Visualization of Regional Material Flow using Over-flow Potential Maps

Hiroki Tanikawa, Tetsunori Sakamoto, Seiji Hashimoto*, Yuichi Moriguchi*
Wakayama University
Faculty of System Engineering, 930 Sakaedani, Wakayama, 640-8510, Japan
tanikawa@sys.wakayama-u.ac.jp, s054023@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: Regional Material Flow, Construction Sector, GIS analysis, Visualization

ABSTRACT

Construction materials are stocked as structures in some years, but overage and unnecessary structures can cause new material flow to be wasted. In the near future, a huge overage stock that was built during a period of rapid growth will cause the new flow to become waste. Therefore, it's important to see "where" and "how much" material flow may emerge in any given city. An Over-flow Potential Map, or OPM, offers a way to visualize Material Flow related to the construction sector. In the course of estimating regional Material Flow using GIS, many map layers must be calculated. An OPM is produced by taking the “recycled In-flow layer” away from the “Outflow layer”. The Over-flow potential is concerned with the age of structures, construction materials used, and maintenance needed. OPM can show both the density of over-flow material, and the contents of over-flow in cities.

OBJECTIVE

As regards material flow balance in Japan, the annual total material input has averaged 2.0 billion tons (Japanese Ministry of the Environment, 1995), 1.1 billion tons of which have been designated for construction and infrastructure. 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 can cause new material flow to be wasted. In the near future, a huge amount of overage stock built during a period of rapid growth in Japan will cause the new material flow to become waste. In the future, the materials balance may change as a result of (1) the increase in waste generation due to the increase in overage structures, 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 society dependent on recycling, we should focus on "upstream" countermeasures, which are more important for the long-term, rather than "downstream" countermeasures, which are effective only in the short-term.

In our former studies, Material Flow Analysis, MFA, was applied to a city, and changes in material flow for the near future were estimated. The results of this MFA were displayed with Material Flow Account figures, and by TMR / capita and DMI / capita indexes. However, the initial large-scale results of this analysis were of limited benefit to local planners.

On a local level, we found that to display material flow “spatially” and “successively” was helpful for all concerned. Local and future material balance was easier to consider with area-specific MFA mapping. Visualizing material flow was an effective way to convey and reflect the concept of MFA into local policy. We considered ways to express the questions of “Where and When do material stocks cause flow? ” and “How much flow volume will occur? ”.

To better visualize material flow, we created an Over-flow Potential Map, or OPM. In the course of estimating City-scale material flow using GIS analysis, many map layers must be calculated, for example: an In-flow map layer, an Out-flow map layer and a Stocked material map layer. An OPM is produced by taking the (recycled In-flow layer) away from the (Outflow layer). OPMs can show the volume and variety of over-flow construction materials (such as wood, iron, concrete), even for small areas on GIS maps.

Using this map, for example, policy decision makers can simulate the local effects of possible changes in policy, such as the removal of restrictions related to recycling and material flow. In this study, Kitakyushu City (Fukuoka Pref., Kyushu Island in southern part of Japan) was selected for a case study since good quality spatial data was available for this city.

EFFECTIVE MAPPING FOR MANAGING RMF

Indicators and Indexes for Regional Material Flow

Material Flow Analysis can elucidate the size and balance of material circulation on local as well as nationwide scales. The result of MFA can show not only the shape of MF but also give many indexes and indicators [2) 3)], such as: Direct Material Input, Hidden Material Flow, Total Material Requirement, Domestic Processed Output, and Total Domestic Output. To evaluate the phases of material cycles, Hashimoto and Moriguchi (2004)[4)] have proposed six indicators, (Fig.1). These indicators can evaluate the volume of flows, and material efficiency from the view of input and output. With these indicators and diagrams, we can see how large of both a direct and indirect environmental impact is caused by our activities. These indicators and figures are helpful for seeing the results of our activities, but when taking into account the need for management of material flows on a regional level, it is indispensable to visualize material flows on a map.

Thinking about the planning cycle, "Plan – Do – See", it is effective to evaluate conditions at the "See" stage using MF Diagrams and MF Indicators. MF mapping is effective at the "Plan" stage as spatially it reflects the results of the MF Indicators. As for policy planners, they can make administrative decisions using an MF Indicator map when putting future MF estimations together. For citizens, their own direct and indirect Material consumption around their own residential area can be clearly and easily understood. These maps may be usable for enlightenment activities such as environmental education as well.

In this report, we offer two new types of mapping techniques by which to give examples of MF visualization. One shows the weight density of our lives based on the larger material aspects of infrastructures and buildings, and is named a city Weight Density Map: WDM. Another shows the distribution of overflow materials beyond the abilities of recycling systems, and is called an Over- Flow Potential Map: OPM.

Distribution of Material Stock as City Weight Density

When visualizing the material volume that supports our lives, it is useful to know the volume of material stock around us, like that in our infrastructures and buildings. Using a city Weight Density Map, WDM, we can know the density of classified materials plus the weight and composition of the city easily. In this study, material stock in the construction sector was quantified, and construction materials were classified into 5 types, sand and gravel, iron, wood, ceramics, and asphalt. As subjects for our estimation, the following 6 types of infrastructures and buildings were selected.

Infrastructure: Road, Landfill, Tunnel, Bridge, Railway, and Sea and River Shorelines

Buildings: for each category of Residential, Commercial and Factory buildings: Wood based, Steel based, and Reinforced Concret

Estimation of material stock accumulated in every urban civil infrastructure and building was made according to resource type and the number of years the stock has been held. The attributes of each structure, such as the length, width, area, build year and usage, were included in the spatial information. Material stock rates were then set for each attribute, as can be estimated from the design blueprints of the representative attributes. Material stock is estimated per attribute by this rate[6)]. This bottom-up approach for material flow estimates and stock was applied to every structure using the GIS (geographical information system).

OPM: Over-Flow Potential Map

GIS map layers corresponding to each phase of the material cycle are produced in the process of estimating

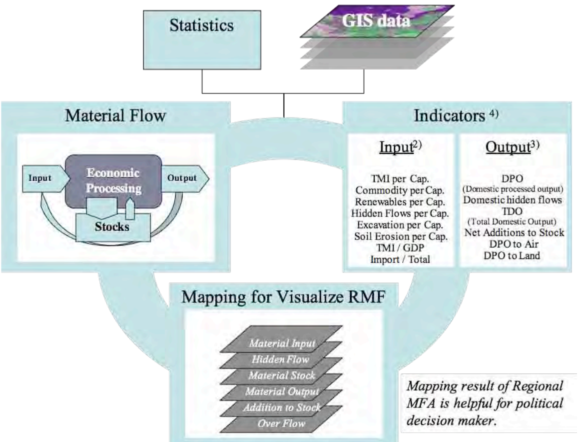

Fig.1 Visualizing and Regional MFA

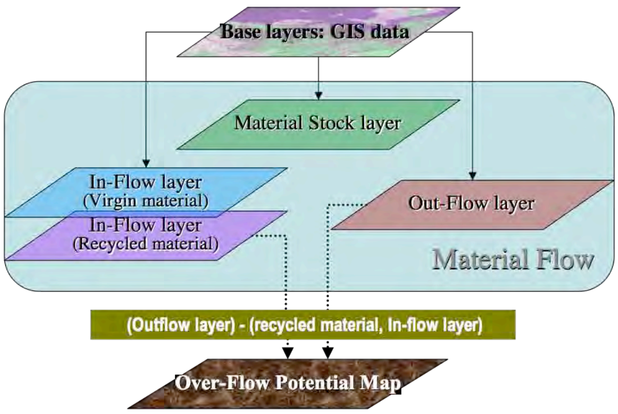

Fig.2 Spatial calculation for establishing Over-Flow Potential Map

Fig.3 Kitakyushu City

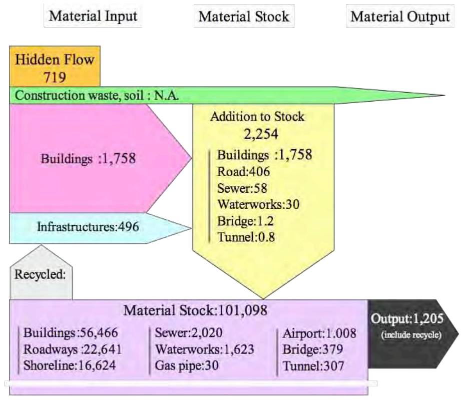

Fig.4 Material Flows of Kitakyushu City (Construction sector, thousand tons, 2000)

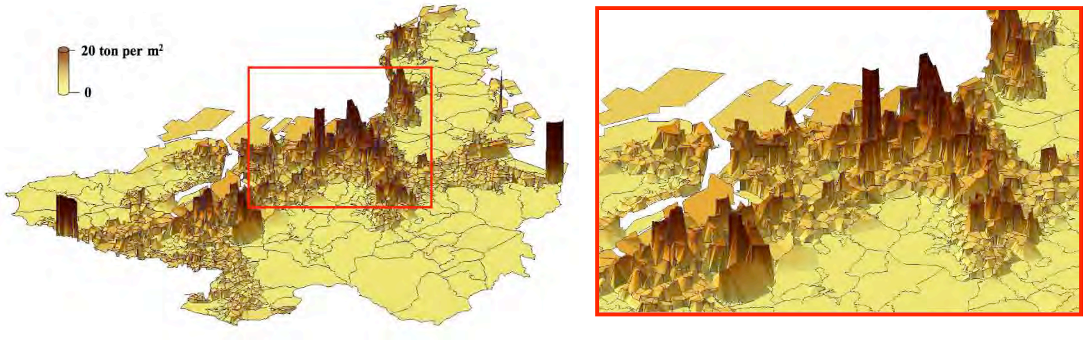

Fig.5 WDM: City Weight Density Map

RMF. Of these map layers an Input map layer, a stock map layer, an output map layer, and a recycled map layer are essential for estimating RMF using GIS. Also, we estimated future material balance based on the attributes of each structure from former studies [6]. The former studies were designed to estimate the total material balance of cities by using a bottom up approach. We discerned that the results of estimates on each structure express the Over-Flow potentials of material accumulated in the structures. So, as one kind of map for visualizing RMFA, we propose an Over-Flow Potential Map, or OPM. Figure 2 shows the relationship between OPM and each map layer. To visualize the Over-flow potential of a city, an OPM is made from the Material Input and Recycled Material in Input layers. Using OPM with any map scale, we can see the quantity of un-used materials, even those yet to be claimed by the recycling process, such as crushed concrete.

CASE STUDY ON KITAKYUSHU CITY

Overview of Kitakyushu City

Kitakyushu City (Fukuoka Pref., Kyushu Island, Japan: Figure 3) was selected for a case study since good quality spatial data is available for this city. Kitakyushu City, selected as a case study district, covers an area of 482.95 km^2, contains 343,099 buildings and 408,080 households, and has a population of 1,011,471 (2000). Figure 4 shows the overview of material flow related to the construction sector. The material stock for all buildings and infrastructures was 101 million tons: 56 million tons for buildings, and 22 million tons for roads. This means that the weight of structures that support the lives of citizens in Kitakyushu City was approximately 100 tons per capita of material stock.

WDM: City Weight Density Map

Figure 5 shows the WDM for Kitakyushu city in the year 2000. Using this map, we can know the distribution material weight that supports our lives. We can see the distribution of construction materials that has been accumulated in our structures. By zooming in, this GIS map can also show the density of classified materials plus their respective weights and composition throughout the city.

OPM: Over-Flow Potential Map

Figure 6 shows the OPM for Kitakyushu city. For this map we estimated over-flow possibilities up until the year 2020. These values are based on the result of future estimates of MF in 2020 [6]. With OPM, it becomes easy to grasp which areas will have high potential for emerging new flows, such as areas with many old structures and will thus be going through renewal at a

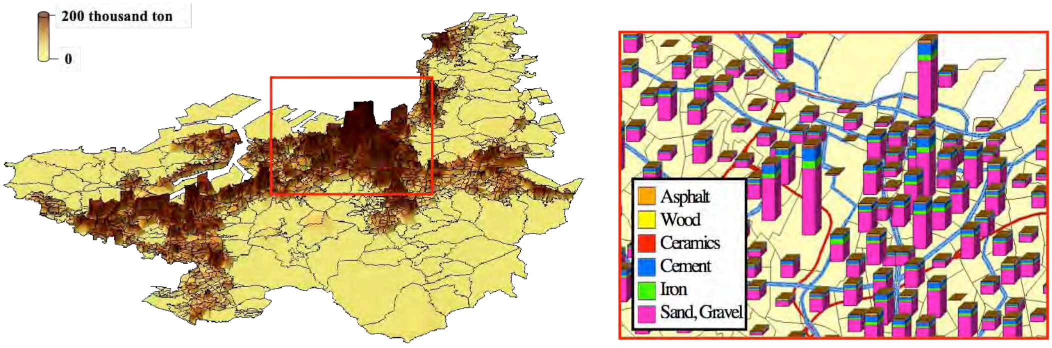

Fig.6 OPM: Over-Flow Potential Map

higher rate. In this OPM (left, Figure 6), the darker areas have high Outflow potential, which is concerned with the age of structures, the construction material used, and the maintenance required. In the detailed map (right, Figure 6), the contents of the outflow can be seen. Overall the largest component is Sand and Gravel.

CONCLUSION

Visualizing RMFA indicators using GIS is an effective tool for the management of Material Flow. It is equally so in the evaluation stage, to understand more clearly the indicators and shape of flow through each phase of MF. In the present study we interpreted the shape and indicators of RMFA by offering two new mapping techniques and were thus able to give vivid visual examples of MF. One shows the weight density of our lives based on the larger material aspects of infrastructures and buildings; the Weight Density Map: WDM. Another shows the distribution of overflow materials that are beyond the abilities of recycling systems; the Over-Flow Potential Map: OPM. A real city, Kitakyushu City, was selected as a case study district to which we applied RMFA and established a WDM and OPM to better visualize the results.

The results obtained from this case study are as follows: (1) The amount of material stock for building and infrastructures was 101 million tons in 2000. (2) Taking an overview from the WDM, material stock density was approximately 20 tons per m^2 in the city center, and averaged 0.2 tons per m^2 over the whole area. (3) The distribution of Over-Flow potential was shown by OPM. By using a detailed OPM map, it was found that the largest component of over-flow material was Sand and Gravel.

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] Seiji Hashimoto and Yuichi Moriguchi, Material and Carbon Flow of Harvested Wood in Japan, NIES, 2004.

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

[6] Hiroki Tanikawa, Seiji Hashimoto and Yuichi Moriguchi, Estimation of Material Stock in Urban Civil Infrastructures and Buildings for the Prediction of Waste Generation, The Fifth International Conference on Ecobalance, pp.803-806, 2002.