FREIGHT FLOW ANALYSIS AND ESTIMATION OF PAVEMENT COST REDUCTION BY OVERLOADED TRUCKS UTILIZING WEIGHBRIDGE SURVEY IN THE CENTRAL JAVA REGION

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ABSTRACT

The Central Java region is located in the central part of Java Island and contains major inter-regional and intra-regional freight corridors. The Government, however, is not capable of collecting sufficient freight transport data such as weight OD table by commodity types. It is not possible to maintain the roads to a high service level due to use by overloaded trucks and budgetary constraints. This paper proposes a new weighbridge survey method requiring minimum resources by utilizing daily operation of weighbridge stations. Overload analysis based on the survey data revealed that bulky commodities, particularly steel and cement damaged the pavement. The commodity weight OD table estimated by the survey data also revealed that the bulky commodities are transported across Java Island. The methodology for estimating the economic benefit of pavement cost reduction by a transportation project using the survey data was proposed and a case study was conducted for the enforcement of overload regulation and the new freight railway project.

Keywords: Weighbridge, Overload, Freight OD, Pavement cost, Developing countries

1. INTRODUCTION

The Central Java region comprising Central Java Province (or *Provinsi Jawa Tengah*) and Yogyakarta Special Province (or *Provinsi Daerah Istimewa Yogyakarta*) is located in the central part of Java Island, the most populated island in the Republic of Indonesia. East-West commodity and passenger flow on the North Java corridor (or *Pantura*); which connects Jakarta, the capital city of Indonesia, and Surabaya, the second largest city of Indonesia, through Semarang, the capital of Central Java Province; is the major traffic corridor in Indonesia. The South Java corridor also connects Jakarta and Surabaya through the southern cities in the Central Java Region such as Yogyakarta and Solo and is also a major corridor in Java Island. Roads and railways connecting Semarang, Solo and Yogyakarta are major intra-regional corridors.

Trucking is the main mode of land freight transport in Java Island while PT. Kereta Api (Persero), which is the sole railway operator in Indonesia and a wholly state-owned company (Persero) with shares owned by the Ministry of State Owned Enterprises, has been losing customers in this decade.

Although there are plans for the development of toll roads in the region including the Trans Java Toll Road, there currently are no toll roads except for the 24.75 km of toll roads surrounding Semarang City. Most cargo is transported through arterial roads.

While the amount of freight that flows by railway on Java Island is available from the railway operation logs of PT. Kereta Api (Persero), freight flows by trucks by commodity types are virtually not available. Since these freight OD tables by commodity types are essential for regional freight policy planning such as demand forecasting, development of an affordable survey method to investigate freight flows by commodity type is highly required.

Overloading of trucks is another major concern of the Ministry of Public Works and the local governments. As roads are damaged, the service level is decreased and thereby it is no longer able to catch up with the deteriorating speed of pavement coupled with limited budget. It is noted that some 3-axle-trucks are converted to 2-axle-trucks by the removal of one rear axle before importation is made to reduce taxes. These trucks have wide and deep loading space that can be overloaded easily.

Impact of overloaded trucks includes damage to road pavement, low travel speed due to low service level of pavement, low travel speed due to overloading particularly along steeply sloped sections, congestion caused by stranded broken down trucks and increase of traffic accidents such as rollover at curved sections. Although the impact of overloading is described, analysis of the current condition and impact of overloading is descriptive or is based only on experimental data rather than quantitative analysis based on surveyed data at the site.

Weighbridge stations, (or *Jembatan Timbang*) which are facilities to weigh freight carrying vehicles along roads, are located on major arterial roads in Indonesia supposedly as the core countermeasure for overloading. All freight vehicles with loads, except for container trucks and tankers, are mandated to use the station when they come from an adjacent arterial road. Overloaded trucks are fined in proportion to their measured weight against the rated capacity. Utilizing weighbridge survey data that can be conducted with minimum resources, this paper proposes a new survey method to understand the current commodity flow as well as the overloading situations. The implications on overloading and freight transport planning are also explained and the effect of alleviating policies is estimated.

2. WEIGHBRIDGE SURVEY

Since all trucks except for container trucks, tankers and empty trucks have to pass a weighbridge, precise freight transport data can be obtained by conducting interview surveys at weighbridge stations. Survey details including method, location, period, sampling and questionnaires relative to the interviews are described below.

2.1 Survey method

Weighbridges are operated 24 hours daily by provincial government transportation authorities and all freight vehicles with loads except tanker and container trucks are obligated to be weighed. The authority records the weight of the freight vehicle and interviews the driver and checks the vehicle registration, origin and destination (OD), and commodity among other pertinent information. Two (2) interviewers for the survey were added, 1 traffic counting surveyor for each weighbridge and a backup surveyor to gather vehicle freight information on OD and commodity information for randomly sampled vehicles.

Vehicles entering a weighbridge station are stopped by the interviewers with the cooperation of a traffic officer to ask the drivers about the trip purpose, OD and commodity type and so forth while another surveyor records the total weight by reading the weighbridge scale as well as vehicle information on vehicle weight and rated loading capacity from the vehicle registration information label posted on one of the sides of the vehicles. An hourly traffic count by vehicle type was also conducted manually for each survey location.

Figure 1 – Weighbridge interview survey

2.2 Survey locations

Weighbridge stations are located at major boundaries of regencies/cities (or *kabupaten/kota*) in the Central Java Region. Interview survey and traffic count were conducted at the following 10 weighbridge stations in the Central Java region consisting of 8 out of 17 stations in Central Java Province and the only 2 stations in Yogyakarta Special Province. While 9 out of 19 bridges in the region have sufficient capacity, with a maximum 18m length and 80 ton loading capacity; regrettably, other weighbridges are not capable of weighing all vehicles due to insufficient capacity. Five bridges complied with the capacity requirements based on the survey.

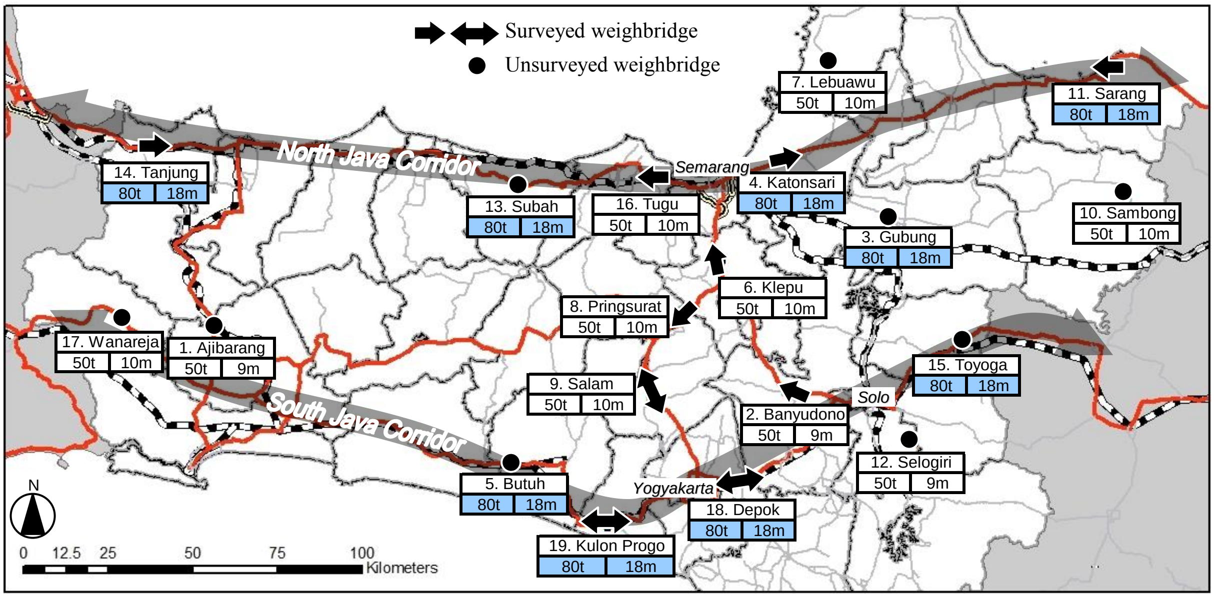


Figure 2 – Weighbridge stations in the Central Java region

2.3 Survey period

In order to reduce road damage caused by overloaded trucks, regulation against overloading is being enforced in accordance with the phased schedule instructions of the central government as shown in Table I hereunder. At each weighbridge, overloaded trucks within the designated maximum allowable percentage are still allowed to use the highway by paying retribution; however, overloaded trucks over the maximum allowable percentage are given a CPPPL (*catatan pemeriksaan perkara pelanggaran lalu lintas*, or the issuance of notice of traffic violation) and are forced either to reduce the load on the spot or to return to the place of origin.

Table I – Enforcement schedule for regulation of overloading

Phase	Effective Period	Maximum Allowable Overload
I	February 1, 2008 – April 30, 2008	50%
II	May 1, 2008 – July 31, 2008	40%
III	August 1, 2008 – September 30, 2008	30%
IV	October 1, 2008 – December 31, 2008	20%

The survey was conducted for 24 hours on a Tuesday or Thursday in July 2008 when the overloading allowance pursuant to requirements was 40%.

2.4 Sampling

Sampling ratios were made so as not to cause traffic congestion and average sampling ratio for all survey locations and all vehicle types was 27%. Sampling ratios for each weighbridge station are shown in the table below. Since empty trucks, tankers and container trucks are exempted from entering a weighbridge, they are excluded from both interview and traffic count.

Table II – Sampling ratio of weighbridge survey by station and by vehicle type

[Unit: vehicles per 24 hours]

#	Weighbridge Stations	Direction (to)	2-Axle Truck			3-Axle Truck			Truck with More than 4 Axles		
			No. of Samples	Traffic Count	Sampling Ratio	No. of Samples	Traffic Count	Sample Ratio	No. of Samples	Traffic Count	Sampling Ratio
2	Banyudono	Semarang	290	857	34%	44	120	37%	5	278	2%
4	Katonsari	Surabaya	282	939	30%	78	235	33%	72	202	36%
6	Klepu	Semarang	367	1,768	21%	78	260	30%	-	10	0%
8	Pringsurat	Magelang	360	2,206	16%	44	261	17%	-	-	0%
9	Salam	Semarang	211	481	44%	40	45	89%	-	61	0%
9	Salam	Yogyakarta	338	661	51%	39	61	64%	2	20	10%
11	Sarang	Semarang	105	354	30%	101	319	32%	110	295	37%
14	Tanjung	Semarang	170	715	24%	173	681	25%	42	326	13%
16	Tugu	Jakarta	327	1,458	22%	27	183	15%	11	146	8%
19	Kulonprogo	Wates	106	274	39%	37	80	46%	23	55	42%
19	Kulonprogo	Purworejo	127	388	33%	37	101	37%	11	39	28%
18	Depok	Klaten	198	473	42%	19	78	24%	12	47	25%
18	Depok	Yogyakarta	265	956	28%	44	172	26%	20	69	29%
	Total	-	3,146	11,530	27%	761	2,596	29%	308	1,548	20%

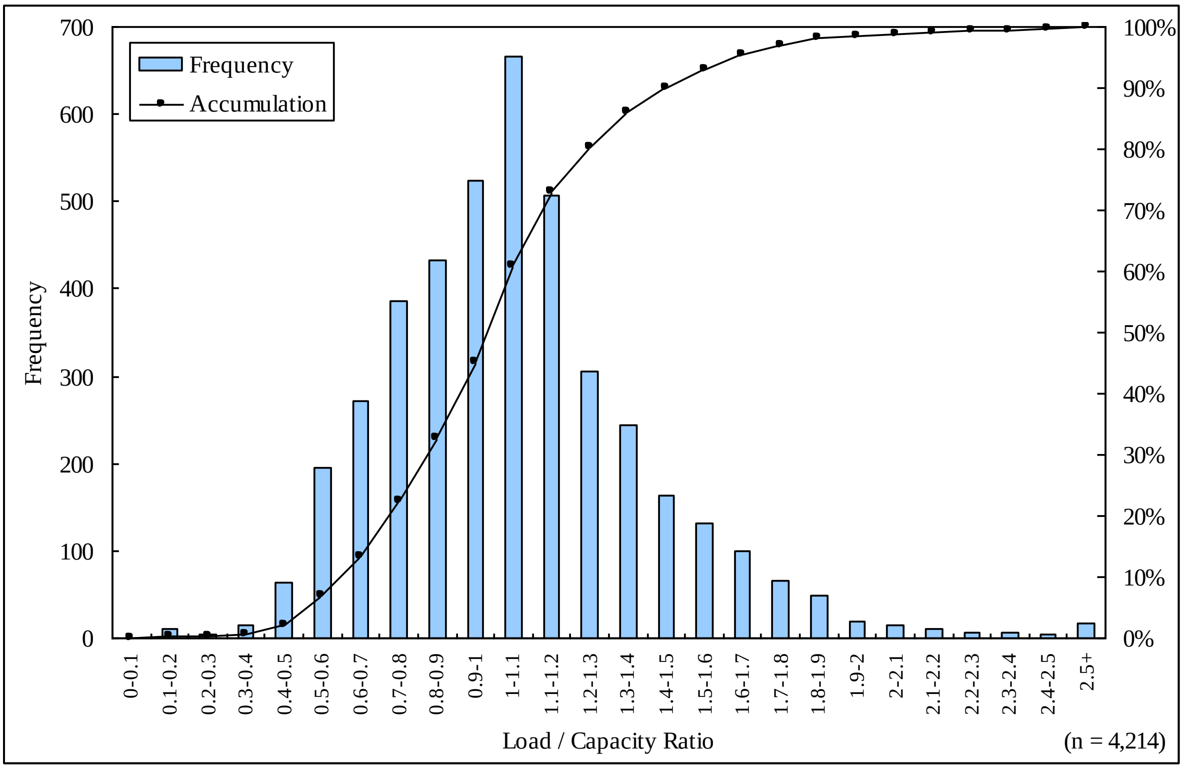
2.5 Interview questionnaires

The origin, destination, and commodity type were surveyed for both intra-provincial and inter-provincial transport. Vehicle type, measured weight of the vehicles at the weighbridge, vehicle weight and rated loading capacity were recorded by the surveyors.

3. ANALYSIS AND IMPLICATIONS

3.1 Overloading

Figure 3 depicts the distribution of load / capacity ratio of trucks. In spite the government's policy to reduce over loaded trucks by fines and regulations, roughly half of the trucks were loaded with cargo of more than their capacities. On the other hand, the share of trucks exceeding the 40% allowable overload of their load rated capacities in July 2008 by enforcement of the new regulation, was approximately 10% while roughly 0.2% of trucks were loaded with cargo of 2.5 times of rated capacity.



Note : Load capacity ratio is calculated by dividing cargo weight (excluding vehicle weight) by rated cargo weight capacity.

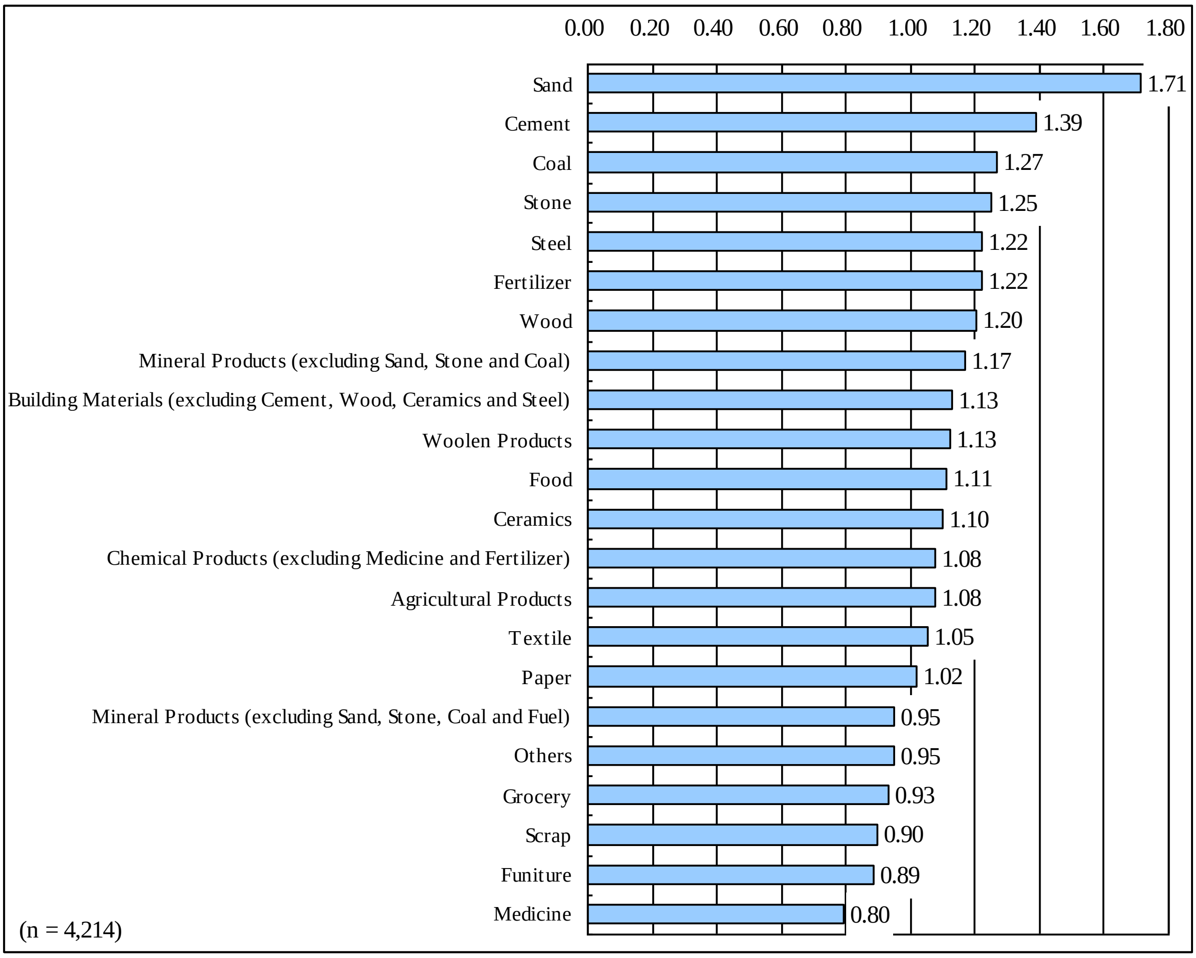
Figure 3 – Load / capacity ratio distribution of trucks at weighbridges

Load / capacity ratio by vehicle type is shown in Table III. The average axle weight was calculated by dividing the gross weight including vehicle and cargo by the number of axles. Vehicles with more than five axles are assumed to be 5.5 axles. Since weight of vehicle and commodity is usually unequally loaded by axles, the result may be underestimated.

Table III – Load / capacity ratio and estimated average axle weight by vehicle type

Vehicle Type	No. of Sample	Average Load / Capacity Ratio	Average Axle Weight (t)
Small 2-Axle Truck	2,360	1.04	3.15
Large 2-Axle Truck	786	1.08	6.94
3-Axle Truck	761	1.16	8.31
4-Axle Truck	214	1.14	8.94
Truck with more than 5 Axles	62	1.18	8.30

Load / capacity ratio is depicted by commodity type as shown in Figure 4. By commodity types, heavy cargo loads such as sand, cement, coal, stone, steel, fertilizer, shows relatively high load / capacity ratio.

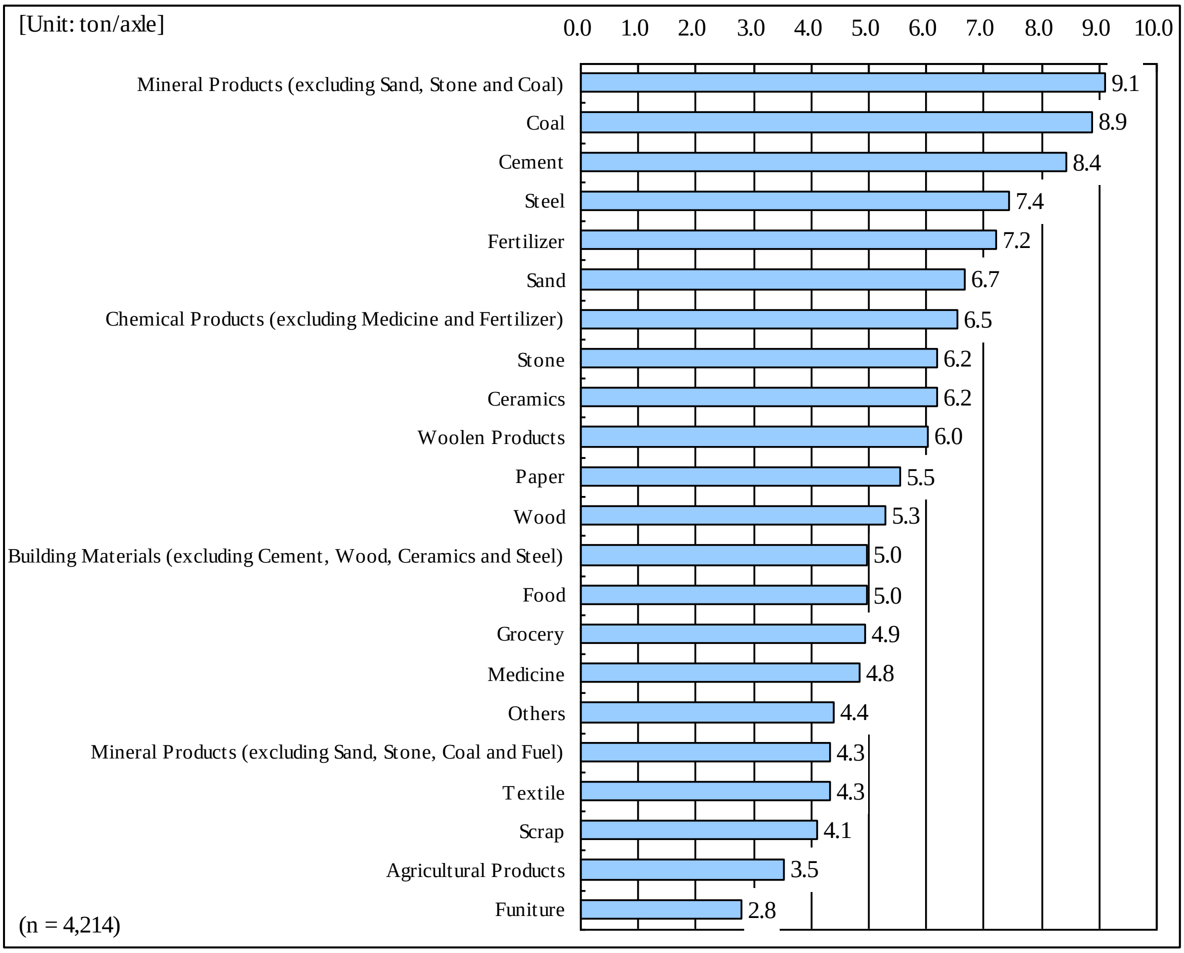


Note: Load capacity ratio is calculated by dividing cargo weight (excluding vehicle weight) by rated cargo weight capacity.

Figure 4 – Load / capacity ratio by commodity type

The estimated average axle load is depicted in Figure 5. Although heavy cargo shows high axle weight as a whole, the estimated average axle weight of sand is lower than coal, cement, steel and fertilizer as against load / capacity ratio. This is because approximately 48% (weight share) of sand is transported by 2-axle small trucks such as pickups. The average share of 2 axle small trucks of all commodity types is 25% by weight.

Since based on the experimental analysis of pavement damage (Japan Road Association, 1992) pavement damage is mainly caused by axle weight, it is implied that regulating heavy cargo traffic such as mineral products, coal, cement, steel, fertilizer, sand, chemical products and stone would significantly reduce pavement damage.



Note: Average axle weight is calculated by dividing gross weight including vehicle weight and cargo by number of axles. Vehicles with more than five axles are assumed to be 5.5 axles.

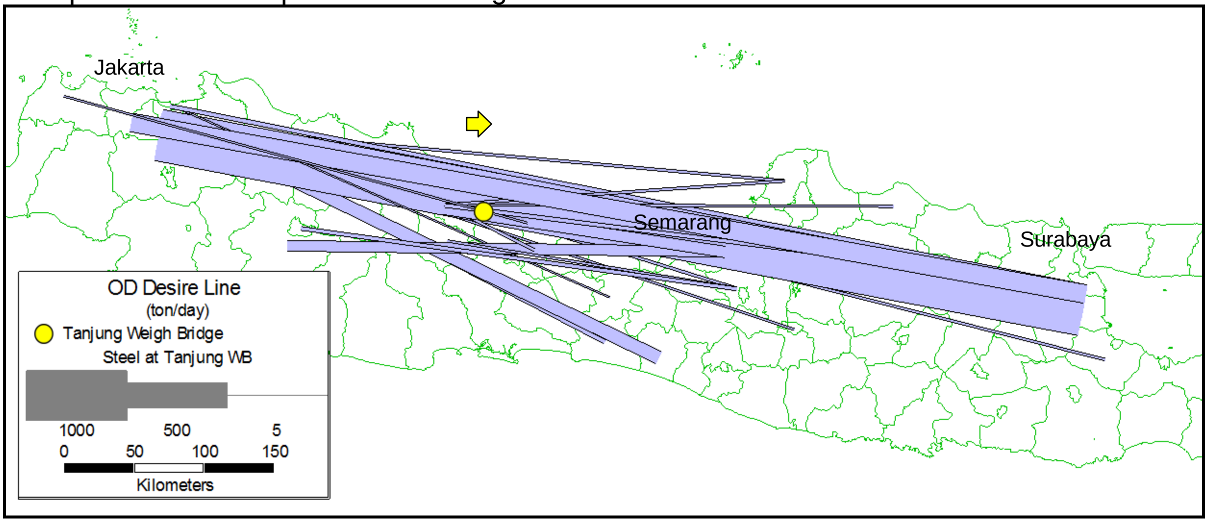
Figure 5 – Estimated average axle weight by commodity type

3.2 Freight flow along north Java corridor

Commodity weight OD table by weighbridge station was estimated utilizing weighbridge survey and traffic count results. Expansion factors by vehicle type by weighbridge station were estimated by dividing the traffic count by the number of surveyed vehicles. Although it should be possible for an OD table for the entire region to be estimated if weighbridge survey data for all the major boundaries of regencies/cities were available, it was not possible to estimate the OD table due to limited the weighbridge distribution pattern as shown in Figure 2. The following subsection shows the characteristic freight flows and their implication to freight transport policy in Java Island.

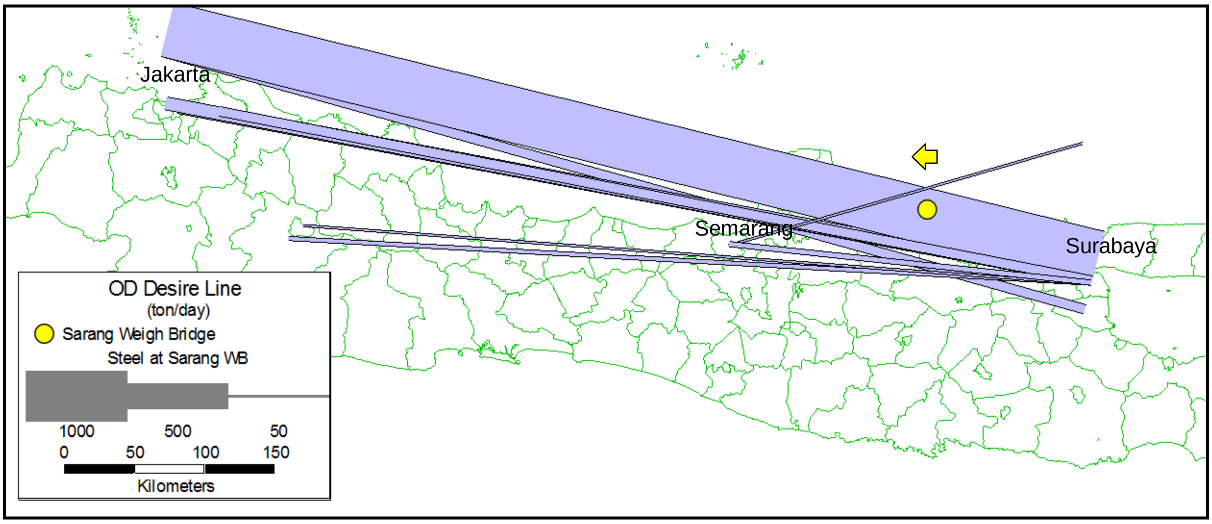
3.2.1 Steel

Steel is one of the major commodities on the Northern Java corridor. Traffic flow of the corridor was surveyed at two major weighbridges in Tanjung and Sarang. Tanjung weighbridge, which is located on the border of Central and West Java provinces, monitors almost all east bound freight vehicles on the Northern Java corridor, while Sarang weighbridge, located on the border of Central and East Java provinces, monitors west bound corridor freights. The desire lines of steel for both weighbridges are shown in Figures 6 and 7. It is noteworthy mentioning that approximately 1,000 tons of steel is transported for more than 500 km by truck for both east and west bound traffic on a daily basis such as the Jakarta – Surabaya route, while short distance flow is relatively smaller. Since impact of loads of steel on road pavement in terms of axle weight and total volume is comparatively high, enforcement of overload restrictions as well as modal shift to railways or marine transport can reduce pavement damage for the North Java corridor.



Note: Only east bound traffic was surveyed.

Figure 6 – Desire lines of steel at Tanjung weighbridge

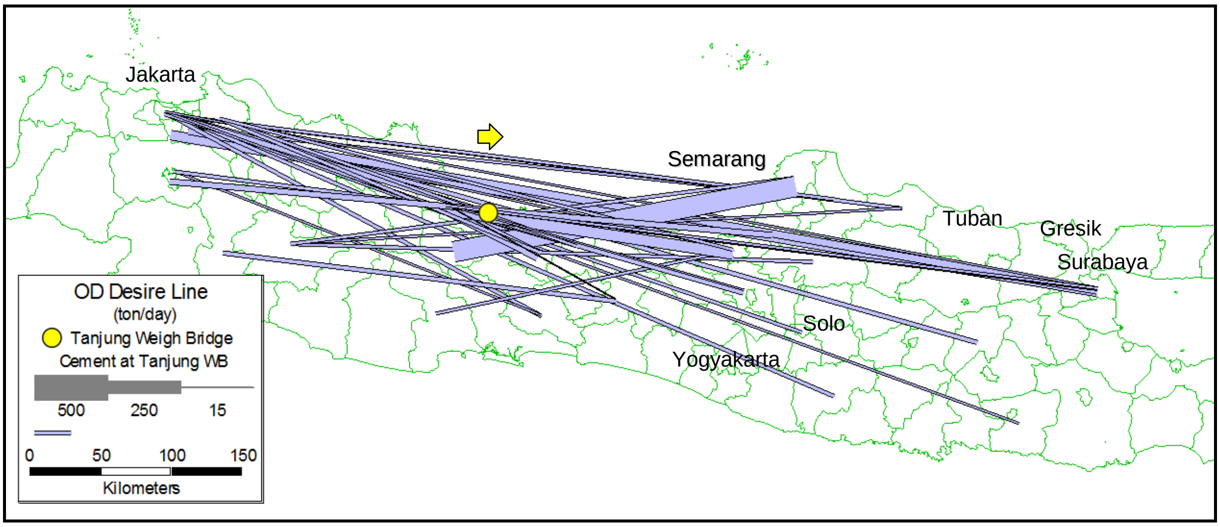


Note: Only west bound traffic was surveyed.

Figure 7 – Desire lines of steel at Sarang weighbridge

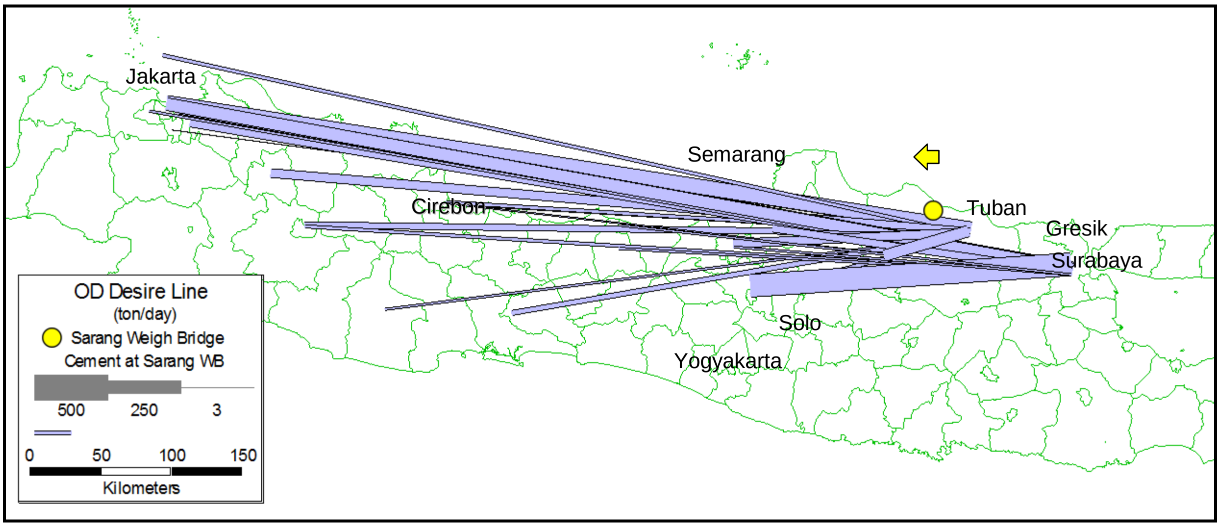
3.2.2 Cement

Cement cargo originate in cities like Gresik, Tuban and Cirebon where huge cement plants are located. The cargos are destined for major cities like Jakarta, Surabaya, Semarang and Solo. While cement is transported by truck for long distances of more than 500 km, the volume of long distance trips is less than that of steel.



Note: Only east bound traffic was surveyed.

Figure 8 – Desire lines of cement at Tanjung weighbridge



Note: Only west bound traffic was surveyed.

Figure 9 – Desire lines of cement at Sarang weighbridge

3.2.3 Other heavy commodities

While the total weight of fertilizer, coal and other minerals is comparatively smaller than steel and cement, the transportation distance is long. Transportation mode of these commodities is also recommended to be shifted to railways or marine transport. On the other hand, travel distance of sand and stone is shorter than other heavy commodities. Impact on pavement damage caused by these commodities can be minimized by overloading restrictions.

4. PRELIMINARY ESTIMATION IN REDUCTION OF PAVEMENT COST BY EFFECTIVE UTILIZATION OF WEIGHBRIDGE SURVEY DATA

Since the above-mentioned weighbridge survey data provides freight flow by commodity type as well as vehicle weight composition which has rarely been available, the survey data is meaningful not only for descriptive analyses on freight flow and overloading, but also for freight policy analyses such as overloading restrictions, road network development projects and even railway development projects. Economic benefit derived from the reduction of pavement material costs as a result of the overload restriction policy as well as the new railway project is estimated by utilizing the weighbridge survey results for the corridor between Semarang, Solo and Yogyakarta.

4.1 A CASE STUDY FOR OVERLOAD RESTRICTION POLICY

4.1.1 Enforcement of the overload regulations

As mentioned above, overloading is deteriorating the pavement of national and local roads. In this case study, the diseconomy of overloading is estimated for the purpose of grasping the impact of overloading. Since Semarang – Solo – Yogyakarta Corridor is one of the most important road sections within the Central Java region, the corridor was selected for this case study. Data availability of the weighbridges as well as existing statistical data is also considered for the selection of locations. By utilizing weighbridge survey data, pavement costs with and without complete enforcement of overloading regulations were estimated.

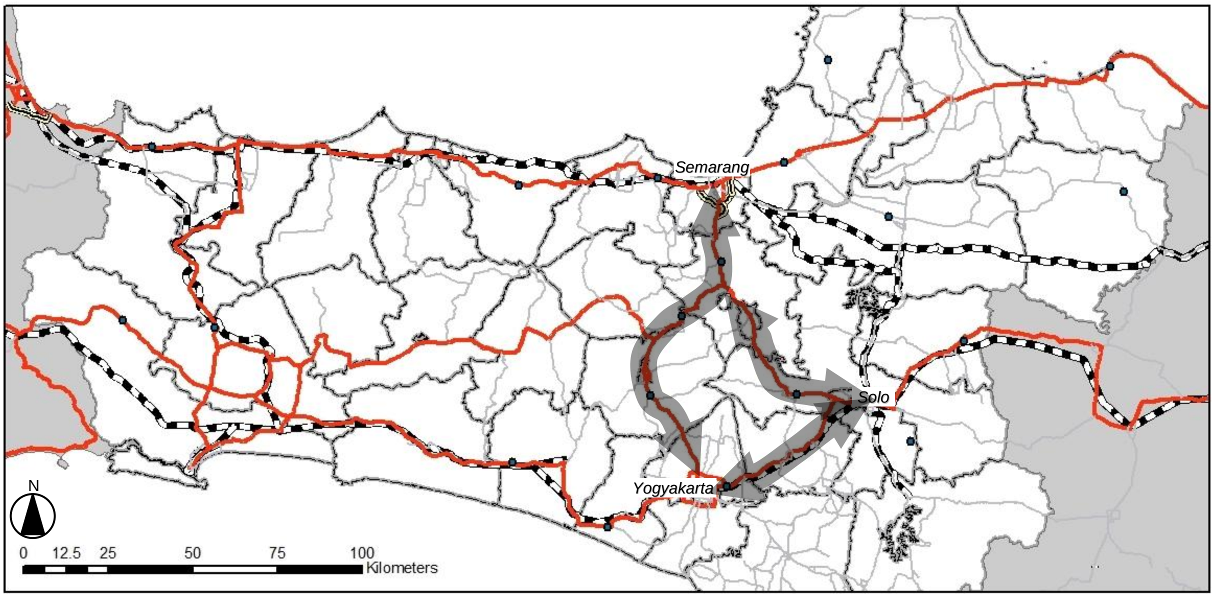


Figure 10 – Semarang – Solo – Yogyakarta Corridor

4.1.2 Methodology

The benefit of pavement cost reduction at the base year was estimated by subtracting the discounted pavement material cost without the complete enforcement of overloading restrictions from the discounted cost with the enforcement. In this case, it is assumed that the cargo which is transported by overloaded tracks is replaced by trucks with maximum cargo equal to the rated capacity. The amount of the cargo that otherwise would have been overloaded is assumed to be transported by other tracks of the same vehicle type. Flexible pavement (asphalt), which is common in the region, is assumed for all roads analysis. While major pavement maintenance works are included in the cost estimation; routine, reactive type annual maintenance costs were not taken into account because the impact is negligible, particularly when discounted over 30 years (Walls and Smith, 1998). Pavement construction is assumed during the project operation starting year and major maintenance works are scheduled for every pavement design period. In the following case study, 10 years are assumed for the pavement design period. Practically speaking, the roads in developing countries are not designed taking overloading into consideration, and the roads are required to be rehabilitated frequently. The roads in the developing countries are, however, sometimes not rehabilitated due to budget constraints of the government authorities in spite of very low service levels. Since these conditions vary for the each central/local government, a 10 year design period was applied in this estimation to standardize the estimation condition.

The required pavement thickness for bearing the axle weight of traffic during the design period is estimated based on the Japanese Manual for Asphalt Pavement (Japan Road Association, 1992). The design method based on the Japanese Manual for Asphalt Pavement is summarized and attached in the Appendix. Pavement thickness design is based on hot asphalt mix equivalent (T_A). The equation for benefit of pavement cost reduction per major pavement maintenance year is shown below. All benefits for the whole analysis period were estimated by accumulating all major maintenances. They are scheduled in 2010, 2020 and 2030 as shown in the example below.

$$B_{S,tb} = \frac{(T_{A,without,tb} - T_{A,with,tb}) \times s \times C_t}{(1+i)^{ta+tb}} \qquad (1)$$

where,

B Benefit of pavement cost reduction for major pavement maintenance in year *tb* of the road section *S*
s Area (m^2) of the road section *S*
i Discount rate
ta Construction period (years)
tb Major pavement maintenance in year
$T_{A,without}$ Required pavement thickness (cm) (hot asphalt mix equivalent) without the project
$T_{A,with}$ Required pavement thickness (cm) (hot asphalt mix equivalent) with the project
Ct Unit cost for 1cm thickness (hot asphalt mix equivalent) per 1 m^2 of pavement

The standard definition of asphalt pavement for national roads in the Central Java Region is shown in Table IV where the unit cost per 1 T_A cm thickness per 1 m^2 (C_t) is estimated at 6,990 IDR/m^2/cm (0.61 USD). The standard thickness, unit cost and material for standard asphalt pavement for national roads in the region were obtained from the local consultants. Other assumptions and source of data is summarized in Table V hereafter.

Table IV – Standard flexible pavement for national roads in the Central Java region

Layer of Pavement	Standard Thickness	Unit Cost	Equivalent Coefficient*	Material
Unit	cm	IDR/m3	-	-
Surface Layer	5.0	563,000	1.00	Asphalt
Base Course	12.5	676,000	1.00	Asphalt
Upper Sub-Base	20.0	240,000	0.35	Crushed Stone
Lower Sub-Base	25.0	217,000	0.25	Sand, CBR is more than 30

Note: IDR is Indonesian currency called the Rupiah
* Equivalent Coefficient: Conversion coefficient of layer which indicate the ratio of the pavement thickness by each material/method to the thickness of hot asphalt mix for the binder and surface courses corresponding to the thickness of each material (See Appendix).

Table V – Summary of basic assumptions and data source for pavement cost estimation

Items	Assumptions
Pavement Type	All roads were assumed to be flexible (Asphalt) pavement.
Unit Cost	Unit cost of asphalt (T_A) per 1m^2 was assumed at 6,990 IDR/m^2/cm.
Vehicle Weight Composition	Vehicle weight composition by vehicle type was obtained from the weighbridge survey data
Road Inventory Data	IIRMS (Indonesian Integrated Road Management System) data was utilized.
Road Traffic Volume Data	Road Traffic Survey in 2008 (JICA and Dephub, 2009) and IIRMS data were utilized. Future growth rates targeted at around 3.8% - 4.7% per annum based on the demand forecast results by JICA and Dishub (2009).
Social Discount Rate	Discount rate at 12%.
Project Life	Project life was assumed at 30 years after start of operation. Operation is assumed to start in 2010.
Pavement Maintenance	Major pavement maintenance works were assumed every 10 years. Routine, reactive type annual maintenance costs are not included.
Exchange Rate	1.00 USD = 11,500 IDR as of November 2008

4.1.3 Estimation results

The estimated reduction in major pavement maintenance cost is summarized in Table VI below. While the estimation is taking only the cost of materials for additional pavement into account, this will be quite conservative and one of the pieces of evidence proving the impact of the enforcement of the overloading laws and regulations.

Table VI – Estimated reduction in pavement cost due to the complete enforcement of overloading restrictions

Year	Current Price		Discounted Price	
Unit	Billion Rupiah	Million USD	Billion Rupiah	Million USD
2010	67	5.8	53	4.6
2020	71	6.2	18	1.6
2030	73	6.4	6	0.5
Total	211	18.3	77	6.7

4.2 A CASE STUDY FOR A RAILWAY PROJECT

4.2.1 Project summary: Semarang – Solo – Yogyakarta freight railway corridor

In addition to the enforcement of overloading regulations, a modal shift to railways will reduce the cost of pavement and will achieve environmentally and economically friendly transport in the region.

Although transport by railways is generally economically feasible transport, it is usually not financially feasible due to the huge initial investment. A subsidy from the government is essential, especially in developing countries where adequate revenue from fares is not expected due to considerations for the poverty group. However, the government authorities in developing counties usually do not have sufficient revenue or budget for transport policies. In this sense, the policies which will increase the revenue of the government or which will reduce the expenditures of the government would be attractive options for them. Since the reduction of pavement cost due to railway projects reduces direct government expenditures, it can be an effective justification for government authorities in those countries.

In this case study, the project called “Semarang – Solo – Yogyakarta Freight Railway Corridor” is selected for case study analysis. The project aims to improve the reliability of freight service through the rehabilitation of the existing railway track, overall traffic control system improvement over the whole 109 km track alignment, renovation of the railway to Semarang port, and railway facility development of a dry port in Solo and an inland port in Yogyakarta. The total length of the project corridor from Yogyakarta to Tanjung Emas (Semarang) port via Solo is around 193 km. Since the corridor services intercity trains and freight trains, the number of tracks and stations will remain the same as the existing conditions. The scope of the project will also include the procurement of new locomotives.

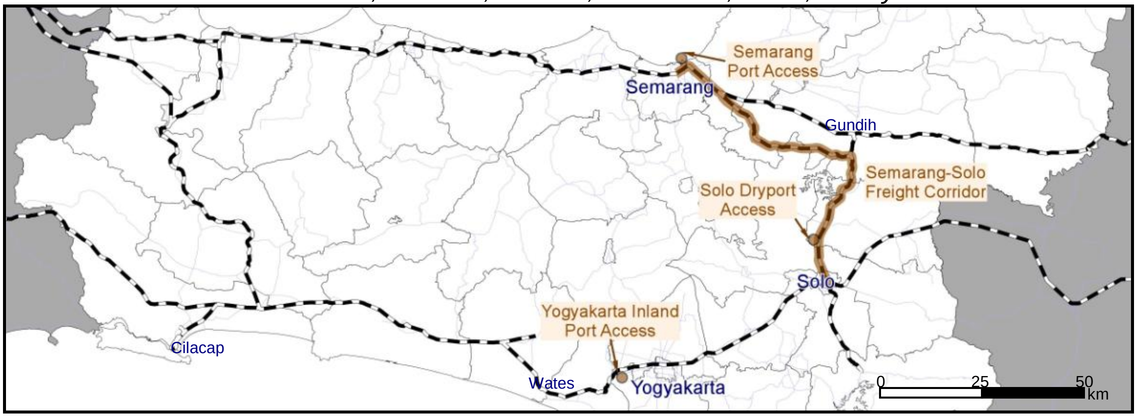


Figure 11 – Semarang-Solo-Yogyakarta railway corridor project

Based on the freight demand forecast conducted by JICA and Dephub (2009), the projected cargo volume for the Semarang-Solo-Yogyakarta railway corridor is shown in Table VII. The freight demand will be served by 3 round trips of train service per day.

Table VII – Projected cargo volume for the Semarang-Solo-Yogyakarta railway corridor

Commodity	Section	Unit	Forecast Volume		Remarks
			2015	2030	
Container	Solo Dry Port – Tanjung Emas Port	TEU / day (2 directions)	164	318	Based on the railway share of 50%
Container	Yogyakarta Inland Port – Tanjung Emas Port	TEU / day (2 directions)	116	224	Based on the railway share of 70%
Cement	Cilacap – Yogyakarta, Solo, Semarang	ton / day	2,388	3,721	Based on the current trend and future plan
Sand	Gundih, Kalasan, Wates, Bojonegoro - Cilacap	ton / day	438	911	Based on the current trend

4.2.2 Estimation results

Methodology of the estimation is generally the same as the previous case study on the enforcement of overloading regulations. The benefit of pavement cost reduction at the base year is estimated by subtracting the discounted pavement material cost without the railway project from the discounted cost with the railway project. In this case, it is assumed that the above-mentioned cargo will use the railway instead of the road running parallel along the railway.

The estimated reduction in major pavement maintenance cost is summarized in Table VIII below. Other economic benefits estimated by the JICA and Dishub (2009) Report are vehicle operation cost estimated at 555 billion rupiah, and savings in travel time estimated at, 1,168 billion rupiah, respectively (discounted at 12%). While reduction of pavement cost is comparatively smaller than other benefits, this estimate can be utilized to justify the subsidy needed for the railway project as this would call for a reduction in direct expenditures of the central and local governments. This is noteworthy that the net benefit of the project is roughly two thirds of that of enforcement of overload restrictions.

Table VIII – Estimated reduction in pavement cost due to the new railway project

Year	Current Price		Discounted Price	
Unit	Billion Rupiah	Million USD	Billion Rupiah	Million USD
2010	39	3.4	31	2.7
2020	50	4.4	13	1.1
2030	53	4.6	4	0.4
Total	142	12.4	48	4.2

5. CONCLUSIONS

This paper proposed the weighbridge survey method with minimum human resources to analyze freight flow and overloading in Central Java, Indonesia. In pursuing the survey, 3 (additional) staffs were engaged, an interviewer/surveyor and a backup surveyor for the monitoring of each weighbridge during the daily operation of the weighbridge stations. The survey data results are useful for the overloading analysis and freight OD analysis. Additionally, the data is important for transport policy analysis particularly for the mode of transport to be adopted as well for policy formulations regarding overloading restrictions and freight transportation infrastructure development as mentioned above. While this paper focused on the Central Java Region as a case study, the survey method can be applied nationwide and worldwide provided that weighbridges are available. Even for countries without stationary weighbridges, this methodology can be applied with periodic overloading checks of freight trucks using movable weighbridges.

Overloading distribution of trucks as well as load / capacity ratio and average axle weight by commodity type were analyzed for purposes of determining the causes of pavement failures. The study revealed that heavy commodities such as steel and cement have a direct bearing on road pavement in terms of axle weight. While load / capacity ratio of sand is the highest among all the commodity types surveyed, the average axle load of sand is comparatively smaller than other heavy cargo because of the use of smaller capacity trucks to carry it. It is also implied that regulating heavy cargo, including mineral products such as coal, cement, steel, fertilizers, sand, chemical products and stone, will significantly reduce damage to the pavement.

Commodity weight OD table by weighbridge station was estimated by utilizing the weighbridge survey and traffic count results. Taking steel and cement as a case in point, the freight flow in North Java corridor was visualized. The result of the survey indicated that the volume of heavy commodities including steel, cement, fertilizer, coal and other mineral goods are transported across Java Island and the strict enforcement of overloading restrictions as well as a modal shift of transport from roads to railways or marine transport was found imperative. Based on the survey results, the travel distance of sand and stone is smaller when compared with other heavy cargo freights.

In light of the foregoing study results, the methodology for estimating the economic benefit of cost reduction in major pavement maintenance with the enforcement of overloading regulations as well as the use of railways for the transport of heavy commodities to prevent pavement damages was proposed for which case studies were conducted for the Semarang – Solo – Yogyakarta corridor as countermeasures to prevent costly pavement damages. While the estimation was rather general in nature in terms of methodology and basic assumptions, it provided an overall and specific picture of the type of modal transport needed to arrest, once and for all, pavement damages due to heavy freight trucks. The savings in direct expenditures of the Central and Local Government for major pavement maintenance can therefore be utilized to justify the needed subsidy to sustain the operation of the proposed enforcement policy and the railway project. It is emphasized however that the proposed railway project is meant not only to reduce the cost of major pavement maintenance but also for the efficient, environmentally friendly and timely transportation of heavy commodities nationwide at reasonable cost.

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APPENDIX

Summary of Asphalt Pavement Design Method by Japan Road Association

Japan Road Association (1989 and 1992) proposed a simple method to design pavement thickness as follows. Thickness is evaluated by hot asphalt mix equivalent thickness of designed pavement, T_A' and required thickness (hot asphalt mix equivalent) for design traffic flow, T_A.

$$T_A' = \sum_{i=1}^{n} A_i T_i \tag{2}$$

where,

- A_i Conversion coefficient of layer *i* which indicates the ratio of the pavement thickness by each material/method to the thickness of hot asphalt mix for the binder and surface courses corresponding to the thickness of each material
- T_i Thickness of layer *i*
- T_A' Thickness of pavement (asphalt equivalent)

$$T_A = \frac{3.84 N^{0.16}}{CBR^{0.3}} \tag{3}$$

where,

- N The number of axle load applications throughout design period converted to 5 ton axle applications (axle / direction)
- CBR CBR (California bearing ratio) of roadbed
- T_A Required thickness of pavement using hot asphalt mix for surface and binder course

The number of axle load applications (5t equivalent) N is calculated by accumulating the following, 5t equivalent weight.

$$\alpha_j = \left(\frac{P_j}{5}\right)^4 \tag{4}$$

where,

- P_j Axle load (ton) of axle *j*
- α_j Damage factor given by an axle load of P_i ton to pavement