>
<td></td>
<td>Sand and gravel</td>
</tr>
<tr>
<td>Steel</td>
<td>3122</td>
<td>3092</td>
</tr>
</tbody>
</table>

Table 5 The structure of surface layer of different asphalt pavement highway

<table>
<thead>
<tr>
<th>Class</th>
<th>Motorway</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Asphalt concrete</td>
<td>Depth/cm</td>
<td>Upper</td>
<td>Middle</td>
<td>Under</td>
</tr>
<tr>
<td></td>
<td>Hot mix asphalt concrete</td>
<td></td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Bituminous penetration</td>
<td></td>
<td>25</td>
<td>24</td>
<td>23</td>
</tr>
</tbody>
</table>

We determined the surface-layer structures for each class of cement-paved highway according to the material requirements outlined in the JTG D40, Specifications of Cement Concrete Pavement Design for Highway (Ministry of Transportation of China, 2002) (Table 5).

Finally, we obtained the material intensity of different classes of highway using the data in Table 5 and the JTG/T B06-01, Itemized Resource Quotas for Rough Cost Estimation for Highway Works (Ministry of Transportation of China, 2007), and the results are shown in Table 6.

2.3 Material stock of the railway system

The material stock of China's railways over time was estimated using the statistical and material intensity data in Table 4. Figure 4 shows the material stock values from 1993 to 2007. The development of the concrete sleeper for Chinese railways began in 1958 (Jin and Xu, 2000). Many wooden sleepers have since been replaced by concrete sleepers, especially along the main railway routes. Wood stock thus decreased from 1997 to 2002. Since 1979, China has implemented a policy of railway development and construction. In 1992, the Notice on Developing Joint Venture Railway Construction by Central and local (General Office of the State Council, No. 44.) was announced. This accelerated the development of joint-venture railways. National railway length increased from about 53,300 km in 1980 to 78,000 in 2007. This development led to higher steel (11.5 MT), cement (4.3 MT), and sand and gravel (283 MT) stocks in 2007, representing 1.5, 2.1 and 1.6 times increases from 1993 values, respectively. In addition, the 1999 specifications for ballast bed width were increased in 2005, contributing to the dramatic increase in sand and gravel stock.

2.4 Material stock of the highway system

More than 90% of motorways in China are paved with asphalt. Cement pavement has been used for...
Notes: The motorway and class I highway have the central partition, but other highway has not it.

Figure 5 The cross section profile of highway
about 25% of motorways and class I highways (Zhang, 1999) and about 45% of class II highways (Gao, 2008). Figure 5 shows the cross-section of a highway. We determined the surface width of each class of highway (Table 7) according to the Design specification for Highway rout (Ministry of Transportation of China, 1994) and the Design specification for Highway Alignment (Ministry of Transportation of China, 2006), and estimated the material stock of the highways over time using the material intensity data in Table 6.

Figure 6 shows the material stock of China's highways from 1993 to 2007 and it indicates that the steel, asphalt and cement stocks of the highway system increased from 1,600 tons, 10.4 MT and 138.2 MT in 1993 to 28,900 tons, 54.4 MT and 380.6 MT respectively. This growth is related to increased highway development and construction during the study period. In 1992, the development of transportation outlined the implementation of reforms to expand and accelerate the development of transportation (Ministry of Transportation, 1992). This policy increased the investment in highway construction. In addition, the width of motorways increased after 2005. According to the JTJ 011 (Ministry of Transportation of China, 1994), many typical four-lane motorways were expanded to six- or eight-lane highways after 2005. Thus, material stock dramatically increased after 2005.

Figure 7 shows the material stock of different classes of highways. These results indicate that the material stock of class IV highways is greatest and has increased most rapidly: Class IV highway

Table 7 The width of highway surface (m)

<table>
<thead>
<tr>
<th></th>
<th>Motorway</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994-2005</td>
<td>21</td>
<td>19</td>
<td>9</td>
<td>7</td>
<td>4.5</td>
</tr>
<tr>
<td>After 2005</td>
<td>30</td>
<td>20</td>
<td>9.5</td>
<td>7</td>
<td>5</td>
</tr>
</tbody>
</table>

Figure 6 The material stock of highway in China

is branch road that connect urban and rural areas. In 2003, the Ministry of Transportation implemented a policy of strengthening road construction and management in rural areas (Ministry of Transportation, 2003). In addition, the Office of the State Council issued a policy in 2006 (General Office of the State Council, 2006) that focused on rural village development, particularly road construction. Since 2006, a project to connect each rural village to the roadway network has been implemented with the aim of incorporating all villages in the network by 2020 (Ministry of Transportation, 1999). Most rural highways are paved with cement, so the consumption of this material will continue to increase. Because we lack data for village highways, we did not calculate the material stock of this road type in this study.

3 CONCLUSIONS

This study calculated the material intensity and characterized the material stock of railway and highway construction in China from 1993 to 2007. Our primary findings were: (1) the steel, cement, the railway system were 11.5 MT, 4.3 MT and 283
MT in 2007, respectively. These quantities represent 1.5, 2.1 and 1.6 times increases from the 1993 values. (2) The steel, asphalt, and cement stocks of highway system increased from 1,600 tons, 10.4 MT, and 138.2 MT in 1993 to 28,900 tons, 54.4 MT, and 380.6 MT in 2007, respectively. (3) Since 2006, a project to connect each rural village to the road network has been implemented. The aim of this project is to incorporate 97% of China's rural villages into the road network by 2020. Because most rural highways are cement paved, this project will increase the consumption of cement.

We plan further research to investigate the future material stock and flow of China's transportation infrastructure by combining traffic development planning, economic development, and the developmental history of country.

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