A Method for Estimating Logistics Environment from Generally Available Indicators and Indexes

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Packaging engineers are always concerned about whether the test severity (or assurance level) they are using is the right choice for their packages to be shipped to countries/regions where no distribution environment data are available. In order to obtain insights which may eventually be utilized for helping those packaging engineers decide on their test severity, Japan National Mirror Committee to ISO/TC 122 came up with a question and decided to study its feasibility. The question was," Can we infer the stress level of distribution environment on countries/regions (where no distribution environment data are available) from publicly available general statistical data and measured acceleration data of other countries/regions reported to industry-accepted conferences/journals, then utilize them to determine test severity?" This report discusses the applicability of this approach.

(http://www.jpi.or.jp/report/data/report2014_jp02.pdf)

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1. Background and Purpose

The standards for performance evaluation tests of packaged freight, as a rule, specify the setting of test severity levels as determined by actually measuring stresses that may occur in the logistics systems involved. However, it is often not easy to carry out actual measurements due to the characteristics of delivery areas or physical distribution systems. As a solution to this problem, it is considered that testing conditions of proper severity could be selected by estimating the logistics environment of a country or region, using generally available statistic data (indicators and indexes) for the country or region.

Before conducting this research, a report entitled "Investigative Research Report on a Method to be Employed when Logistics Environment cannot be Measured" was compiled by actually surveying and analyzing various statistical data.

This investigative research aimed at narrowing down highly usable indicators and indexes, collecting statistical data (indicators and indexes) concerning model countries and regions, and performing a correlation evaluation of those data relative to available measured data (Grms values of transportation vibration). Thus, the method to be employed when the logistics environment cannot be measured was further investigated in a more concrete manner.

2. Constitution of this Report

The present investigative research and its report have been constituted using a procedure as listed below:

- Selection of model countries with available actual measurement data from proceedings of international academic conferences and peer reviewed papers
- Summing up of actual measurement data (Grms values of transportation vibration in this research)
- Search for highly usable indicators and indexes
- Final narrowing-down of indicators and indexes through correlation analysis and multiple regression analysis
- Derivation of multiple regression equation for predicting logistics environment (transportation vibration)
- Application of multiple regression equation to countries without actual measurement data and study of possibility of test severity level classification

3. Review of the Report of the Previous Research

Examination and analysis were conducted on the data sources as listed in Table 1 to find general statistical data which were considered closely related to the stresses encountered in logistics environments. As items to be investigated, the "generally available statistical data for countries and regions" were selected on the following criteria:

(1) Statistical data directly concerning transportation.

(2) Statistical data considered closely related to the stresses encountered in logistics systems even if they are not directly concerning transportation (e.g., overall national competitiveness or income level of the country).

(3) Indexes released by internationally recognized institutions that are reliable and consistent (as a rule, public institutions and major non-profit-making institutions).

Table 1. List of institutions investigated for indicators and indexes

Name and URL	Acronym
World Economic Forum www.weforum.org	WEF
The World Bank www.worldbank.org	WB
International Monetary Fund www.imf.org	IMF
Organisation for Economic Co-operation and Development www.oecd.org	OECD
World Meteorological Organization www.wmo.int	WMO
Asian Development Bank www.adb.org	ADB
European Bank for Reconstruction and Development www.ebrd.com	EBRD
Inter American Development Bank www.iadb.org	IADB
The Asia Foundation asiafoundation.org	AF
United Nations Economic and Social Commission for Asia and the Pacific www.unescap.org	UNESCAP
The Association of Southeast Asian Nations www.aseansec.org	ASEAN
International Road Federation www.irfnet.org	IRF
Japan External Trade Organization www.jetro.go.jp	JETRO
Japan International Cooperation Agency www.jica.go.jp	JICA
Japan Meteorological Agency www.jma.go.jp	JMA
US Department of Transportation www.dot.gov	US DOT
National Oceanic and Atmospheric Administration www.noaa.gov	NOAA
Government of Alberta (Ministry of Transportation) www.transportation.alberta.ca	

The following findings have been made as a result of the examination and analysis of these data sources:

- "The Global Competitiveness Report" by the World Economic Forum (WEF) and "World Development Indicators" by the World Bank (WB) have considerable influence on the choice of global indicators and indexes.

- Many indicators and indexes concerning trade and physical distribution are available from WEF's "The Global Enabling Trade Report" and WB's "Connecting to Compete." These data, which are based on questionnaire surveys of business leaders and logistics experts, are expected to provide highly reliable and relevant information.

- Under the circumstances where actual field measurements are not practicable, it is considered a possibly valid method to determine the severity of testing conditions by reference to these indicators and indexes. However, the relative scarcity of supporting data may compromise the reliability of the tests chosen based on such indicators and indexes. Therefore, it will be necessary to accumulate sufficient actual measurement data in developing this method in the future.

Also, the following two assignments have been identified for further investigation:

(1) Technical assignment
- Further analysis and evaluation of calculation methods for individual indicators and indexes
- Narrowing-down of indicators and indexes which are considered usable
- Study into proper weighting and combination of indicators and indexes

(2) Practical assignment
- How are we to conduct the collection and analysis of actual measurement data which may provide a basis for the utilization of indicators and indexes?
- This method may not be acceptable to the countries among the ISO members which are ranked lower by the indicators and indexes. Whether it is necessary to examine the way to obtain those countries' acceptance, or not?

Note that the present report corresponds mainly to (1) Technical assignment above.

4. Research Methodology

From the report of the previous research, it has been decided to select and narrow down the indicators and indexes for estimation of the logistics environment from the following four representative data sources:

(1) The Global Competitiveness Report (WEF)
(2) The Global Enabling Trade Report (WEF)
(3) World Development Indicators (WB)
(4) Connecting to Compete – Trade Logistics in the Global Economy (WB)

Also, the present research, which did not rely on actual measurement of transportation environments, used published data available from proceedings of international academic conferences and peer reviewed papers, defining them as "actual measurement data." From the relative abundance of published data, the Grms values of transportation vibration of trucks and trailers were selected as data that can be used easily.

Using these "actual measurement data" as an objective variable, a multiple regression analysis was conducted on each of the indicators and indexes as explanatory variables. Thus, attempts were made to estimate the logistics environment (Grms values of transportation vibration, in this research) from generally available indicators and indexes, and the results were examined.

As was the case in the report of the previous research, it is to be noted that in this report, too, the numerical information such as GDP or total road length are referred to as "indicators" and the numerical values generalized by statistical processing such as the competitiveness or the quality of infrastructure of a country are referred to as "indexes."

5. Selection of Model Countries and Regions

5.1 Basic policy

As already mentioned, the countries for which published data are available from proceedings of international academic conferences and peer reviewed papers were the main targets of this research. As a rule, measurement data which had been obtained in the last 10 years or less were selected. It was found as a result that a nearly adequate amount of data were available concerning the Grms values of transportation vibration.

There were also published data on drop impacts of small cargoes from such countries as the USA and China and regions covering several European countries. Yet, those data, which were available in a small number, were not subjected to individual analysis in this report. If a sufficient amount of drop impact data is obtainable, it may be possible to estimate the logistics environment for such cargoes using the same technique as for the transportation vibration analysis.

5.2 Source literature for data

Table 2 lists the literature and their sources presenting data that were employed. The sources included the proceedings of the IAPRI Symposium on Packaging, data from Dimensions, proceedings of the Transport Packaging Symposium, papers from the Packaging Technology and Science magazine, and papers from the Journal of the Society of Packaging Science & Technology, Japan. In the research, full use was made of the summary papers on transportation vibration made available by the Transport Packaging Laboratory, Graduate School of Maritime Sciences, Kobe University.

Table 2. Literature and their sources of data employed

Country/Region	Literature #	Author	Title	Source	Year
Bolivia	Bolivia 1	Rodriguez, Rossi, Takayama	Measuring environmental data in the Oruro - Yacuiba route in Bolivia to develop testing methods for packaging for future implementation in the laboratory	Journal of Packaging Science & Technology. Japan Vol.13 No.6	2004
Brazil	Brazil 1	Rissi, P. Singh, Burgess, J. Singh	Measurement and Analysis of Truck Transport Environment in Brazil	PACKAGING TECHNOLOGY AND SCIENCE 21, 231-246	2008
China	China 1	Singh, Joneson	Measurement and Analysis of the Global Distribution Environment	Proceedings of the 22nd IAPRI Symposium on Packaging	2005
	China 2	Singh, Joneson	Measurement and Analysis of Global Truck, Rail and Parcel Shipments	Proceedings of 15th IAPRI World Conference on Packaging, 18-11	2006
	China 3	Yuan, et al.	Data Acquisition for Distribution Environment in the Region of South-Central of China	Proceedings of 15th IAPRI World Conference on Packaging, 12-18	2006
	China 4	Young, Baird	The China Project: An Assessment of the China Shipping and Handling Environments	Dimensions.04	2004
India	India 1	P. Singh, Sandhu, J. Singh, Joneson	Measurement and Analysis of Truck and Rail Shipping Environment in India	PACKAGING TECHNOLOGY AND SCIENCE 20, 381–392	2007
	India 2	Paul Singh, Eric Joneson	Measurement and Analysis of the Global Distribution Environment	Proceedings of the 22nd IAPRI Symposium on Packaging	2005
Japan	Japan 1	Lu, Ishikawa, Shiina, Satake	Analysis of Shock and Vibration in Truck Transport in Japan	PACKAGING TECHNOLOGY AND SCIENCE 21, 479–489	2008
	Japan 2	Saito	Intermittent Measurement of Loading Platform Vibration	Proceedings of 15th IAPRI World Conference on Packaging, 60-63	2006
Mexico	Mexico 1	Guzman-Siller, et al.	Vibration Test on Mexican Highways	Proceedings of 25th IAPRI Symposium on Packaging	2011
Spain	Spain 1	Bernad, et al.	Transport Vibration Laboratory Simulation: On the Necessity of Multiaxis Testing	PACKAGING TECHNOLOGY AND SCIENCE 24, 1–14	2011
	Spain 2	Garcia-Romeu-Martinez, et al.	Measurement and Analysis of Vibration Levels for Truck Transport in Spain as a Function of Payload, Suspension and Speed	PACKAGING TECHNOLOGY AND SCIENCE 21, 231–246	2008
Spain・Sweden	Spain 3	Giner, García-Romeu-Martínez	Improvement on Transport Simulation Through Agricultural Routes Monitoring	Proceedings of 17th IAPRI World Conference on Packaging, 695-697	2010
Thailand	Thailand 1	Chonhenchob, et al.	Measurement and Analysis of Truck and Rail Vibration Levels in Thailand	PACKAGING TECHNOLOGY AND SCIENCE 23, 91–100	2010
	Thailand 2	Chonhenchob, et al.	Measurement and Analysis of Distribution Environment in Thailand: The Case of Produce Distribution	Proceedings of 15th IAPRI World Conference on Packaging, 26-30	2006
UK	UK 1	Griffiths, Hicks, Keogh, Shires	Investigating the Suitability of Testing Standards for Simulating Vehicle Vibrations during Supermarket Home Delivery	Proceedings of 17th IAPRI World Conference on Packaging, 695-697	2010
USA	USA 1	J. Singh, P. Singh, Joneson	Measurement and Analysis of US Truck Vibration for Leaf Spring and Air Ride Suspensions, and Development of Tests to Simulate these Conditions	PACKAGING TECHNOLOGY AND SCIENCE 19, 309–323	2006
	USA 2	Joneson	Developing a Random Vibration Profile Standard	Proceedings of the 23rd IAPRI Symposium on Packaging	2007
	USA 3	Joneson, P. Singh, J. Singh	Developing Safe Loading and Damage Reduction Methods for Less than Truck Load Shipments	Proceedings of 15th IAPRI World Conference on Packaging, 1-7	2006

5.3 Model countries and regions

Model countries and regions for this report were selected as listed in Table 3 from the source literature cited in 5.2.

Table 3. Model countries and regions

Country	Region
Bolivia	South America
Brazil	South America
China	East Asia
India	Central Asia
Japan	East Asia
Mexico	Central America
Spain	Europe
Thailand	Southeast Asia
United Kingdom	Europe
United States	North America

6. Summing-up of Actual Measurement Data (Grms values of transportation vibration)

6.1 Limitations of data

Generally, the information used to represent the characteristics of transportation vibration is the PSD profile (frequency characteristic) and its corresponding Grms values of random vibrations in three directions, namely, the longitudinal, lateral, and vertical directions. However, it is difficult to analyze and estimate the differences in the PSD profile using the generally available statistical data. In this research, therefore, the Grms values were used by defining them as "actual measurement data." Also, in the estimation, only the Grms values in the vertical direction which had the greatest vibration acceleration component among the three directions was employed. In fact, some of the referenced literature listed the PSDs and Grms values in the vertical direction only as the measurement results.

The truth of the matter, however, is that these data were not necessarily consistent due to the differences in the size of vehicle, suspension, and loading weight, as well as the differences in measuring devices and their settings. Yet, it was not practicable for us to carry out transportation vibration measurements in those countries under the current circumstances. Despite these limitations, we considered the Grms data sufficiently usable.

6.2 Sum-up method of Grms values

These data from the source literature could not be used directly because they were a mixture of data obtained under varying conditions as mentioned above. Nevertheless, it was also difficult to coordinate these data on unified criteria. Based on this understanding, we summed up the Grms value data on a certain number of criteria, thus creating information adequate for the objective of this research. The criteria we employed were as follows:

- All the vehicles are assumed to be ones with leaf suspensions unless there is a clear mention of air suspensions in the literature.

- The measurement of Grms values is mostly done with a measuring equipment located in the rear portion of the truck bed. This is due to the understanding that greater acceleration occurs in the rear rather than in the front of the truck bed. Accordingly, even when there is no clear mention of the position of the measuring equipment, we assume that the measuring equipment is located in the rear portion of the truck bed.

- At the time of measurement, the vehicle may be empty, half-loaded, fully loaded, or loaded in any other way. For simplicity, no consideration is given to the differences in loading weight in this research.

Also, the sum-up procedure employed was as follows. Note that the averaging and the equalization of different types of suspensions were done at our discretion.

(1) Information is summarized by country.

(2) Data are classified by vehicle, suspension, and loading weight, and the Grms values in the vertical direction are recorded.

(3) The average of Grms values is calculated for each suspension type and used as the "representative Grms value" of the air suspension or the leaf suspension.
(In doing so, no consideration is given to the difference in loading weight at the time of measurement.)

(4) The "representative Grms value" for the air suspension is adjusted by multiplying by 2.37.

<u>Reason for multiplication by 2.37</u>

- Literature # "USA 1" compares the Gmrs values of trailers with leaf suspensions and those with air suspensions measured under the same conditions. The data show the Grms value for the leaf suspension 2.37 times that for the air suspension.
- To achieve the consistency of the values, the Grms values used were adjusted to those for the leaf suspension which come under severer acceleration condition.
- This does not necessarily mean that we stand for unification of Grms values in the future standardization. This was done only for the adjustment of data to simplify our analysis in this report.

(5) Finally, the "representative Grms value" for each country is unified by averaging the "representative Grms value" for the leaf suspension and the "adjusted representative Grms value" for the air suspension. The results are used as the "representative measured Grms values for the respective countries" in the subsequent analysis.

[Note]

For a full-scale measurement of transportation vibration, well-defined vehicles, suspensions, loading weights, and measuring device locations as well as predetermined initial settings of the measuring equipment must be used in gathering data. Also, this investigative research included no data analysis from the viewpoint of "acceleration tests" to shorten the testing time. The research covered only the method for estimating unknown Grms values of transportation vibration from generally available statistical data by making use of the measured Grms values of transportation vibration derived from the source literature.

6.3 Sum-up results of Grms values

Table 4 shows the results of calculation of representative measured Grms values by country. They were calculated from the measured Grms values of transportation vibration selected from the source literature data using a method described in 6.2.

Special handlings applied in organizing the data were as follows:

- The data from Brazil had a mention of "acceleration trigger measurement at a trigger level of 0.25G," which may push the average Grms value higher than an actual level. However, without any other data to be referenced, the data of the literature were used as they were.

- The data from Spain included the transportation vibration data (Spain 3) of the transportation from Spain to Sweden.

- The data of UK indicate the vehicle as vans. However, without any other valid data available, the values of the literature were used as they were solely for the purpose of this research.

- USA 1 represents the average PSDs and Grms values derived for the upper 30% events and the other 70% events of Grms value, respectively. In obtaining the "representative Grms values", those data were modified by weighted-averaging.

- USA 2 represents the average PSDs and Grms values derived for the upper 20% events and the other 80% events of Grms value, respectively. In obtaining the "representative Grms values", those data were modified by weighted-averaging.

Table 4. “Representative measured Grms values by country calculated from the source literature data

Country Literature #	Vehicle	Suspension	Load	Grms value (vertical)	Representative Grms value	Adjusted representative Grms value	Representative measured Grms values for the respective countries
Bolivia							0.43
Bolivia 1	Trailer (25 tons?)	Leaf	2 tons	0.43	0.43	0.43	
Brazil							0.63
Brazil 1	Combination of 6 tons Truck and 26 tons Trailer	Leaf	0.5 - 26 tons	0.63	0.63	0.63	
China							0.43
China 1	Trailer	Leaf	Half Loaded (details unknown)	0.11	0.15	0.15	
	Trailer	Leaf	Half Loaded (details unknown)	0.20	0.15	0.15	
China 2	Open Trailer	Leaf	Half Loaded (details unknown)	0.15	0.15	0.15	
	Open Trailer	Leaf	Half Loaded (details unknown)	0.16	0.15	0.15	
China 3	Street Truck (2 - 4 tons)	Leaf	Empty	0.92	0.65	0.65	
	Street Truck (2 - 4 tons)	Leaf	Fully Loaded (details unknown)	0.20	0.65	0.65	
	Closed Truck (7 tons)	Leaf	Half Loaded	0.78	0.65	0.65	
	Closed Truck (7 tons)	Leaf	Fully Loaded	0.48	0.65	0.65	
	Closed Truck (5 tons)	Leaf	Fully Loaded	0.93	0.65	0.65	
	Closed Truck (5 tons)	Leaf	Half Loaded	0.88	0.65	0.65	
	Closed Truck (7 tons)	Leaf	Over Loaded (14 tons)	0.38	0.65	0.65	
China 4	11' Small Truck (2 - 4 tons)	Leaf	Light Load (details unknown)	0.39	0.27	0.27	
	35' Trailer	Leaf	Heavy Loaded (details unknown)	0.20	0.27	0.27	
	UPS Feeder	Leaf	?	0.23	0.27	0.27	
India							0.29
India 1	Truck	Leaf	5 - 6 tons	0.15	0.15	0.15	
India 2	Truck	Air-ride	?	0.15	0.15	0.36	
	Truck	Air-ride	?	0.16	0.15	0.36	
Japan							0.19
Japan 1	14 tons Truck	Air-ride		0.06	0.06	0.14	
Japan 2	Trailer	Air-ride	13 tons	0.10	0.10	0.25	
Mexico							0.38
Mexico 1	Trailer	Leaf	?	0.27	0.27	0.27	
	Trailer	Air-ride	?	0.21	0.21	0.50	
Spain							0.23
Spain 1	Truck	Air-ride	1/3 of 4 tons Loaded	0.13	0.12	0.28	
	Truck (A single-unit truck pulling a double-axle pup trailer)	Air-ride	Half Loaded	0.11	0.12	0.28	
Spain 2	Truck	Air-ride	Empty	0.09	0.09	0.21	
	Truck	Air-ride	21 tons	0.09	0.09	0.21	
	Truck	Leaf	Empty	0.25	0.22	0.22	
	Truck	Leaf	3 tons	0.19	0.22	0.22	
Spain 3 (Spain to Sweden)	Truck	Air-ride	0.66 tons	0.09	0.09	0.21	
Thailand							0.31
Thailand 1	Small Truck	Leaf		0.22	0.22	0.22	
Thailand 2	4.8m Trailer	Leaf	0.72 tons	0.31	0.34	0.34	
	4.8m Refrigerated Trailer	Leaf	7.2 tons (Full)	0.29	0.34	0.34	
	7.1m Refrigerated Trailer	Leaf	4 tons	0.36	0.34	0.34	
	7.1m Refrigerated Trailer	Leaf	15 tons (Full)	0.40	0.34	0.34	
UK							0.27
UK 1	Van	Leaf	Empty	0.30	0.30		
	Van	Leaf	Empty	0.28	0.28		
	Van	Leaf	Empty	0.22	0.22		
USA							0.41
USA 1	26 tons Trailer	Air-ride	21 tons	0.28	0.19	0.44	
	26 tons Trailer	Air-ride	21 tons	0.15	0.19	0.44	
	26 tons Trailer	Leaf	21 tons	0.66	0.45	0.45	
	26 tons Trailer	Leaf	21 tons	0.35	0.45	0.45	
USA 2	?? tons Trailer	Air-ride	?? tons	0.25	0.17	0.39	
	?? tons Trailer	Air-ride	?? tons	0.15	0.17	0.39	
USA 3	LTL ?? tons Trailer	Leaf	?? tons	0.34	0.37	0.37	
	LTL ?? tons Trailer	Leaf	?? tons	0.33	0.37	0.37	
	Pup Trailer	Leaf	?? tons	0.44	0.37	0.37	

7. Narrowing-down of Highly Usable Indicators and Indexes

7.1 Narrowing-down criteria

Table 5 lists the indicators and indexed employed in the report of the previous research.

Table 5. A list of indicators and indexes

Category	Indicators and Indexes	Source	Publisher	Charged?
Economy	GDP、GDP per capita	World Economic Outlook	IMF	
	GNI、GNI per capita	World Development Indicators	WB	
Competitiveness	Global Competitiveness Index (GCI)	The Global Competitiveness Report	WEF	
	Enabling Trade Index (ETI)	The Global Enabling Trade Report	WEF	
	Logistics Performance Index (LPI)	World Development Indicators	WB	
	Logistics Performance Index (LPI)	Connecting to Compete	WB	
Transport infrastructure	Basic Requirements	The Global Competitiveness Report	WEF	
	Infrastructure (全体)	The Global Competitiveness Report	WEF	
	Transport infrastructure	The Global Competitiveness Report	WEF	
	Quality of overall infrastructure (Transport)	The Global Competitiveness Report	WEF	
	Transport and communications infrastructure	The Global Enabling Trade Report	WEF	
	Availability and quality of transport infrastructure	The Global Enabling Trade Report	WEF	
	Availability of transport infrastructure	The Global Enabling Trade Report	WEF	
	Transshipment connectivity index	The Global Enabling Trade Report	WEF	
	Quality of trade and transport related infrastructure	Connecting to Compete	WB	
	Ease of arranging competitively priced shipments	Connecting to Compete	WB	
	Competence and quality of logistics services	Connecting to Compete	WB	
	Ability to track and trace consignments	Connecting to Compete	WB	
	Frequency with which shipments reach the consignee within the scheduled or expected delivery time	Connecting to Compete	WB	
	% of shipments meeting quality criteria	Connecting to Compete	WB	
	Physical inspection	Connecting to Compete	WB	
	EBRD index of infrastructure reform	Transition Report	EBRD	
Roads	Quality of roads	The Global Competitiveness Report	WEF	
	Paved roads	The Global Enabling Trade Report	WEF	
	Paved roads	World Development Indicators	WB	
	Paved roads	Key Indicators for Asia and the Pacific	ADB	
	Paved roads	World Road Statistics	IRF	Yes
	Paved roads	Statistical Yearbook for Asia and the Pacific	UN ESCAP	
	Paved roads	The ASEAN Statistical Yearbook	ASEAN	
	Road surface condition of major ASEAN roads	ASEAN Distribution Network Map	JETRO	Yes
	Traffic condition of major ASEAN roads	ASEAN Distribution Network Map	JETRO	Yes
	Road management entities	World Road Statistics	IRF	Yes
	Road related expenditure	World Road Statistics	IRF	Yes
	International Roughness Index		WB, etc.	
	Access to an All- Season Road (percent of rural population)	Key Indicators for Asia and the Pacific	ADB	
	Port or airport supply chain Distance (export)	Connecting to Compete	WB	
	Port or airport supply chain Lead time (export)	Connecting to Compete	WB	
	Port or airport supply chain Distance (import)	Connecting to Compete	WB	
	Port or airport supply chain Lead time (import)	Connecting to Compete	WB	
	Land supply chain Distance (export)	Connecting to Compete	WB	
	Land supply chain Lead time (export)	Connecting to Compete	WB	
	Land supply chain Distance (import)	Connecting to Compete	WB	
	Land supply chain Lead time (import)	Connecting to Compete	WB	
Railroads	Quality of railroad infrastructure	The Global Competitiveness Report	WEF	
	Major railroad network of ASEAN	ASEAN Distribution Network Map	JETRO	Yes
Air transport	Quality of air transport infrastructure	The Global Competitiveness Report	WEF	
Ocean transport	Quality of port infrastructure	The Global Competitiveness Report	WEF	
	Quality of port infrastructure	World Development Indicators	WB	
	Quality of Port Infrastructure	DataGov	IADB	
Warehousing	Border administration	The Global Enabling Trade Report	WEF	
	Efficiency of import-export procedures	The Global Enabling Trade Report	WEF	
	Efficiency of the clearance process	The Global Enabling Trade Report	WEF	
	Time to import	The Global Enabling Trade Report	WEF	
	Time to export	The Global Enabling Trade Report	WEF	
	Lead time to import	World Development Indicators	WB	
	Lead time to export	World Development Indicators	WB	
	Efficiency of the clearance process	Connecting to Compete	WB	
	Clearance time (days)	Connecting to Compete	WB	
Temperature and humidity	Monthly Climatic Data for the World	Japan Meteorological Agency website	JMA	
	Monthly Climatic Data for the World	World Meteorological Organization website	WMO	
	Monthly Climatic Data for the World	NOAA Monthly Climatic Data for the World	NOAA	

A primary narrowing-down of indicators and indexes was carried out on the following criteria:

- When there are indicators and indexes intuitively similar to each other, more general ones are to be selected from them.
- The data are to serve as primary information.

Note, however, that the WEF's Global Competitiveness Index (GCI) and WB's Logistics Performance Index (LPI) included a number of secondary indicators and indexes. While they could not be used as primary information, those indexes were left undiscarded and checked for their impact.

7.2 Narrowed-down indicators and indexes (primary narrowing-down)

Table 6 lists indicators and indexes narrowed down from Table 5 on the criteria cited in 7.1. They are the indicators and indexes representing "overall national competitiveness," "quality of infrastructure," and "facility of trade."

Table 6. List of narrowed-down indicators and indexes

Category	#	Indicators and Indexes	Source	Institution
Economy	1	GDP	World Development Indicators	WB
	2	GDP per capita	World Development Indicators	WB
	3	GNI	World Development Indicators	WB
	4	GNI per capita	World Development Indicators	WB
Competitiveness	5	Global Competitiveness Index (GCI)	The Global Competitiveness Report	WEF
	6	Logistics Performance Index (LPI)	World Development Indicators	WB
Transport infrastructure	7	Quality of overall infrastructure (Transport)	The Global Competitiveness Report	WEF
	8	Availability and quality of transport infrastructure	The Global Enabling Trade Report	WEF
Roads	9	Quality of roads	The Global Competitiveness Report	WEF
	10	Paved roads	World Development Indicators	WB
Railroads	11	Quality of railroad infrastructure	The Global Competitiveness Report	WEF
Air transport	12	Quality of air transport infrastructure	The Global Competitiveness Report	WEF
Ocean transport	13	Quality of port infrastructure	The Global Competitiveness Report	WEF
Warehousing	14	Lead time to import	World Development Indicators	WB
	15	Lead time to export	World Development Indicators	WB

These narrowed-down indicators and indexes were finally reduced further through a multiple regression analysis.

8. Performance of Multiple Regression Analysis

A multiple regression analysis was performed using the measured Grms values (representative measured Grms values by country) of transportation vibration as the objective variable and the generally available indicators and indexes as explanatory variables. Thus a multiple regression equation for predicting Grms values was derived for countries and regions where the logistics environment cannot be determined by actual measurements.

8.1 Correlation matrix

After the narrowing-down in 7.2, there were as many as 15 indicators and indexes remaining as explanatory variables for the multiple regression analysis. These indicators and indexes often have strong correlation and dependency between each other, so that a multiple regression analysis on this many indicators and indexes may result in an unstable analysis due to "multicollinearity." Hence, the correlation between these indicators and indexes was first checked by a correlation matrix to eliminate one of each pair which have strong correlation with each other. Table 7 shows a correlation matrix of the 15 indicators and indexes.

Table 7. Correlation matrix of indicators and indexes

	Measured Grms value	National land area (thousand km^2)	GDP 2011 ($ Billions) (w/o PPP)	GDP per capita ($) (w/o PPP)	LPI 2012	GNI ($ Billions) (w/o PPP)	GNI per capita ($) (w/o PPP)	GCI 2012-13	Quality of overall infrastructure	Quality of roads	Quality of railroad infrastructure	Quality of port infrastructure	Quality of air transport infrastructure	Paved roads (%)	Total road network (km)	Lead time to export (days) (WDI 6.9)	Lead time to import (days) (WDI 6.9)
Measured Grms value	1																
National land area (thousand km^2)	0.7016	1															
GDP 2011 ($ Billions) (w/o PPP)	0.1007	0.6837	1														
GDP per capita ($) (w/o PPP)	-0.3975	-0.0274	0.5896	1													
LPI 2012	-0.4585	0.0738	0.5671	0.8483	1												
GNI ($ Billions) (w/o PPP)	0.0478	0.6092	0.9880	0.6486	0.5770	1											
GNI per capita ($) (w/o PPP)	-0.4247	-0.0590	0.5607	0.9886	0.8419	0.6304	1										
GCI 2012-13	-0.3626	0.1609	0.6984	0.8663	0.9539	0.7141	0.8578	1									
Quality of overall infrastructure	-0.7017	-0.2570	0.3997	0.8419	0.8792	0.4500	0.8516	0.8167	1								
Quality of roads	-0.7286	-0.2795	0.3918	0.7790	0.8178	0.4399	0.7969	0.7704	0.9855	1							
Quality of railroad infrastructure	-0.7500	-0.1893	0.3968	0.6913	0.7263	0.4045	0.6901	0.6606	0.7505	0.7390	1						
Quality of port infrastructure	-0.7494	-0.2680	0.3815	0.7423	0.7899	0.4413	0.7943	0.7417	0.9426	0.9624	0.7702	1					
Quality of air transport infrastructure	-0.7762	-0.3471	0.2599	0.6044	0.7080	0.3308	0.6611	0.6451	0.8996	0.9237	0.6257	0.9548	1				
Paved roads (%)	-0.7807	-0.3971	0.1228	0.5330	0.7360	0.1684	0.5764	0.6141	0.8731	0.8768	0.6186	0.8837	0.9416	1			
Total road network (km)	0.1969	0.7717	0.8182	0.1979	0.2762	0.7975	0.1894	0.3659	0.0425	0.0272	0.2244	0.1094	0.0638	-0.0661	1		
Lead time to export (days) (WDI 6.9)	0.2305	-0.1696	-0.2755	-0.3021	-0.6447	-0.2505	-0.2683	-0.5627	-0.4920	-0.4315	-0.2401	-0.3586	-0.4489	-0.4865	-0.2714	1	
Lead time to import (days) (WDI 6.9)	0.2028	-0.1901	-0.3015	-0.3514	-0.7031	-0.2734	-0.3279	-0.6355	-0.5239	-0.4656	-0.2513	-0.4010	-0.4647	-0.5059	-0.2418	0.9840	1

In Table 7, the pairs having the absolute value of correlation coefficient of above 0.8 are indicated in red, and those from 0.4 to 0.8 in yellow. Thus, the explanatory variables which had red-colored correlation were further narrowed down while taking account of the relationship with the objective variable.

8.2 Narrowing-down of explanatory variables

Table 8 shows the finally narrowed-down indicators and indexes by reducing the explanatory variables by use of the correlation matrix and multiple regression analysis (using step-down procedure) while heeding the multicollinearity. These results do not necessarily reflect the general importance of the individual indicators and indexes, but show the validity of these variables in adequately explaining the objective variable which was the data used for this research ("representative measured Grms values by country" derived by arbitrarily selecting the measurement results of the Grms values of transportation vibration). Also, the number of explanatory variables was reduced to match as few as 10 objective variables used in this research.

Table 8. Correlation matrix of finally narrowed-down indicators and indexes

	Grms Value	National land area (thousand km^2)	Quality of railroad infrastructure	Total road network (km)	Lead time to import (days)
Grms Value	1				
National land area (thousand km^2)	0.7016	1			
Quality of railroad infrastructure	-0.7500	-0.1893	1		
Total road network (km)	0.1969	0.7717	0.2244	1	
Lead time to import (days)	0.2028	-0.1901	-0.2513	-0.2418	1

Though "national land area" and "total road network" had a high correlation coefficient at 0.7717, these two variables were left untouched for reasons given in 8.3.

8.3 Derivation of multiple regression equation

The multiple regression equation derived from the results of a multiple regression analysis using the finally narrowed-down four indicators and indexes as the explanatory variables and the Grms values of transportation vibration as the objective variable y is expressed as Equation 1 below.

$$y = (3.08E-05)x_1 + (-0.0356)x_2 + (-2.5E-08)x_3 + (0.0029)x_4 + 0.423 \quad \text{(Equation 1)}$$

y: predicted Gmrs value
x_1: national land area (1,000 km^2)
x_2: quality of railroad infrastructure
x_3: total road network
x_4: lead time to import

The coefficient of determination adjusted for the degree of freedom (correction R2) of this multiple regression equation is 0.93, which points to an excellent applicability of this multiple regression equation.

x_3 (total road network) has a positive simple correlation coefficient relative to the objective variable in Table 8 and a negative partial regression coefficient in Equation 1. Although there may be some multicollinearity, the values employed as the objective variable for the multiple regression analysis (representative measured Grms values by country) are primarily tentative values. Also, this research did not specifically aim at the derivation of a highly accurate multiple regression equation. Therefore, no further attempt at validation was made for the handling of these two variables. Also, the variable of "total road network" was left as it was because the following interpretation was also possible.

When there is a positive correlation between the Grms value and the national land area and there is also a positive correlation between the Grms value and the total road network, the partial regression coefficient of the total road network in the multiple regression equation normally comes in a positive value (the country having a large total road network has a large Grms value). However, when two countries having an identical national land area are compared with each other, the one having a larger total road network value may be taken as having a higher quality of infrastructure (a smaller Grms value accordingly).

Just for information, if the number of variables is further reduced and an analysis is performed using only two variables of "national land area" and "quality of railroad infrastructure", then it will be possible to obtain a multiple regression equation which has no correlation problem between variables and exhibits an excellent applicability with the determination coefficient adjusted for the degree of freedom (correction R2) of 0.86.

As for a detailed validation method for the relationship between individual explanatory variables, further study will be required when all the valid data are obtained in the future.

8.4 Comparison with actual measured values

Table 9 shows a comparison between the representative measured Grms values of ten countries predicted using the multiple regression equation derived in 8.3 and actual measurement data used in this research. In the table, the magnitude of the predicted Grms values is shown in three different colors classified using the standard deviation (σ).

Red:	Greater than 10 country average + 1σ	(Severity 1)
Yellow:	Between 10 country average ± 1σ	(Severity 2)
Green:	Smaller than 10 country average - 1σ	(Severity 3)

Further study and analysis may be necessary to determine whether this classification is appropriate or not. However, we believe it possible to use these predicted Grms values (or other predicted values to be developed in years to come) as a quantitative basis in selecting from the testing levels (test severities 1 to 3) of the current ISO 4180 standard. The possibility of classification of test severity levels will be discussed again in chapter 9.

Table 9 Comparison between predicted Grms values and measured Grms values and an example of classification

Country	National land area (thousand km^2)	Quality of railroad infrastructure	Total road network (km)	Lead time to import	Predicted Grms value	Measured Grms value	
Bolivia	1,099	3.0	62,479	28.3	0.43	0.43	
Brazil	8,515	1.8	1,751,868	3.9	0.59	0.63	
China	9,600	4.6	3,730,164	2.6	0.47	0.43	
India	3,287	4.4	4,236,429	5.3	0.28	0.29	
Japan	378	6.6	1,200,858	1.0	0.17	0.19	
Mexico	1,964	2.8	366,096	2.5	0.38	0.38	
Spain	505	5.7	667,064	7.1	0.24	0.23	
Thailand	513	2.6	180,053	2.6	0.35	0.31	
United Kingdom	244	5.0	419,634	1.9	0.25	0.27	
United States	9,832	4.8	6,506,221	4.0	0.41	0.41	
					0.36	0.36	Mean
Partial regression coefficient	3.07893E-05	-0.035601646	-2.45919E-08	0.002864145	0.13	0.13	Standard deviation (σ)
y-intercept	0.42345352				0.23	0.23	-1σ
					0.48	0.48	+1σ

8.5 Notes on this analysis

The multiple regression equation derived in 8.3 appears to realize highly accurate prediction. However, the following notes must be kept in mind in addition to the problem of how the explanatory variables are to be selected:

- The number of data (Grms values by country) serving as a basis for analysis was as small as 10.
- The calculated representative Grms values were a mixture derived by arbitrary methods using various vehicular conditions.
- No consideration was given to the frequency characteristic (PSD) of vehicles.
- The results were based on the analysis using truck and trailer data only because there were much fewer actual measurement data available on railroad transportation vibration.

Therefore it must be stressed here again that this investigative research had been conducted to validate the technique thus far presented rather than to prove the usability of the multiple regression equation derived in 8.3 for the prediction of the Grms values of transportation vibration in various countries. Thus, quite possibly, the explanatory variables and their coefficients to be incorporated into the multiple regression equation may change along with the transportation vibration data to be acquired in years to come, and accordingly it is possible that the multiple regression equation takes a drastically different form.

As stated in 6.1, this analysis does not allow the estimation of PSD, which is an important piece of information in determining the frequency characteristic of transportation vibration. Therefore, a possible solution may be to use a separately determined representative PSD profile with which the Grms value for each of the test severity levels is combined.

With the data on railroad transportation vibration accumulated in the future, it may be possible to estimate the Grms values for railroad transportation vibration using the same procedure as for the estimation for the transportation by trucks and trailers. Small and medium-sized enterprises may find it difficult to grasp the modes of transportation by which their cargoes will be carried to their destinations. When they assume a high possibility of railroad transportation in a particular region, they may find it convenient if they can design their testing sequence based on the generally available information such as the amount of railroad freight or the total distance of railroad lines.

Note that while the analysis itself can be made by any dedicated statistical analysis software, the present research has postulated the use of Microsoft's spreadsheet software "Excel" to achieve broad utility. However, for more detailed analysis which may be necessitated in the future, it may be necessary to consider the utilization of some dedicated statistical analysis software.

8.6 Technique for estimating drop impact

In principle, the same procedure as the one for transportation vibration can be used for estimating drop impacts. Our experience indicates that the data on drop heights in cargo handling are greatly varied. Also, it is necessary to incorporate such information as the number of drop tests to be conducted and the direction of dropping into the test conditions. Therefore, as stated in 8.4 and in chapter 9, the analysis of this research may be used in the classification of test severity levels rather than in estimating the drop height as a testing condition.

Also, the following points can be cited as additional explanatory variables for the estimation of the drop impact (rough handling). Yet, they should be selected carefully because they may have strong correlation with other variables (e.g., GNI per capita) in the correlation analysis of explanatory variables.

- Wage level of workers (transport, port operations, warehousing, etc.)
- Level of education (ratio of people completing higher education)

Drop impact may come in greatly varied values depending on the mode of transportation and the form of freight. In measuring drop impacts, therefore, it is extremely important to use unified measuring methods and conditions as in measuring transportation vibration.

8.7 Technique for estimating loading factor for compression test

The factors that can greatly affect the reduction in compressive strength of cargoes and consequent damage (corrugated packages in particular) may be load from above as well as temperature, humidity, number of storage days, and vibration and shocks during transportation. Another important factor may be the quality of transportation infrastructure, such as warehouses, that can protect packages from extreme temperature and humidity environments.

Concerning compression damage, it was difficult to obtain numerical data such as the measured Grms values of transportation vibration used as the objective variable in the multiple regression analysis of the present research. Therefore, an analysis at the same level as one of vibration cannot be carried out, but it may be possible to derive an equation for calculating the load coefficient using such indicators and indexes as the temperature and humidity, lead time to export/import (the number of storage days) and the quality of transportation infrastructure. There have been fewer reports on actual dynamic compressive force and the corresponding damage measurements done in transportation environment measurement studies. Therefore, estimating the loading factor for compression tests may require the selection of indicators and indexes and weighting them in accordance with the basic data on corrugated box strength and experience.

9. Possibility of Classification of Test Severity Levels

In this part of the research, the Grms values of transportation vibration in countries without actual measurement data were predicted using the multiple regression equation derived. Twenty countries for which indicators and indexes were available were first selected form respective regions. And based on the results, the possibility of classification of the vibration test levels was examined by the method discussed in 8.3.

Table 10 shows the explanatory variables (indicators and indexes) and their coefficients of the 20 countries without actual measurement data. Also, Table 11 shows the predicted Grms values and the results of classification using the standard deviation (σ) of the 20 countries.

Table 10 Explanatory variables of 20 countries without actual measurement data

Country	National land area (thousand km^2)	Quality of railroad infrastructure	Total road network (km)	Lead time to import
Argentina	2,780	1.7	231,374	3.8
Australia	7,741	4.3	818,356	2.8
Egypt	1,001	3.1	104,918	3.1
France	549	6.3	951,200	4.5
Germany	357	5.7	644,288	2.4
Hungary	93	3.5	197,534	5.0
Indonesia	1,905	3.2	437,759	5.4
Netherlands	42	5.7	136,135	1.9
Qatar	12	5.5	7,790	2.3
Peru	1,285	1.9	102,887	3.8
Philippines	300	1.9	200,037	5.0
Poland	313	2.4	383,313	3.6
Romania	238	2.2	198,817	2.0
Russian Federation	17,098	4.2	963,000	2.9
Saudi Arabia	2,000	3.7	221,372	6.3
South Africa	1,219	3.4	362,099	3.3
Sweden	450	4.7	574,741	2.6
Turkey	784	3.1	426,951	3.8
Uruguay	176	1.3	77,732	3.0
Vietnam	331	2.6	160,089	1.7
Partial regression coefficient	3.07893E-05	-0.035601646	-2.45919E-08	0.002864145

* The quality of overall infrastructure was used as a substitute for the quality of railroad infrastructure of Qatar.

Table 11. Example of classification of testing levels by predicted Grms values

Country	Predicted Grms value	Severity
Argentina	0.45	2
Australia	0.50	1
Egypt	0.35	2
France	0.21	3
Germany	0.22	3
Hungary	0.31	2
Indonesia	0.37	2
Netherlands	0.22	3
Qatar	0.23	2
Peru	0.40	2
Philippines	0.37	2
Poland	0.35	2
Romania	0.35	2
Russian Federation	0.78	1
Saudi Arabia	0.37	2
South Africa	0.34	2
Sweden	0.26	2
Turkey	0.34	2
Uruguay	0.39	2
Vietnam	0.34	2
Mean (Severity 2)	0.36	
Standard deviationσ	0.13	
-1σ (Severity 3)	0.23	
+1σ (Severity 1)	0.48	

According to the multiple regression equation derived by this research, the average of the predicted Grms values of the 20 countries was 0.36, and the standard deviation 0.13. The "predicted Grms values" were classified into three different colors in the same way as in 8.3 (see below).

[Coloring criteria]
The magnitude of the predicted Grms values is shown in three different colors classified using the standard deviation (σ).

Red: Greater than 20 country average + 1σ (Severity 1)
Yellow: Between 20 country average ± 1σ (Severity 2)
Green: Smaller than 20 country average - 1σ (Severity 3)

The distribution of the predicted Grms values was quite close to the results for the 10 countries which represented the use of actual measurement data from the source literature (rounding to the nearest hundredth produced exactly the same values). This led us to conclude that provided a sufficient number of highly accurate actual measurement data is available, it is possible to classify the testing severity levels using the predicted values calculated by the multiple regression equation.

10. Conclusion

Based on the report of the previous research, trials and examinations were carried out to verify the method to estimate the logistics environment using generally available indicators and indexes. In this research, we gathered measured Grms value data of transportation vibration as a factor representing the logistics environment from selected literature and estimated the Grms values by performing a multiple regression analysis from generally available indicators and indexes. As a result, we have reached the following understandings:

- It is possible to make a highly accurate prediction of the logistics environment by the multiple regression analysis if proper explanatory variables are selected. However, the measured Grms values used as the objective variable were not necessarily consistent data because of differences involved in the size of vehicle, type of suspension, loading weight, as well as the differences in measuring devices and their settings. Therefore, the multiple regression equation derived in this research should be used as reference only.

- There is a possibility of using the predicted Grms value in determining a test severity level even if it is not used as a testing condition.

- A sufficient number of measured data samples are required if the accuracy of prediction is to be raised.

- The method dealt with in this research does not allow the estimation of the PSD profile which is essential in determining the vibration test conditions. It is necessary to separately determine a representative PSD profile for each type of vehicle.

- The procedure similar to the one for predicting transportation vibration may be applied to the estimation of drop impacts. The procedure may be used in determining the test severity level rather than in estimating the drop height as a testing condition.

- Concerning compression damage, it is possible to use this technique in calculating the loading coefficient by selecting the indicators and indexes and weighting them in accordance with the basic data on the strength of corrugated boxes and experimental rule.

The following future assignments have been identified. “How are we to conduct the collection and analysis of actual measurement data?” cited as the “practical assignment” in the report of the previous research is now all the more important.

- In order to obtain highly accurate predicted values, it is necessary to create a regression model by obtaining a sufficient amount of actual measurement data using unified conditions and methods. We must investigate the concrete methods for gathering actual measurement data (applicable to vibration and drop impacts also).

- To confirm the accuracy of predicted values, it will become necessary to carry out verification tests on actual transportations in a number of countries. Who will shoulder the time and expenses for obtaining convincing data?

In addition to the above, we must continue dealing with the question: “How can this approach be accepted by other countries, and what should we do to have it accepted by them?”

We are positive that the developed testing method using generally available indicators and indexes is valid, but it is still our major challenge to find a better method for obtaining sufficient actual measurement data for this development.

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