Estimation of Material Stock in Urban Civil Infrastructures and Buildings for the Prediction of Waste Generation

Hiroki Tanikawa, Seiji Hashimoto*, Yuichi Moriguchi*
Wakayama University
930 Sakaedani, Wakayama, 640-8510
tanikawa@sys.wakayama-u.ac.jp
*National Institute for Environmental Studies
16-2 Onogawa, Tsukuba, Ibaraki 305-0053, Japan
hashimoto.seiji@nies.go.jp, moriguti@nies.go.jp

Keywords: Material Flow Analysis, Material Stocks, GIS (Geographical Information Systems), Locality

ABSTRACT

Construction materials account for 48% (1.1 billion tons (1995)) of all material flow in Japan. Most of these materials are accumulated in cities as stock. In the near future, the stock will cause the new material flow as wastes. In the present study, MFA (material flow analysis) is applied to Kitakyushu City, and the material stock used for construction and roads is quantified via GIS (geographical information system). The change in material flow is then estimated for the near future. The main results obtained herein are as follows: (1) The amount of material stock for construction and roads was 74 million tons in 1995. (2) In 2020, the amount of overage stock is expected to become 1.4 million tons.

OBJECTIVE

The quantification of material needed to support our way of life is the first step toward achieving a sustainable society having a proper eco-balance. Material Flow Analysis (MFA) is an effective method by which to quantify and evaluate such materials. As to material balance in Japan, the total material input is 2.0 billion tons (1995), 1.1 billion tons of which have been designated for construction and infrastructure [1]. The Total Material Requirement (TMR), including the Hidden Material Flow (HMF) (45.2 tons/capita), is 5.6 billion tons (1994) [2]. The TMR/capita of Japan was approximately half the respective TMR/capita values for the U.S., the Netherlands, or Germany. Approximately one-billion tons of material are accumulated as structure or infrastructure every year. Such construction materials are stocked as structures in some years, but overage and unnecessary structures cause the new material flow to become waste. In the near future, a huge overage stock that was built during a period of rapid growth will cause the new material flow to become waste.

A new law to promote recycle was established in 2000, and "downstream" countermeasures in the material flow of cities have been arranged. A construction recycling law was passed in order to reduce construction waste and improve the recycling rate. as a result, the resource recycling rate has risen from 58%(1995) to 85%(2000). In the future, the materials balance may change as a result of (1) the increase in waste generation due to the increase in overage structure, and (2) the decrease in civil engineering projects, such as road construction, that use the greatest share of recycled material in the construction industry. In order to avoid becoming a recycling-dependent society, we should focus on "upstream" countermeasures, which are more important for the long-term, rather than "downstream" countermeasures, which are effective in the short-term.

In the present study, MFA is applied to a city, and the material stock of buildings and roads is quantified using a GIS (geographical information system), then, the change in the material flow for the near future is estimated. Kitakyushu City (Fukuoka Pref., Kyushu Island in Japan) was selected for a case study since good quality spatial data are available for this city. The following analyses are performed in the present study:

(1) Estimation of material stock accumulated in every urban civil infrastructure according to resources type and the number of years the stock has been held. The bottom-up approach is applied to every structure using the GIS (geographical information system).

(2) The renewal schedule is set according to the attributes of each structure, and the material flow for the near future is estimated.

ESTIMATION OF MATERIAL STOCK

Estimation system

Figure 1 shows the analysis flow used to estimate the material stock of civil infrastructures (roads, traffic systems, and buildings). In this estimation, the GIS

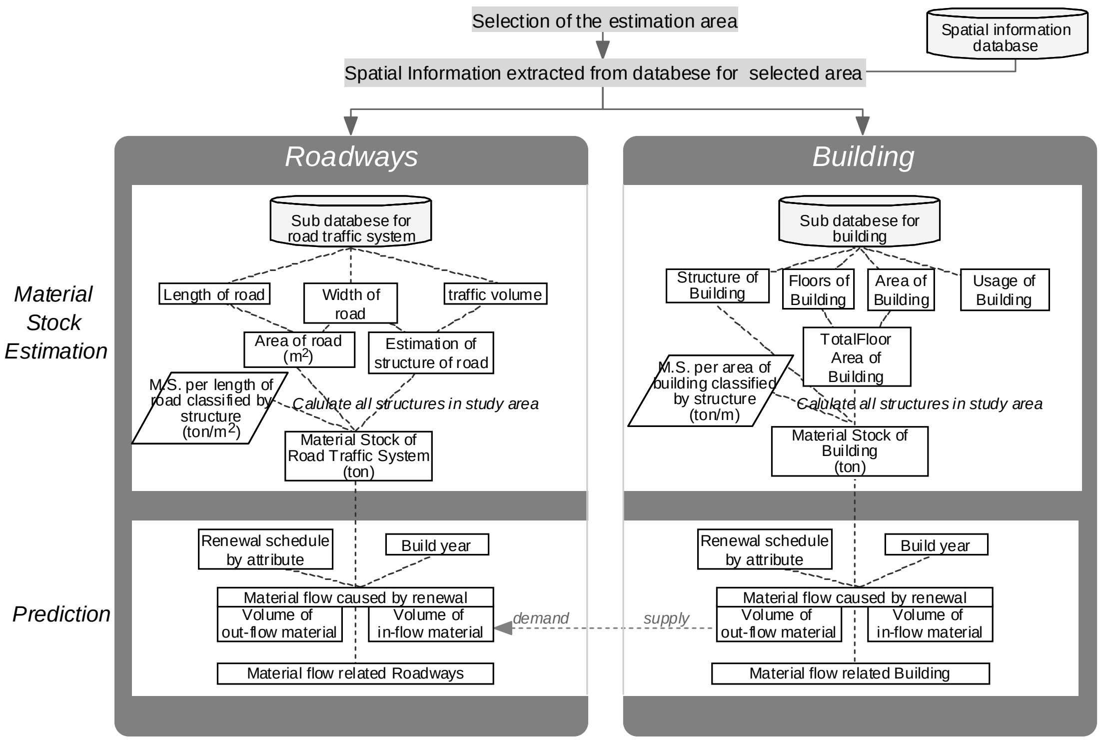

Fig.1 Method of estimating roadway- and building-related material stock

is used to assist in the analysis of the location and size of facilities. Figure 2 shows an overview of the GIS database for buildings and roadways. First, spatial information of the roadways and buildings in the study area is extracted. The attributes of each structure, such as the length, width, area, build year and usage, are included in the spatial information. Based on the extracted spatial information, material stock are estimated by multiplying total area of structures and the material stock rates. Material stock rate is divided by the type of the structure [4]. In the present study, we assume that the unit volume does not change, as reported by Hashimoto and Terashima (1999) [5]. The target materials of this estimation are iron, wood, sand and gravel, cement, and asphalt.

In order to quantify future changes in material flow, the renewal cycle is set on based on the build year of any remaining structure. In addition, new construction in 1995 - 2020 is estimated from past trends using zero population growth. Material flow related roadways and buildings in 1970, 1995 and 2020 are estimated using statistic data and GIS data of roadways and buildings. First, in order to estimate the endurance period of the buildings, the proportion of remaining buildings is calculated using the difference between statistical data and GIS data for the entire study area. In the case in which the endurance period is not set by this method because of some error of GIS data, the period is set using the probability function modeled using Weibull curves. On the other hand,

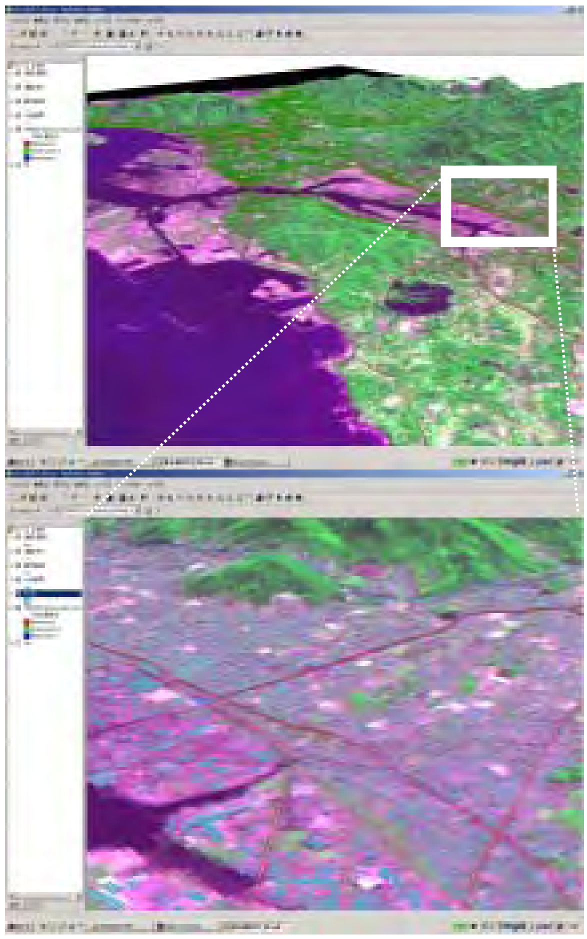

Fig.2 GIS database using the present analysis

roadways are renewed systematically as compared to buildings, so that overage roadways are mainly a result of traffic volume and structure. In the present study, since no traffic volume data could be obtained, we assumed that systematic maintenance and repair were performed for all roadways. The period until renewal (maintenance and repair) is assumed to be 10 years.

Results 1: Material Stocks in study city

Kitakyushu City, selected as a case study district, covers an area of 482.95 km2, contains 342,419 buildings and 388,741 households, and has a population of 1,019,598 (1995). The material stock for all buildings and roadways was 74 million tons: 57 million tons for buildings, and 17 million tons for roads. The use of roadways and buildings was found to require 73 tons per capita of material stock in Kitakyushu City.

Results 2: Overage Stocks and Material Flow

Figure 3 shows the composition of the age of the material stock related to the buildings in Kitakyushu City (1995). The amount of building-related material stock was 57 million tons, and the average age of the material stock was 20.4 years. In addition, 80% of material stock is under 30 years old. On the other hand, 20% (11 million tons) of the material is passed over 30 years. These buildings were constructed during a period of rapid growth. In the near future, these buildings will become overage stock, and cause new material flow as waste. Figure 4 shows the distribution of the age of building-related material stock in Kitakyushu City (1995). Sand and Gravel made up 67% of all material stock. Since the proportion of SRC and RC structures has increased starting in the 1960's, the material stock of iron, cement, and sand and gravel, has increased.

Figure 5 shows the distribution of the age of roadway-related material stock in Kitakyushu City. Some statistic error seems to be included because a time lag exists between the year in which roads opened for use and the year in which construction was started. In this estimation, the former data is used for the calculation. Thus, the distribution of roadway-related material stock is biased. However, roadways were renewed according to a road master-plan (another cause of over endurance), so the extinction curve is not like that for the buildings.

Figures 6, 7, and 8 show the material flows for 1970, 1995, and 2020. The roadway-related material stock projected for 2020 increases remarkably compared to 1970 and 1995. This is a result of the roadway network being rapidly developed due to the popularization of the automobile and population growth. However, in the study area, in recent years, construction for function

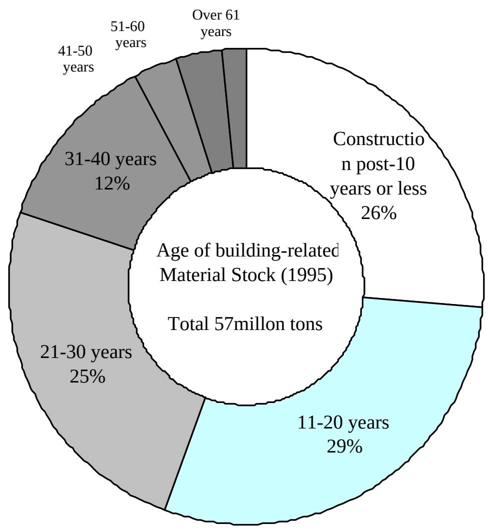

Fig.3 Age of material stocks related the buildings (1995, Kitakyushu City)

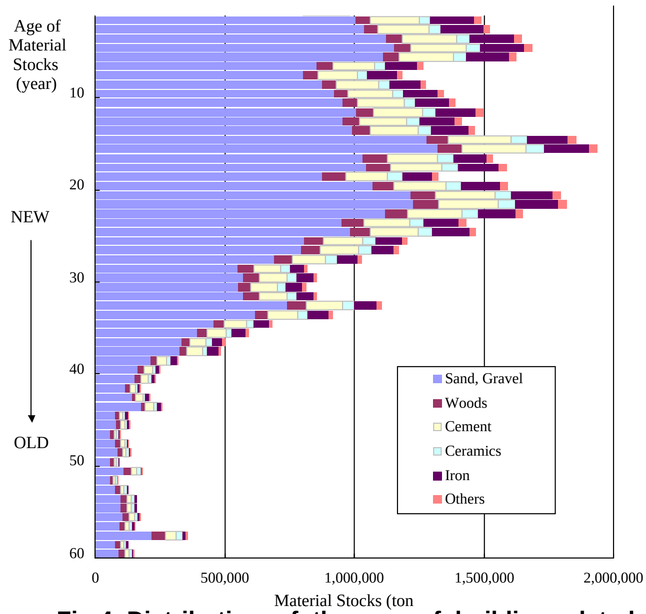

Fig.4 Distribution of the age of building-related material stock (1995, Kitakyushu City)

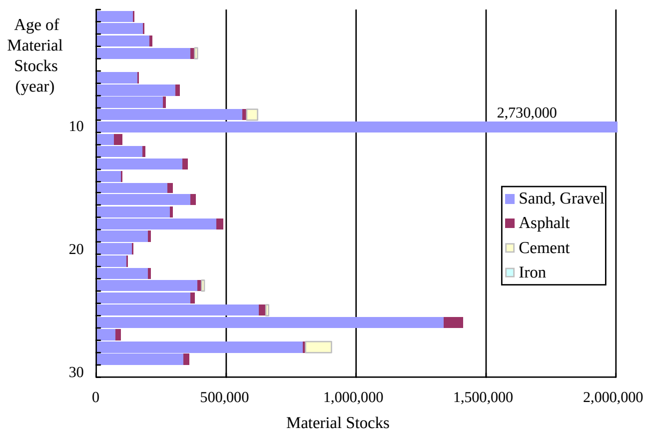

Fig.5 Distribution of the age of roadway-related material stock

enhancement and maintenance, such as width expansion and pavement renewal, rather than new roadway construction has been increasing. The material input in 2020 is projected to be 2.1 million tons, a decrease of 88% compared with the figures for 1995. The material input for buildings decreases from 2.0 million tons (1995) to 1.3 million tons (2020), but the material input for roadways increases from 0.4 million tons (1995) to 0.8 million tons (2020). That is, considerable material input is required for maintenance and repair of the developed roadway network. In addition, recycled material is estimated to be 0.8 million tons in 2020, which is approximately the same volume of the material input for roadways. The waste concrete generated from buildings is recycled as pavement material for roadways. Therefore, balancing overage buildings and roadway renewal is important.

CONCLUSION

The present paper estimated the material stock used for roadways and buildings in a local region, using data based on the GIS. In addition, the material flows in 1970, 1995 and 2020 were estimated. The material flow in 2020 was estimated from past trends using zero population growth. The main results obtained herein are as follows: (1) The amount of material stock for building and road construction was 74 million tons in 1995. (2) In 2020, the amount of overage stock is expected to become 1.4 million tons. Future subjects of study are as follows: (1) Setting a detailed renewal schedule for structures in order to obtain a more accurate prediction. (2) The examination of the detailed material balance of roadways and buildings. (3) The examination of future changes in the material input rate for both new construction and renewal projects.

REFERENCES

[1] Ministry of the Environment, Sustainable Society White Paper, pp.38, 2000.

[2] Albert Adriaanse, Stefan Bringezu, Allen Hammond, Yuichi Moriguchi, Eric Rodenburg, Donald Rogich, Helmut Schutz, Resource Flows – the material basis of industrial economics –, 1997.

[3] Emily Matthews et al., The Weight of Nations – material outflows from industrial economies –, WRI, 2000.

[4] Hiroki TANIKAWA, Hidefumi IMURA, Quantification and evaluation of total material requirement related to the urban construction: case study for residential development, Journal of Environmental Systems and Engineering, No.671, VII-18, pp.35-48, 2001.

[5] Seiji Hashimoto, Yutaka Terashima, On the Waste Generation Rates of Building Demolition, Waste Management Research, Vol. 10, No.1, pp.35-44, 1999.

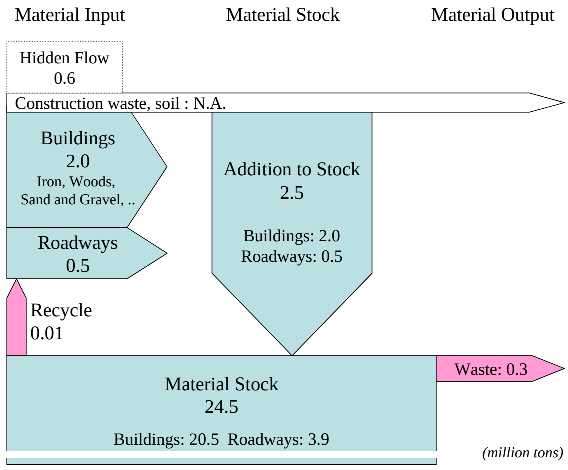

Fig.6 Material Flow Balance for buildings and roadways in Kitakyushu City, 1970

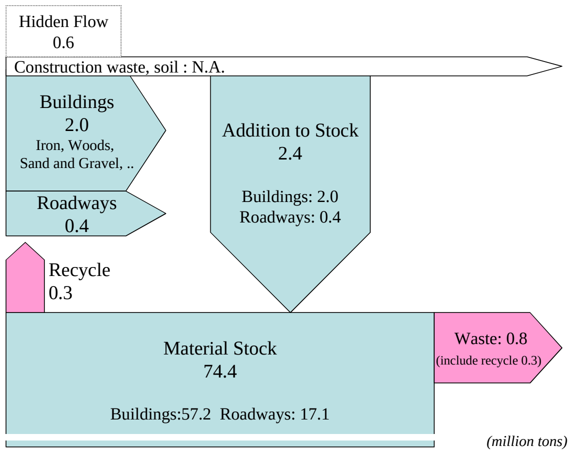

Fig.7 Material Flow Balance for buildings and roadways in Kitakyushu City, 1995

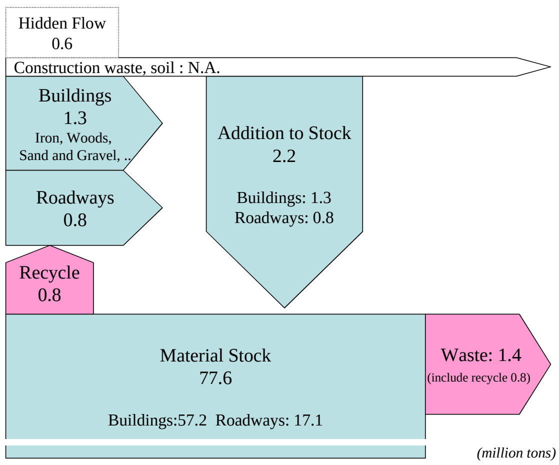

Fig.8 Material Flow Balance for buildings and roadways in Kitakyushu City, 2020