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Study on Mainstreaming Disaster Risk Reduction in the Transport Sector of Developing Countries

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STUDY ON MAINSTREAMING DISASTER RISK REDUCTION IN THE TRANSPORT SECTOR OF DEVELOPING COUNTRIES

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ABSTRACT

Disasters have affected billions of people, in particular, the poor and vulnerable in developing countries. Since 1980, more than two million people and over $3 trillion have been lost to disasters caused by natural hazards. DRR is a broad term that includes anything we do to prevent or reduce the damage caused by natural hazards like earthquakes and floods. The funding for disaster prevention and preparedness contributes to reducing the number of deaths. In developing countries, there is a high demand for the development of transport infrastructure, which is the basis of national and regional socio-economic activities. Whenever they are acting as a connection to crucial services during emergency situations, sustainable transport systems are critical to disaster risk management.

The aim of the study is to develop an institutional and technical framework for mainstreaming disaster risk reduction in the road sector of developing countries and constructing a mechanism for effectively and efficiently implementing measures against disaster risks. It was required to convey necessary institutional and technical knowhow in an understandable manner for policy makers and practitioners in national and local governments. The study reviews best practices for disaster prevention measures in the world to propose the management framework contributing to disaster risk reduction targeted for road geohazards, such as debris flows and flash floods.

The effectiveness of disaster risk management actions needs to be assessed in line with the disaster life cycle phase consisting of mitigation, preparedness, response, and recovery. A resistant transportation network is not a network that is "unbreakable" by natural disasters, but rather a network that can be restored and reconstructed using multiple means and routes. It is useful to study the characteristics of travel time, traffic flow, and other factors after a disaster in order to consider measures to minimize the functional deterioration of the

transport systems. With the development of ICT in recent years, it has become possible to analyze inter-regional traffic flow after occurrence of the disasters using transport big data. There are risk management actions, the effectiveness of each of which can only be assessed by analyzing traffic after disaster on a microscopic level through transport big data. This study focuses on the development of the trip estimation method for small areas, such as urban districts, using the transport big data.

In conclusion, the developed framework is comprised of the stages of (1) institutional capacity and coordination, (2) systems planning, (3) engineering and design, (4) operations and maintenance, and (5) contingency planning. The framework would be put in place in a step-by-step manner depending on the capacity and financial constraints of the project-implementing countries. The effectiveness of disaster risk management is assessed by analyzing the actual state of transport functions after the disaster using transportation big data. The authors developed a method for estimating trip volume and trip modes for small areas such as “within a walking distance” using Wi-Fi data and mobile phone location data. A case study has been carried out in Tachikawa City to verify the accuracy of the estimation results. For future work, technology transfer to developing countries is required so that more advanced disaster risk management can be realized by adding traffic analysis using transport big data to the developed framework. The authors will upgrade the method for automating the data processing and continual trip monitoring. Finally, field testing in other cities besides Japanese cities needs to be conducted to improve the usability.

途上国の交通分野における災害リスク軽減の主流化に関する研究

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概要

近年、災害は何十億もの人々、特に開発途上国の貧困層や脆弱層に影響を与えている。1980 年以降、自然災害によって 200 万人以上の人々と 3 兆ドル以上が失われている。災害リスク軽減（Disaster Risk Reduction（DRR））とは、地震や洪水などの自然災害を防ぎ、被害を軽減するために行うあらゆる活動である。災害リスク軽減への投資は、死亡者数の減少に寄与する。途上国では、国や地域の社会経済活動の基盤となる交通インフラの整備が強く求められているが、緊急時においても各種サービスへのアクセスを提供する持続可能な交通システムは災害リスクマネジメントに不可欠とされている。

本研究の目的は、開発途上国の道路セクターにおける災害リスク軽減の主流化の制度的・技術的フレームワークの開発とし、防災対策を効果的・効率的に実施するためのメカニズムの構築を実現目標とする。途上国では、国や地方公共団体の政策立案者や実務者に対して、必要な制度的・技術的ノウハウをわかりやすく伝えることが求められている。本研究では、世界の防災対策のベストプラクティスを検証し、地滑りや堆積土石流などの道路ジオハザードを対象とした災害リスク軽減に資するマネジメントフレームワークを提案する。フレームワークを策定にあたっては、ISO 31000（リスクマネジメント手法のガイドライン）に準拠することで、災害リスクに対して調査・分析・評価・対策を行い、組織内での実践に不可欠なコミュニケーションやモニタリングを体系的に実施できるものとした。策定したフレームワークについては、交通や防災分野を担当する世界銀行の専門家等を得てその技術的妥当性を確認し、また、途上国への適用性を検証するため、ブラジル国およびセルビア国の現地政府の関係者等へのヒヤリングによりケーススタディを実施した。

災害リスク軽減に向けたマネジメントの有効性は、被害軽減、事前準備、応急復旧および復興といった災害対策の各段階に対して評価される必要があり、このような評価手法は、リスク・信頼性・脆弱性・堅牢性・レジリエンス等の視点から数多く存在する。評価に用いられる指標は、移動時間、交通流、アクセス性など交通システムが提供する「交通のサービス機能に関する指標」と、ネットワーク上の結節点や区間の相対的な位置関係や相互接続性を表現する「幾何的ネットワークに関する指標」に分類される。災害時における交通システムを評価するケースの多くは、

前者の指標を採用し、起こり得る災害やその影響をシミュレーションする。

災害に強い交通ネットワークとは、自然災害に「壊れない」ネットワークではなく、複数の手段やルートを使って復旧・再構築が可能なネットワークである。災害リスク軽減のためのマネジメントフレームワークの有効性は、災害時に交通システムが必要な機能を果たすことが可能か否かを分析することで評価される。すなはち、災害直後の移動時間や交通流などの特性を調べることが重要である。日本のパーソントリップ調査をはじめとする交通調査手法では、災害時の交通特性を把握することは不可能であったが、近年の ICT の発展に伴い、交通ビッグデータを用いて、災害発生後の広域の地域間交通流を分析することが可能となっている。一方、避難計画、地域内道路のリスクモニタリング、局地災害に対応する復旧計画、復興地区の経済再生などのマネジメントの評価には、狭域での災害時交通流を推計することが必要となるが、その手法は確立していない。そこで本研究では、都市中心部などの小規模エリアに焦点をあて、交通ビッグデータによるトリップ推定手法を開発した。

結論として、開発したフレームワークは、(1)組織能力と調整、(2)システム計画、(3)設計とエンジニアリング、(4)メンテナンスと運用および(5)危機管理計画の５段階で構成される。フレームワークの各対策は、プロジェクト実施国の能力や財政的な制約に応じて、段階的に導入していくことが可能である。また、フレームワークの適用は、簡易な低コストの技術から難易度の高い技術まで幅広く選択できるように工夫した。災害リスクマネジメントの有効性は、交通ビッグデータを用いて被災後の交通機能の実態を分析することで評価される。本研究では、Wi-Fi および携帯電話から取得されるデータを用いて、「徒歩圏」などの小規模エリアの交通量や移動手段を推定する手法を開発した。本手法を適用したケーススタディを立川市で実施し、推定結果の確からしさを検証した。今後の研究課題として、開発したフレームワークに交通ビッグデータによる災害時の交通分析を加え、より高度な災害リスクマネジメントが実現できるよう、途上国への技術移転が求められる。また、災害時の交通調査手法は、データ処理を自動化し、継続的に交通流をモニタリングする仕組み開発するとともに、日本以外の都市でのフィールドテストを実施する。

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1. Introduction

1.1. Background

Disasters have affected billions of people, in particular, the poor and vulnerable in developing countries. Since 1980, more than two million people and over $3 trillion have been lost to disasters caused by natural hazards. The total damage has been increasing by more than 600% per year, from $23 billion a year in the 1980s to $150 billion a year in the last decade (World Bank 2019). Kikuchi et al. (2015) evaluated 445 disaster prevention projects funded by the Japanese government, focusing on the number of reduction effects of death, and the world disaster-related funding since 1990 was analyzed by the same evaluation indicator. The funding for preparedness contributes to reducing the number of deaths, and the financial assistance, which is placed fifth in terms of the total amount of funding, is the main factor in terms of death toll reduction. Japanese funding is highly evaluated to give priority to investing for the promotion of prevention and preparedness.

The Japan-World Bank Program for mainstreaming disaster risk management was started in 2014 with funding from Japan to share knowledge, expertise, and technology with developing countries in order to give priority to disaster risk reduction (DRR) (World Bank 2018). DRR is a broad term that includes anything we do to prevent or reduce the damage caused by natural hazards like earthquakes and floods. Since developing countries lack sufficient funds and knowledge to implement full-scale disaster prevention measures, this program will enable each country to mainstream disaster prevention in national development plans and infrastructure investment programs depending on the capacity constraints of the country. It was pointed out that there is a need for a mechanism to effectively and efficiently implement DRR. In addition, it was required to convey the necessary institutional and technical knowhow in an understandable manner for policy makers and practitioners in national and local governments.

In developing countries, there is a high demand for the development of transport infrastructure, which is the basis of national and regional socio-economic activities. Whenever they are acting as a connection to crucial services during emergency situations, transport linkages are critical to disaster risk management. Strategically planned transport systems are foundational to the resilience of urban and rural residents (World Bank 2017). In particular, since there is an enormous need for highway development, disaster risk countermeasures should be put in place at each stage of planning, implementation, and management in order to mainstream disaster prevention in highway projects in developing countries. One of the major natural disaster risks in the road sector is road geohazards, which is defined as “events caused by geological, geomorphological, and climatic conditions or processes that represent serious threats to human lives, property, and the natural and built environment” (Solheim et al. 2005). The authors have targeted road geohazards for this study, in which disaster risk countermeasures will be examined, and a framework for road geohazard risk management will be proposed.

An institutional and technical framework contributing to DRR will be proposed through a review of best practices for disaster prevention measures in the world. Development of the framework will be phased in stages according to the capacity and financial constraints of developing countries. The framework will be utilized to mainstream disaster prevention in the road sector in developing countries and to construct a mechanism for effectively and efficiently implementing measures against disaster risks.

With regard to the mainstreaming of disaster reduction in the road sector, there is one more important issue that the function of roads in disasters has not been fully considered in the evaluation approach even in disaster-prone countries like Japan (Harada et al. 2017). When a large-scale disaster occurs, people will suffer from serious impacts such as impassable routes, lengthy detours, and severe traffic congestion. Impassable routes make it difficult to transport goods, and the lengthy detours delay life-saving emergency services. As roads play an important role in disasters, it is necessary to develop a reliable road network that would not become seriously dysfunctional even in disasters.

In evaluating road improvement projects, the benefits of travel-time saving, reduction in travel costs, and reduction in traffic accidents are quantified with sufficient accuracy. However, there are few cases, to the best of our knowledge, where the performance of improved roads in disasters is included in benefit-cost analysis. In order to effectively and efficiently develop a road network that can function in times of disaster, it is important that the cost-effectiveness of road improvement is ensured by quantifying the function of roads in disasters in addition to that in normal times. In Japan, a method of evaluating the function of roads in disasters has been proposed in order to prioritize road improvement projects with higher cost-effectiveness in terms of disaster risk reduction. But, since it is not possible to convert the evaluation results of the function of roads into monetary units, they cannot be incorporated into cost-benefit analysis (Ministry of Land, Infrastructure, Transport, and Tourism in Japan 2016).

Faturechi et al. (2015) provided a comprehensive overview of the literature on transportation infrastructure system performance in disasters. The literature on disaster-related performance measurement can be categorized by whether qualitative assessment results are given or quantitative measures are defined. Qualitative assessment can provide insights into risk evaluation and risk management tactics. Quantitative measures, on the other hand, provide direct measurement that can be used to predict the impact of disasters. Such measures can aid in the prioritization of mitigation, preparedness, and adaptive actions. Some quantitative measures have been implemented within software or other types of decision support tools, in which mathematical models or quantification techniques are provided. Mathematical models support transportation risk management including the prioritization and optimization of pre- and post-disaster investment options with the aim of maximizing a system's coping capacity, reducing disaster losses, and/or restoring performance.

It is critically important to understand the characteristics of traffic flow and travel time at the occurrence of large-scale disasters because traffic flow occurs for rescue, medical care, supply of commodities, restoration works, safety confirmation of family members, volunteers, and so on. Since it is difficult to precisely estimate the external disaster forces and damaged areas, it is equally difficult to estimate the traffic volume and travel speed during a disaster. However, with the development of ICT in recent years, the use of big data in the field of disaster management has been progressing, and there have been several reports on the use of location data from cell phones (Yoshida et al. 2018).

1.2. Objective of the study

The aim of the study is to develop an institutional and technical framework for mainstreaming disaster prevention in the road sector of developing countries and constructing a mechanism for effectively and efficiently implementing measures against disaster risks. Developing countries lack sufficient funds and knowledge to implement full-scale disaster prevention measures, and it is required to convey the necessary institutional and technical knowhow in an understandable manner for policy makers and practitioners in national and local governments. The study reviews the best practices for disaster prevention measures in the world to propose a framework contributing to disaster risk reduction targeted for road geohazards such as debris flows, sediment flows, and flash floods. Development of the framework will be phased in stages according to the capacity and financial constraints of developing countries.

This study also develops a method for analyzing real traffic in the event of disasters using big data in the transport sector, as shown in Figure 1.1. It is important to evaluate transport systems in disasters in line with the disaster life-cycle phase consisting of mitigation, preparedness, response, and recovery. Evaluation of disaster prevention measures in the disaster life-cycle needs to be undertaken to assess the effectiveness of disaster risk management actions. It is useful to study the characteristics of travel time, traffic flow, and other factors after a disaster in order to consider measures to minimize the functional deterioration of transport systems. With the development of ICT in recent years, the use of big data in the field of disaster risk management has been progressing to analyze inter-regional traffic flow after disasters. This study will focus on the development of the trip estimation method for small areas, such as urban districts, using transport big data.

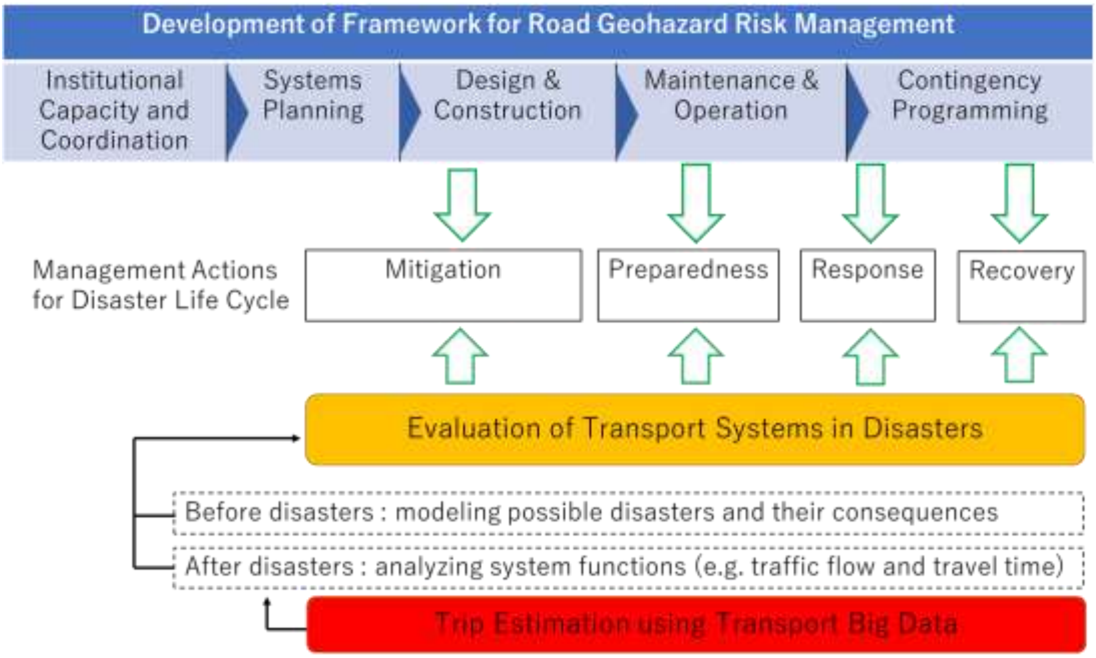
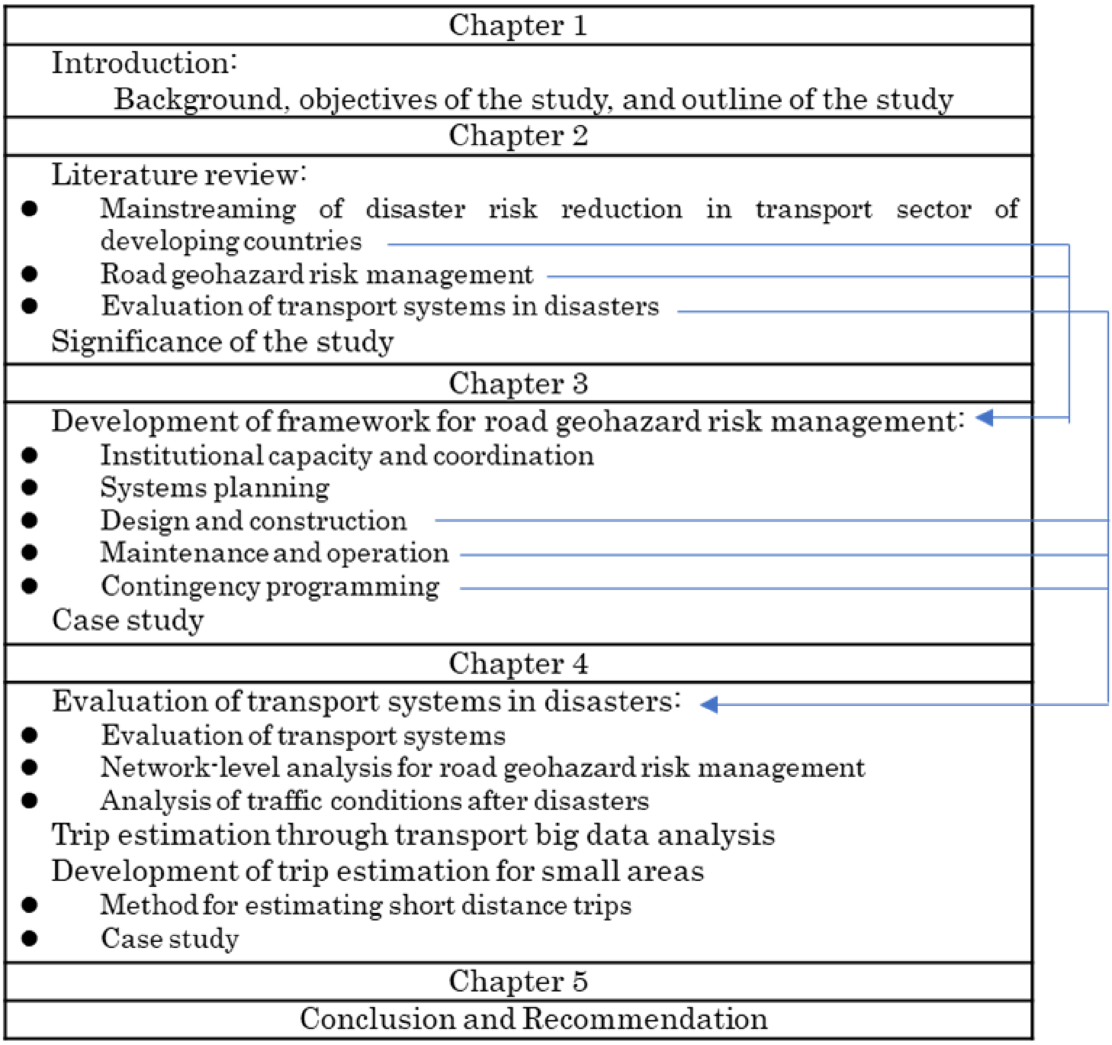


Figure 1.1 Scheme of the study

1.3. Outline of the study

Chapter 1 introduces the background and objectives of the study. Chapter 2 provides literature reviews and the significance of the study. Chapter 3 explains the details of the development of the road geohazard risk management framework for mainstreaming disaster risk reduction in developing countries. The framework components include institutional capacity and coordination, systems planning, design & construction, maintenance & operation, and contingency programming. Chapter 4 explains the details of project evaluation and trip estimation for DRR in the transport sector. Project evaluation explains methods to evaluate transport systems in disasters, related to the network-level evaluation method for road geohazard risk management. The discussion leads to the development of the short distance trip estimation method through transport big data analysis. As shown in Figure 1.2, Chapter 3 is linked with the first two literature contents. The last literature review content and the last three contents in Chapter 3 lead to Chapter 4. Chapter 5 concludes the thesis with recommendations and future works.



Chapter 1

Introduction:

Background, objectives of the study, and outline of the study

Chapter 2

Literature review:

- Mainstreaming of disaster risk reduction in transport sector of developing countries
- Road geohazard risk management
- Evaluation of transport systems in disasters

Significance of the study

Chapter 3

Development of framework for road geohazard risk management:

- Institutional capacity and coordination
- Systems planning
- Design and construction
- Maintenance and operation
- Contingency programming

Case study

Chapter 4

Evaluation of transport systems in disasters:

- Evaluation of transport systems
- Network-level analysis for road geohazard risk management
- Analysis of traffic conditions after disasters

Trip estimation through transport big data analysis

Development of trip estimation for small areas

- Method for estimating short distance trips
- Case study

Chapter 5

Conclusion and Recommendation

Figure 1.2 Chapter contents

2. Literature review and significance of the study

2.1. Mainstreaming of disaster risk reduction in the transport sector of developing countries

Approaches to mainstream DRR in developing countries and frameworks for disaster risk management in the transport sector are found in the following cases. Asian Disaster Preparedness Center and Department of Disaster Management (Bhutan) (2014) developed a policy recommendation on numerous options for mainstreaming DRR into the road and bridge sector in Bhutan. These options include the use of disaster risk assessments during the construction of new roads as well as the use of natural hazard risk information in land use management. It is indicated that the consideration of hazard and risk information at the early stages of the project management process can lead to long-term savings, both in terms of the initial cost of the project and the cost of maintenance operations over the life of the infrastructure. This is because investment in the mitigation and management of risk has generated high economic rates of return.

The World Bank (2015) proposed an analytical framework for mainstreaming resilience in transport systems. This framework addresses the three key levels when identifying problems in a transport system and planning, designing, and evaluating transport projects. These levels are temporal dimensions, transport management domains, and principles of resilience. The temporal dimensions are the three key stages: pre-disaster risk assessment and management, emergency response and risk reduction, and post-disaster recovery and reconstruction. Transport management domains introduced for resilience are policies, institutions, and processes; expertise; financial arrangements and incentives; operations and maintenance; and technical planning and design. Nine principles of resilience, including safe failure, redundancy, and good governance, are introduced across these domains and stages to measure resilience in transport systems. The World Road Association (2013) compiled a technical report on risks associated with natural disasters, climate change, man-made disasters, and security threats for highway management and operations. This work focuses on four key areas: (1) a step-by-step user guide to assist road authorities in evaluating risks associated with all hazards, (2) practical techniques for managing risks associated with natural disasters, (3) case studies documenting the step-by-step user guide to assist road authorities in reducing or mitigating risks, and (4) a proposed web-application Risk Management Toolbox.

Park et al. (2013) proposed risk and resilience approaches integrated into catastrophe management in engineering systems, in which resilience can be defined as the capability of systems to anticipate and adapt to the potential for surprise and failure. They argue that resilience is better understood as the outcome of a recursive process that includes sensing, anticipation, learning, and adaptation. In this approach, resilience analysis can be understood as differentiable from, but complementary to, risk analysis with important implications for adaptive management in the engineering systems. Meyer et al. (2012) argue that most transportation asset management plans do not currently detail the specific causes of failure in the State DOTs in the USA. Any hazard that affects the condition, performance, and life of the asset and its ability to provide a reliable and safe service will influence the timing of rehabilitation and replacement. They concluded that risk ratings or vulnerability indicators can be included in an asset-management database, which could be gathered by engineering surveying, to enable agencies to quickly determine where to target adaptation actions.

As a result of the literature review, despite the frequency of natural hazards and the threat of more extreme weather as a result of climate change, there are few works on how a systematic approach can be established to address natural disaster risks in the transport sector. To the best of the authors' knowledge, no studies have been done on comprehensive risk management frameworks for particular risk hazards to mainstream DRR in the transport sector in developing countries.

2.2. Road geohazard risk management

An institutional and technical framework will be proposed through a review of best practices for disaster prevention measures in the world. As a result of an initial review, the authors set up the following six pillars, from which the framework will be developed (World Meteorological Organization 2011, World Road Association (PIARC) 2012, Japan Sabo Association 2012, Japan International Cooperation Agency 2007, Ministry of Water and Resources in Nepal 1999, World Road Association (PIARC) 2010, Deoja et al. 1991):

- Country capacity review
- Inspection and identification of road hazards
- Evaluation and planning

- Structural measures
- Non-structural measure
- Emergency response, recovery, and reconstruction

Each of the framework pillars is described as follows.

Country capacity review

The procedure for the country capacity review would be developed and would describe the manner in which the procedure is to be performed. The purpose of the country capacity review is to assess the institutional capacity of a country and its current technical practices in order to take the necessary actions to tailor DRM to the unique circumstances of each targeted country and local authority. The main activities are defined:

Assessment of the roles and responsibilities of national and local governments and communities. It is important to examine practical mechanisms of coordinating government organizations and relationships between national and local governments. While local governments should have the primary responsibility in DRM, the national government should support local governments by providing technical and financial assistance in normal times, and by coordinating the organizations concerned and deploying specialized teams to respond to disasters (Global Road Safety Facility 2013).

Disaster management planning, countermeasures, and investment programs in developing countries. Each country should mainstream DRM into policy, planning, and management in all relevant sectors. Mainstreaming DRM has important implications for a country's growth and development agenda, since disasters can pose serious obstacles to socio-economic development. It is important to effectively integrate disaster risk considerations into sustainable development policies, planning, programming, and financing at all levels of government.

Assessment of institutional and technical coordination mechanisms at national and local levels. Each country should have a coordination mechanism for various organizations at different levels, e.g., a project coordination mechanism between government departments and agencies in charge of roads, rivers, agriculture, and other rural infrastructures. Inter-sector coordinating mechanisms are needed to properly design and implement DRM strategies. In order to promote DRM, the mechanism requires a number of elements: (i) political, (ii) technical, (iii) participatory, and (iv) resource mobilizing components. As the complexity of society increases, different institutions and formal or informal groups can be effectively involved in DRM.

Reviewing geohazard-related laws and regulations. The sediment-related disaster prevention law is the key to instituting comprehensive non-structural measures to protect people from geohazard-related disasters. These non-structural measures include the publication of risk information, development of warning and evacuation systems, restrictions on new land development for housing and other purposes, and promotion of the relocation of existing houses.

Assessment of levels of available technologies in structural and non-structural countermeasures. Technological capabilities have always been a fundamental component of development practice. However, access to advanced technology needs to be accompanied by substantial efforts for it to be absorbed, adopted, and learned. The assessment of levels of technologies is a vital stage in the process of a country taking the necessary actions to tailor sediment disaster management technology and expertise to its unique circumstances. The manual should cater to various levels of technology available in countries at differing stages of development.

Inspection and identification of road hazards

The procedure for carrying out the inspection and identification of potential hazardous locations should be described in detail, in order to develop suitable step-by-step interventions. The main activities are defined:

Regional inventory survey along road alignments. The inventory covers the classification of disasters, geohazard factors, hazard level, and other engineering details. The details of inventories shall be recorded on a specific recording form. Hazard level is an expectation of disasters, which will be scored according to the extent of road hazardousness based on geomorphic, geological, hydrological, meteorological, vegetation, and road conditions.

Identification of sediment-related risks in upstream and downstream areas. Geohazard-related disasters are categorized as three types, which are debris flow, landslide, and slope failure, to make structural and non-structural countermeasures effective and efficient for each phenomenon. The identification of sediment-related risks in upstream and downstream areas will involve investigations, such as a photogrammetric survey and geological survey, analysis of the geohazard disaster mechanism, and development of prediction methods for the entire catchment.

Scoring systems of risk levels and social factors. The risk level is set for the planning of measure works and emergency responses. The risk level will be scored not only by the hazard level obtained in the inventory survey but also by social factors. Social factors of roads consist of traffic volume, the existence of important facilities, key industry area, or existence of detour.

Preliminary prioritization of identified hazardous locations. High prioritization will be assigned where high-hazard locations and high-risk locations are concentrated. This information should be freely available from the road administration office for all interested people to ensure risks are easy to find. Also, it is recommendable to prepare a map on which hazard levels and risk levels are entered in order to enable these locations to be understood by managers and engineers.

Evaluation and planning

The manner in which hazardous locations are identified will be described and evaluated in order to undertake various actions and schemes, including structural/non-structural measures, hazard mapping, preventive traffic control in abnormal weather conditions, patrol/monitoring procedures, and the development of ICT networks for evacuation and early warning systems. The procedure for the planning of the DRM policy and program shall also be developed and shall describe the manner in which the procedure is to be performed. The main activities are defined:

Risk analysis to rate the consequences of damage on each hazardous location for quantification. Identified hazards cause natural disasters that may affect the target area and roads. Risk analysis determines if the damage actually occurs or not and the damage level by combining the vulnerability of each road facility and hazard.

Evaluation of the impact on damaged public facilities and private assets with rating of the likelihood of a particular hazard. Direct damage, such as human damage and physical damage to road facilities, and indirect damage, such as the disruption of road traffic, will be estimated in order to evaluate the consequences of disasters. Risks are evaluated quantitatively by multiplying the likelihood of a hazard and its consequences (Keiichi Tamura 2013).

Prioritization of appropriate intervention options in order to plan and

undertake specific structural and non-structural measures. Both structural and non-structural measures for the risks need to be considered. The priority of the measures should be examined based on the cost of the disaster prevention measures and the effectiveness of the measures (Ministry of Land, Infrastructure and Transport in Japan 2013).

Formulation of DRM policy and an action program for road and rural infrastructures. Based on the results of prioritization of intervention options, a comprehensive disaster prevention plan, including a recommended geohazard-related law and regulation, shall be developed to address the disaster risk areas where high-hazard locations and high-risk locations are concentrated. The comprehensive disaster prevention plan will be a practical combination of structural and non-structural measures, both of which will be undertaken step by step.

Structural measures

The procedure for the design of structural measures shall be developed and shall describe the manner in which the procedure is performed. The purpose of designing and implementing structural interventions is to make roads/communities more resilient to landslide disasters. The main activities are defined:

Investigation. The purpose of an investigation is to conduct field surveys/testing, such as geological and geotechnical surveys, prior to countermeasure works in order to categorize landslide types, such as slope collapse, rock fall, and mass movement, and to analyze the disaster factors. Field investigations should start with a comprehensive evaluation of general conditions (topography, geology, vegetation, etc.). The locations where abnormal conditions are found shall be monitored.

Selection of countermeasures. The purpose of the selection of countermeasures is to adopt appropriate structural measures that are cost effective and suitable based on a sound understanding of the characteristics of landslide disasters. The basic concept of a prevention measure shall be to remove the primary factor and the contributory factor. The primary factor is the ground's ability to remain healthy. It is the makings of the ground such as the geological or geomorphic characteristics. The contributory factor is the direct cause of landslides. It is natural phenomena such as heavy rain and earthquakes.

Development of design considerations. Countermeasures include all measures to avoid geohazard disasters which have occurred and occur repeatedly. The design specifications for designing the structural measures can be to prevent geohazard types. These measures can be applicable under limited budgets and with low construction technologies. Measures for geohazard disasters involving roads and communities are classified into earth work, surface cover, water drainage, slope work, vegetation, wall and resisting structures, protection work, and others (World Bank 2012; JICA 2009).

Risk management for road planning and design. There will be many cases where new roads are constructed in risk areas where landslides, debris flows, and slope failure are likely to occur. It is essential to consider and perform risk management at the planning, design, and construction phases of road development projects. Risk management techniques, such as road geometric design specifications (or considerations), for newly constructed roads should be developed.

Non-structural measures

The procedures for carrying out non-structural measures should be developed in order to preserve road infrastructures and communities in/near risk spots from landslides. The non-structural measures developed here will include hazard mapping, traffic control in abnormal weather conditions, patrol/monitoring procedures, and the development of ICT networks for evacuation and early warning systems:

Daily observation. The purpose of daily observation is to check the slope stability for the safe movement of vehicles and pedestrians and for taking immediate and suitable action for disaster prevention. The daily observation focuses on unusual or anomalies identification on road surfaces, cut slopes, foot slopes on river contact, drainage systems, retaining walls, gabions, etc. in patrol and monitoring activities on roads and rural infrastructures.

Risk monitoring. Risk monitoring involves installing instruments, such as wire sensors, extension meters, and monitoring cameras, which can be applied to high-risk spots in order to monitor critical slopes where landslides are likely to occur, and to collect information and data for designing future countermeasures. Since there have been many sediment disasters related to water, precipitation monitoring through a rain gauge and other instrumentations should be mandatory, in particular for early warning and evacuation (Ministry of Land, Infrastructure and Transport Infrastructure Development Institute – Japan 2004).

Early warning and evacuation. The purpose of an early warning and evacuation system is to notify the road management office of alerts when ICT devices detect the signal/symptoms of landslides through the automatic information system, together with the precipitation monitoring system for the wider area. Establishment of the system will require monitoring and forecasting of sediment disasters, delivery and transmission of sediment disaster information, and an evacuation plan (Typhoon Committee Sediment-Related Disaster Forecasting/Warning System Project 2009; Gasiorowski-Denis et al. 2016).

Geohazard-related risk management through a legal approach. Risk management will be strengthened through a legal approach, such as a license system for land development, restrictions on building structures, and the recommendation of the relocation of buildings, that designate sediment-related disaster hazard areas.

Hazard mapping. It is important that the construction of roads and highways takes into account the possibilities of sediment-related disasters from a watershed perspective. This not only reduces reconstruction costs but also reduces the potential loss of lives. Hazard maps provide information to communities on appropriate areas to build and potential areas that residents can evacuate to before a disaster occurs. A hazard map of geohazard-related disasters is prepared and made public in municipalities at risk of sediment disasters, thus providing residents with information for disaster risks, evacuation, and for land-use planning. The community participatory process and public awareness shall describe the manner in which the procedure is to be performed (Ministry of Water and Resources in Nepal 1998; ESCAP/WMO Typhoon Committee 2012).

Emergency response, recovery, and reconstruction

The procedure of recovering activities mid-disaster and post-disaster shall be developed and shall describe the manner in which the procedure is to be performed. The goal of these activities is to reduce the economic loss in cases of severe disasters by implementing emergency actions, i.e., warnings, evacuation, road closures, and publicizing information, and by mobilizing contractors and the resources necessary for highway restoration works. The main activities are defined:

Emergency inspection. The responsible government departments and agencies need to collect information such as the locations of landslides, damage, the conditions of the roads, the possibility of deaths, victims, and other disaster-related situations. The supervisor should report the site's condition to the follow-up engineer in charge.

Emergency traffic control and public notice. The responsible government departments and agencies need to block road sections that are in danger of being swept away or are not capable of being used in order to maintain the safety of vehicles and pedestrians. Information on traffic control shall be publicized in order to prevent many vehicles from being affected.

Recovery works. Temporary restoration shall be executed efficiently with the analysis of information that is collected in the emergency inspection. The ways of undertaking restoration work, such as diversion routes and temporary drainage installment, depend on the magnitude of the disaster, i.e., financial and institutional arrangements, procurement process, etc.

Reconstruction. It is a challenge to reconstruct destroyed roads and rural infrastructures in the long and medium term, taking into account recurring disaster risks in the future. Insights into the planning and delivery of post-disaster reconstruction shall be provided, based on many of the lessons and good practices, which will have value for future reconstruction scenarios in other countries.

2.3. Evaluation of transport systems in disasters

Disaster-related performance evaluation provides direct measurements that can aid in the prioritization of mitigation, preparedness, and adaptive actions. The literature on performance indicators for these evaluation methodologies can be categorized as risk, reliability, vulnerability, robustness, and resilient (Faturechi et al. 2015). A general definition of each indicator is shown in Table 2.1, and Figure 2.1 provides a schematic of their boundaries and interaction. A literature review on the disaster-related evaluation methodologies will be provided as follows.

Table 2.1 Definition of common evaluation indicator

Indicator	General definition
Risk	Combination of probability of an event and its consequences in terms of system performance
Vulnerability	Susceptibility of the system to threats and incidents causing operational degradation
Robustness	Ability to withstand or absorb disturbances and remain intact when exposed to disruptions
Reliability	Probability that a system remains operative at a satisfactory level post-disaster
Resilience	Ability to resist, absorb and adapt to disruptions and return to normal functionality

Source: Data from Faturechi et al. (2015)

Figure 2.1 Boundaries and interactions of evaluation indicators

Source: Illustrated based on Faturechi et al. (2015)

Risk

Chang et al. (2010) developed a systematic approach for risk modeling and disaster management of transportation systems in the context of earthquake engineering. The regions potentially unreachable after a damaging earthquake are identified by using network reachability algorithms that provide essential information for rapid emergency response decision-making. An integrated simulation model of travel demand is also developed to approximate “abnormal” post-earthquake travel patterns and evaluate the functional loss of the transportation systems. The methodologies are intended to maximize the overall system functionality and the benefit of mitigation investment for transportation infrastructure systems.

Kikuchi et al. (2019) developed the system dynamics model to estimate the impacts of transport and land-use adaptation policies on flood risk. The model was applied to Ubon Ratchathani, which is a middle-sized city in Thailand. The municipality was planning various adaptation policies for reducing flood damage due to the rising maximum flood water level. Utilization of the existing by-pass road and the dispersal of residents by using the flood hazard were selected as the scenario settings for the adaptation policies. It was found that the adaptation policies for the reduction of flood risk could help to reduce the total damage cost by 95.4 billion THB.

Vulnerability

Liu et al. (2016) presented a new theory for examining the vulnerability of the form of the network. The purpose is to not only identify the ways a road network can become partially or completely dysfunctional but to identify high-consequence events (but low-probability) that may arise from vulnerable weaknesses in the form of the network. The theory has been developed through an analogy with the structural vulnerability theory using systems thinking. The consequences of damage are evaluated by a change in the performance measure called ‘well-formedness’, which is related to the form of a network (including lengths, capacities, etc.) but is independent of traffic demand.

Abad et al. (2017) assessed the vulnerability of alternate traffic routes in Metro Manila to flooding. The alternate routes (17 routes in total) are locally called ‘Mabuhay Lanes (ML)’, which were designed to provide an alternate route for car users going to and from the northern and southern cities of Metro Manila. Reduced road serviceability depending on the level of flood hazard in the road network is used to assess the vulnerability of the Mabuhay Lanes. Network robustness indexes calculating the change in the coast when the network becomes unusable were applied as well. The study identified which among these routes would be most affected in the event of a 5-year annual exceedance probability flood.

Robustness

Cappanera et al. (2011) developed a game theoretic approach for allocating protection resources among the components of a network so as to maximize its robustness to external disruptions, which may result in traffic flow delays through the affected components or in the complete loss of some elements. The proposed method identifies the set of components to harden so as to minimize the length of the shortest path between a supply node and a demand node after a worst-case disruption of some unprotected components. The solution method is able to identify optimal protection strategies for networks of significant size.

Ando et al. (2021) attempted to improve the connectivity of a road network so that it can be robust against possible natural or man-made disasters. The study uses the eigenvector centrality (EC) measure that indicates the strength of the connection of one node to its adjacent nodes based on a network topology with a small computational load, taking into account their strengths of connection. It was found that the capacity-weighted eigenvector centrality analysis can identify the strongly and weakly connected parts of the network, and it can be used to evaluate the connectivity of the network for robustness.

Reliability

Pkharel et al. (2016) proposed a network evaluation methodology, from the viewpoint of reliability, to prioritize road network links for improvement to avoid network closure and to identify the network performance at any time during the restoration of damaged links. During network closure, the travel time is increased due to the detour, and traffic flow increases along the available route immediately after a disaster, causing congestion. The proposed methodology prioritizes the closed road network links in two stages: it prioritizes the links necessary for the network connection, and it prioritizes links to increase the network performance. The proposed methodology was applied to the Tohoku regional road network, where numerous links were closed after the Great East Japan Earthquake.

Tani et al. (2018) proposed a stochastic user equilibrium assignment model under stochastic origin-destination (OD) demand and link capacity that follows lognormal distributions. The model aims to evaluate the reliability of a road network that had degraded as a result of a natural or man-made disaster. Heavy congestion interferes with traffic related to the restoration or reconstruction work around the degraded road network. Therefore, it is important to consider congestion in the degraded network when evaluating network reliability. The model can compare the link flows and link travel costs in the normal state with those in the degraded state.

Resilient

Miller-Hooks et al. (2012) formulated a two-stage stochastic methodology to address the problem of measuring a network's maximum resilience level and simultaneously determining the optimal set of preparedness and recovery actions under budget and level-of-service constraints. The methodology, employing the integer L-shaped method and Monte Carlo simulation, is proposed for its solution. The optimal allocation of a limited budget between preparedness and recovery activities is explored on a case study of the United States rail-based intermodal container network.

Tirtom et al. (2015) proposed a mathematical planning model to find the most effective links to be fortified in order to secure the inter-city passenger transportation service facing the interdiction risk of each link in the network. The planning model is formulated based on the multi-modal network planning (MNP) model that distributes the given OD traffic onto a multi-modal transport network and finds the frequency of all links in the network that minimize the monetary sum of the total passenger travel time and total operation cost. In the fortification model, the operation cost just after a disaster will be financed by a special budget of the national government, considering the total travel time including detours under physical connectivity and capacity.

The World Risk Index (WRI) has been published annually since 2011 to assess countries' vulnerability and exposure to natural hazards such as earthquakes and floods. For the development of disaster prevention measures in Japan, research is being conducted on natural disaster risk assessment indicators applicable to a wide range of sectors, including the transportation sector. Since transportation systems play a variety of roles in disaster risk management, it is expected that more effective and efficient evaluation indicators will be developed (Ito 2017; Research Committee on Gross National Safety for natural disasters 2020).

2.4. Significance of the study

This study has special significance in developing a comprehensive risk management framework for particular risk hazards to mainstream DRR in the transport sector in developing countries. There is an urgent need for geohazard-related disaster risk reduction in developing countries. According to the International Panel of Climate Change (IPPC), there have been statistically significant trends in the number of heavy precipitation events in some regions. It is likely that more of these regions have experienced increases than decreases, although there are strong regional and sub-regional variations in these trends. Catastrophic geohazard disasters occur across the globe – for example, in June 2013, the Himalayan state of Uttarakhand, India, received heavy rainfall with the total rainfall reaching 833.9 mm in Dehra Dun, resulting in flash floods, extensive landslides, and debris flow causing the loss of 580 human lives with 5,400 reported missing.

Thus, from a practical point of view, this institutional and technical framework needs to be phased in stages according to the capacity and financial constraints of developing countries. The framework will be designed for developing countries at any level. First, for low-budget, low-capacity countries, the focus is on retaining the usability of critical roads (often the all-weather road network) to the maximum extent possible, while accepting that noncritical roads can be closed during certain times of the year. Second, for low-budget, moderate-capacity countries, medium-term targets should focus on nonstructural measures such as the monitoring of geohazards (potentially using automatic measuring devices linked to automated warning systems). Finally, for moderate-budget, moderate-capacity countries, long-term targets can focus on structural measures for the management of all-weather-type roads. For countries at any level, techniques and practices compiled in the framework should be adapted for technical assistance projects for road geohazard risk management.

It is obvious that there is a need for the evaluation of transport systems in disasters using performance indicators such as risk, reliability, vulnerability, robustness, and resilient. When a large natural disaster occurs, traffic flow occurs for rescue, emergency, medical care, the supply of supplies, restoration work of the facility, confirmation of family safety, volunteers, and so on. With the development of ICT in recent years in both developed and developing countries, the use of big data in the field of disaster risk management has become more and more important to analyze real traffic after disasters and recovery situations of highways, railways, and airlines. It is indispensable that the impacts of disasters on transport systems be evaluated in line with the disaster life-cycle of mitigation, preparedness, response, and recovery. Therefore, the study will develop a method for analyzing real traffic flow in the event of disasters using big data in the transport sector.

3. Development of a road geohazard risk management framework for mainstreaming disaster risk reduction in developing countries

3.1. Study methodology

This study aims at proposing an institutional and technical framework for preparation, planning, design, construction, and maintenance for road geohazard risk management. Technical skill is required to implement effective road disaster prevention measures because it is difficult to assess risks in the road geohazards (e.g., debris flows, sediment flows, and flash floods). In other words, it is difficult to identify the likelihood and consequence of such risks occurring. As technical assistance in this area is an urgent issue, a universal framework for managing risks in road geohazards needs to be proposed. The best practices of road geohazard risk management in the world including Japan have been analyzed, and a technical framework examined the following areas: (1) responsibility and role-sharing between central and local governments, (2) laws and regulations on geohazard disasters, (3) disaster risk management plan, (4) countermeasures and investment plan, (5) implementation of structural and nonstructural measures, (6) inspection, survey, and management of road geohazard disasters, (7) risk calculation and index for DRR investment, (8) advanced technology for nonstructural countermeasures, and (9) emergency response/recovery/reconstruction.

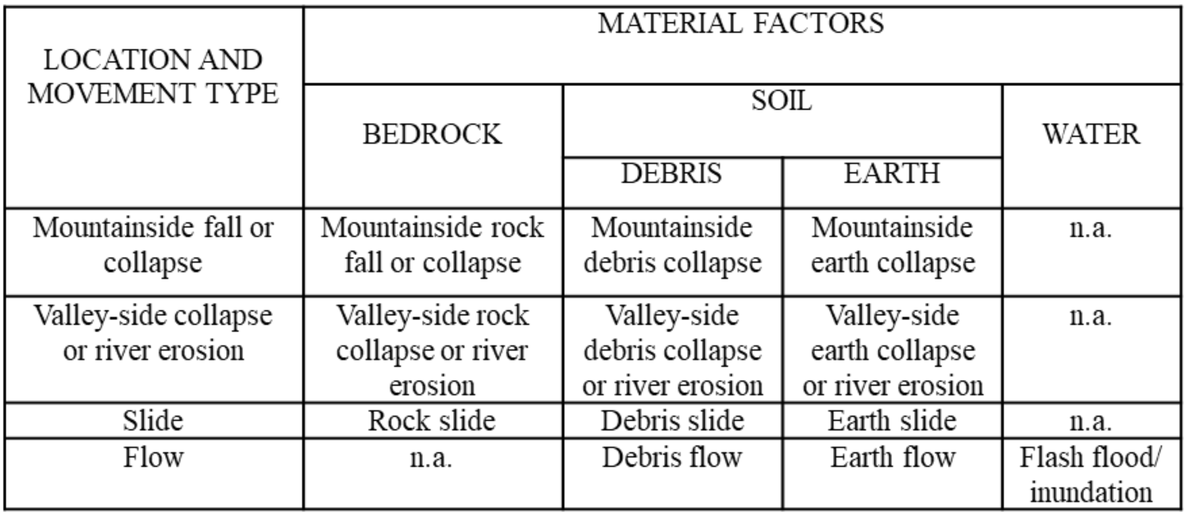
Depending on the capacity and financial constraints of the project-implementing country, it will be possible to gradually manage road geohazard risks through the proposed framework. The framework was devised so that simple/low-cost technology or high-cost technology could be selected. Furthermore, the technical validity of the framework was confirmed with the cooperation of the World Bank's transportation experts and other experts in the field of disaster management. Finally, case studies in Brazil and Serbia were conducted to verify the applicability of the framework.

Definition and classification of road geohazards

This study addresses the typical types of geohazard that adversely affect roads, classifying them based on their combination of location, movement, and the materials involved in the movement (Table 3.1). The typical risk management method is different for each type of movement, location, and material involved in a geohazard affecting a slope or landscape ecosystem

(Cruden et al. 1996; Henning et al. 2017).

Table 3.1: Road geohazards by location, movement, and material type



LOCATION AND MOVEMENT TYPE	MATERIAL FACTORS			
	BEDROCK	SOIL		WATER
		DEBRIS	EARTH	
Mountainside fall or collapse	Mountainside rock fall or collapse	Mountainside debris collapse	Mountainside earth collapse	n.a.
Valley-side collapse or river erosion	Valley-side rock collapse or river erosion	Valley-side debris collapse or river erosion	Valley-side earth collapse or river erosion	n.a.
Slide	Rock slide	Debris slide	Earth slide	n.a.
Flow	n.a.	Debris flow	Earth flow	Flash flood/ inundation

The material factors affecting road geohazards include the following (as also illustrated in Photos 1.1–1.8):

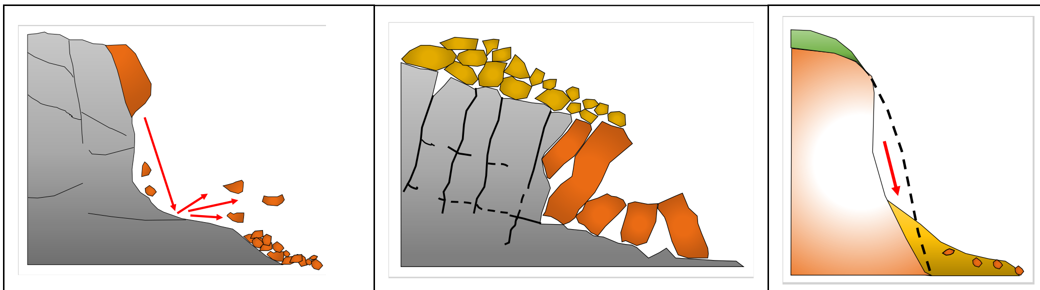
- Bedrock: hard or firm rock that was intact and in its natural place before the movement began
- Soil: any loose, unconsolidated, or poorly-cemented aggregate of solid particles—generally of natural mineral, rock, or inorganic composition and either transported or residual—together with any interstitial gas or liquid
- Debris: soil that contains a weight proportion of more than 20 percent of coarse material greater than 2 millimeters in size (pebble, cobble, and boulder stones)
- Earth: soil that contains a weight proportion of more than 80 percent of fragments smaller than 2 millimeters in size (sand, silt, and clay)
- Water: material that is more than 50 percent water by volume, with the remaining volume composed of soil or other materials.

Furthermore, five general movement types are defined as follows:

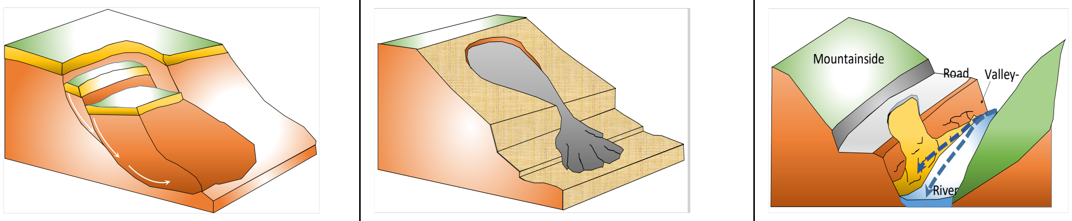
- Fall: a rapid downward movement of a mass of rock or soil that travels mostly through the air by free fall, leaping, bounding, or rolling, with little or no interaction between one moving unit and another (Figure 3.1, panel a)
- Collapse: a gradual or rapid downslope movement of soil or rock under gravitational stress, often because of artificial factors such as the removal of

material from the foot of a slope (Figure 3.1, panels b and c)

- Slide: a mass movement of earth, snow, or rock under shear mode along one or several sliding surfaces (Figure 3.1, panel d)
- Flow: a movement that exhibits a continuity of motion and a plastic or semifluid behavior, usually requiring considerable amounts of water (Figure 3.1, panel e)
- Erosion: a movement of rock fragments or soil particles from one place to another, mostly by water flow (Figure 3.1, panel f)



(a) Fall (rockfall) (b) Collapse (rock) (c) Collapse (soil)



(d) Slide (e) Flow (f) Erosion (river erosion)

Figure 3.1: Road geohazard types

3.2. Framework for road geohazard risk management

The road geohazard risk management approach proposed in the study aligns with the practices in the ISO 31000 standard (ISO 2018). It is indicated that "the risk management process involves the systematic application of policies, procedures, and practices to the activities of communicating and consulting, establishing the context and assessing, treating, monitoring, reviewing, recording, and reporting risk," as illustrated in Figure 3.2. Road geohazard mitigation measures fall into two broad categories: (1) proactive, applied before a disaster; and (2) response and recovery, applied after a geohazard event to manage secondary damage and recovery. For the former, road geohazard risks against the probability (or likelihood) of disasters and consequences (or impacts) of occurrence need to be assessed. The management of such risks can be integrated into all phases of the infrastructure's lifespan: ensuring risk-informed designs, engineering resilient infrastructures, managing existing assets, planning for emergencies, and building partnerships to improve transportation infrastructures for the future. The risk management methodologies are further discussed in Section 3 from institutional aspects.

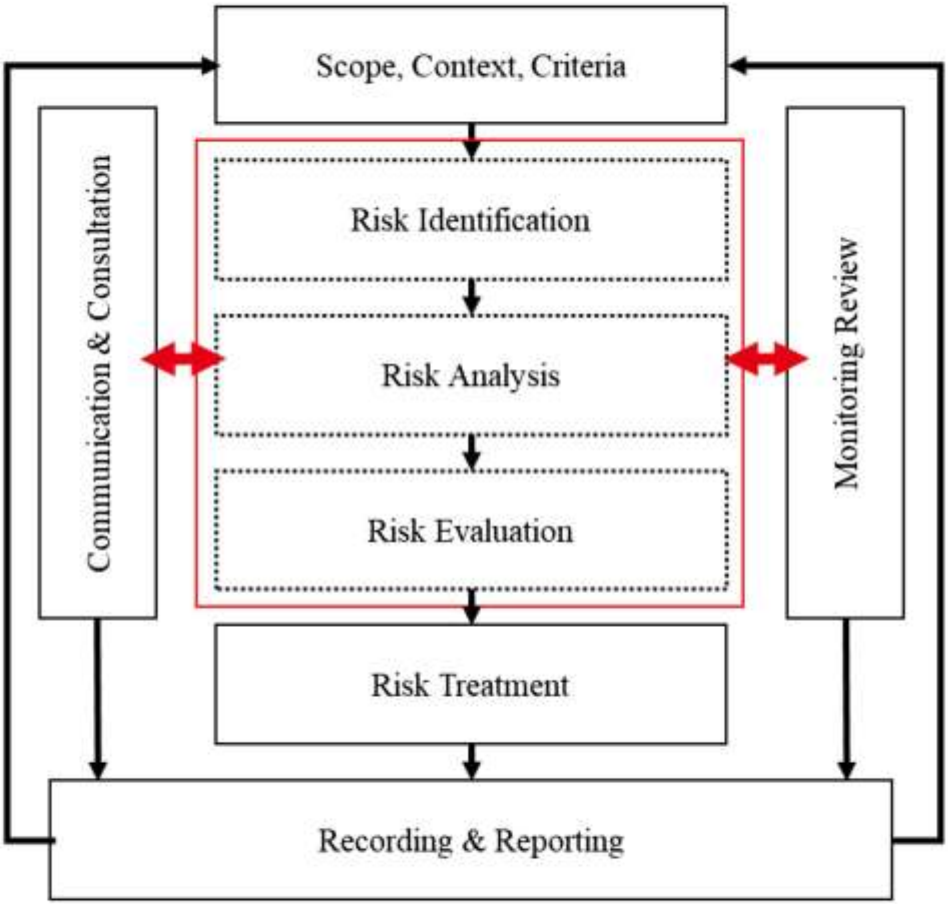


Figure 3.2 Risk management process (ISO 31000)

(Source: ISO 2018.)

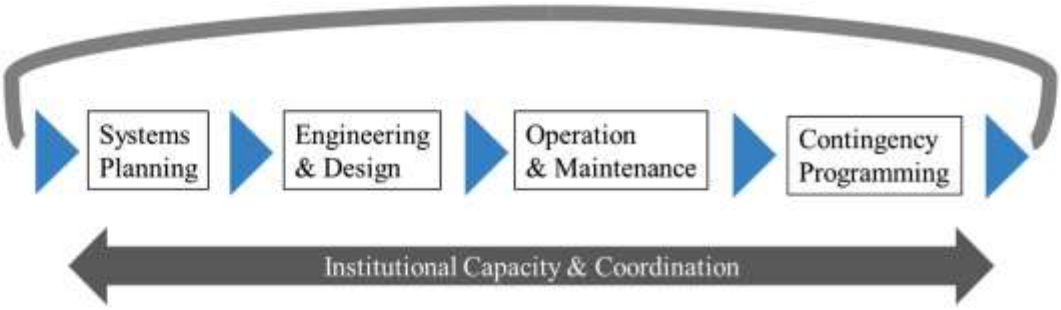


Figure 3.3 World Bank disaster-resilient infrastructure life-cycle approach

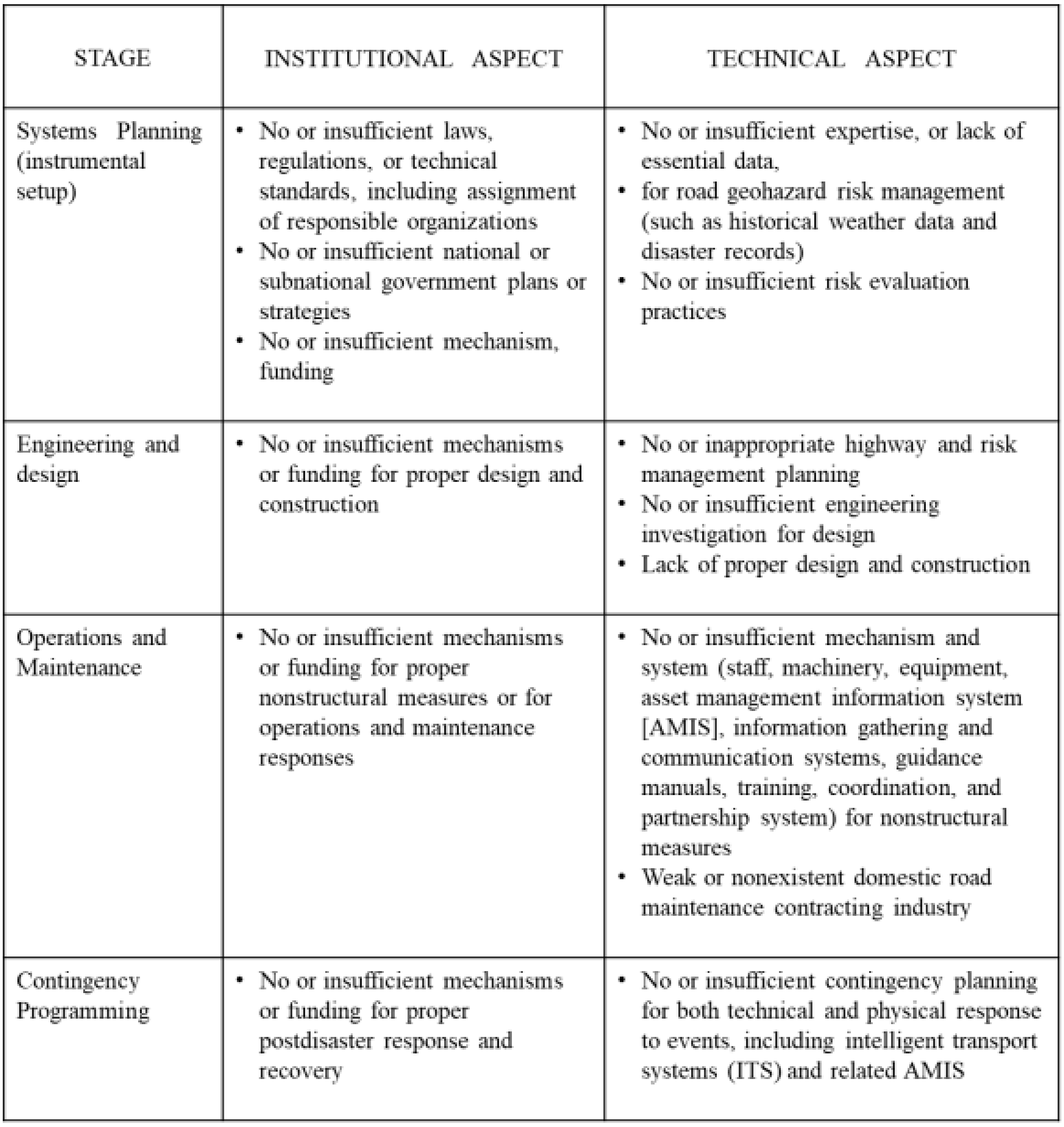
(Source: World Bank 2020.)

The World Bank's approach to proactively manage the risks of disasters and hazards for resilient transport is to consider the entire life-cycle of the infrastructure from system planning, engineering and design, operations and maintenance, and contingency programming, as shown in Figure 3.3 (World Bank 2017). In addition, insufficient knowledge and capacity to implement disaster prevention measures should be addressed in the context of low- and middle-income countries. Therefore, a proposed road geohazard risk management framework is composed of the following stages:

- Institutional capacity and coordination cover the institutional arrangements that are necessary for the successful implementation of geohazard management.
- Systems planning covers the planning aspects pertaining to the identification, assessment, evaluation of risks, and risk management, along with raising awareness of disasters.
- Engineering and design deals with the engineered solutions to address geohazard risks, giving examples of different solutions to particular risk types.
- Operations and maintenance focus on the operation and maintenance aspects of geohazard management—whether through the maintenance of previously engineered solutions or the nonengineered solutions available to mitigate the impacts of geohazard risks.
- Contingency programming addresses contingency programming issues, such as post-disaster response and recovery, and the important issue of funding arrangements.

For most countries, there are significant opportunities to enhance the existing means of geohazard management, covering all stages of the life-cycle, as shown in Table 3.2.

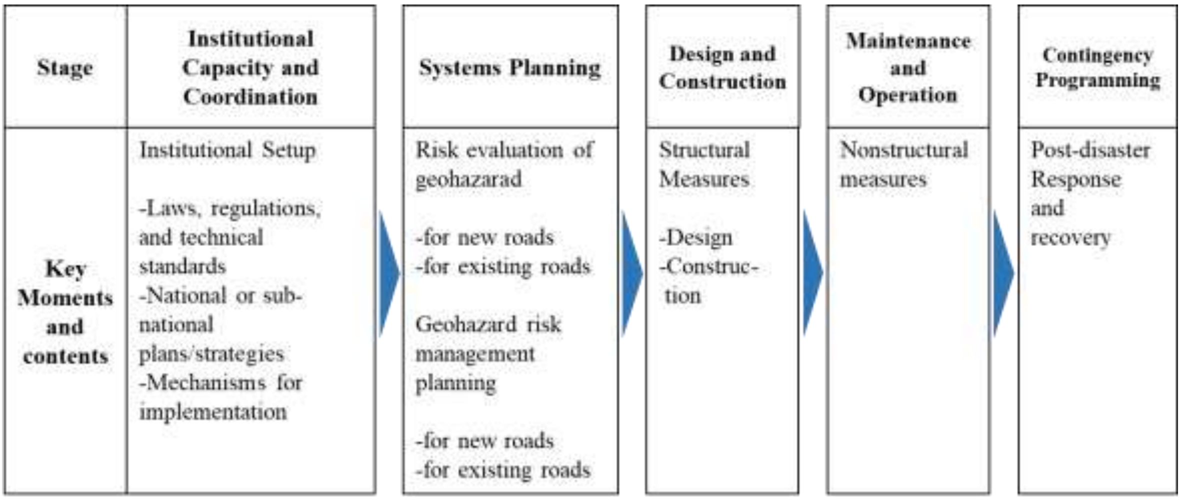
Table 3.2 Opportunities for enhancing road geohazard risk management by life-cycle stage



STAGE	INSTITUTIONAL ASPECT	TECHNICAL ASPECT
Systems Planning (instrumental setup)	• No or insufficient laws, regulations, or technical standards, including assignment of responsible organizations • No or insufficient national or subnational government plans or strategies • No or insufficient mechanism, funding	• No or insufficient expertise, or lack of essential data, • for road geohazard risk management (such as historical weather data and disaster records) • No or insufficient risk evaluation practices
Engineering and design	• No or insufficient mechanisms or funding for proper design and construction	• No or inappropriate highway and risk management planning • No or insufficient engineering investigation for design • Lack of proper design and construction
Operations and Maintenance	• No or insufficient mechanisms or funding for proper nonstructural measures or for operations and maintenance responses	• No or insufficient mechanism and system (staff, machinery, equipment, asset management information system [AMIS], information gathering and communication systems, guidance manuals, training, coordination, and partnership system) for nonstructural measures • Weak or nonexistent domestic road maintenance contracting industry
Contingency Programming	• No or insufficient mechanisms or funding for proper postdisaster response and recovery	• No or insufficient contingency planning for both technical and physical response to events, including intelligent transport systems (ITS) and related AMIS

Source: Data from the World Bank (2020).

Road geohazard risk management entails three main elements covered by the framework: (1) institutional setup, (2) road geohazard risk management for new roads, and (3) road geohazard risk management for existing roads. An adequate institutional framework is a necessary condition to guarantee proper road geohazard risk management, and the activities typically follow the road project management stages of preconcept, concept, design, construction, and operation and maintenance. The road geohazard risk management processes for new and existing roads differ only in the risk assessment and geohazard risk management planning stages. The measures common to both new and existing roads include (1) proactive structural measures, (2) proactive nonstructural measures, (3) post-disaster response, and (4) recovery. The proposed road geohazard risk management framework is summarized in Fig. 3.4. The framework is characterized by institutional and technical approaches that are applicable to developing countries. It is designed for application across all road types and road hierarchies. The World Bank disseminates the road geohazard risk management framework by compiling details of its techniques and practices into a handbook. The subsequent chapters will discuss concrete measures followed by recommendations on how techniques and practices in the framework can be applied to the developing world.



Stage	**Institutional Capacity and Coordination**	**Systems Planning**	**Design and Construction**	**Maintenance and Operation**	**Contingency Programming**
Key Moments and contents	Institutional Setup -Laws, regulations, and technical standards -National or sub-national plans/strategies -Mechanisms for implementation	Risk evaluation of geohazarad -for new roads -for existing roads Geohazard risk management planning -for new roads -for existing roads	Structural Measures -Design -Construc-tion	Nonstructural measures	Post-disaster Response and recovery

Figure 3.4 Framework for road geohazard risk management

3.3. Institutional capacity and coordination

3.3.1.Institutional setup and asset management

Without an appropriate institutional setup, within which the geohazard risk management tasks are implemented, there is little chance of a successful outcome. The institutional setup covers two primary aspects:

- Institutional framework, such as the appropriate laws, regulations, and technical standards to enable geohazard management.

- The appropriate capacity and capability of human resources to deliver an appropriate geohazard risk management program.

While the underlying laws, regulations, and technical standards may be largely the same from country to country regarding the need to manage the road network safely and efficiently, the amount of human capital expended on geohazard management will reflect the relative risk exposure in each country (or part of a country). For instance, a road authority managing a road in a mountainous country with high rainfall will reasonably be more concerned about geohazards and hence invest more time and effort in their management.

This study is intended to put geohazard risk management in place within national governments, road agencies, and local authorities managing road infrastructure. In the majority of countries, road assets are financed by the government budget, and managing costly road assets requires a systematic approach, which assures an adequate decision in each step of the project life-cycle, namely planning, designing, building, and managing. The importance of efficient infrastructure asset management is significantly increasing. As defined by the AASHTO, "Transportation Asset Management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life-cycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well-defined objectives" (AASHTO 2016).

Geohazard management activities must fit within the road authority's overarching asset management framework, as shown in Figure 3.5. For some developing countries that have incorporated road asset management practices into the project life-cycle, it would not be difficult to put road geohazard risk management in place with the financial and technical support of international organizations and developed countries. For developing countries that have not yet started road asset management, most road geohazard risk management activities can correspond with the traditional management processes of the road authorities.

Figure 3.5 Road geohazard risk management in asset management

3.3.2.Institutional framework

An integrated and effective institutional setup is required to promote a systematic and efficient approach to road geohazard risk management. The institutional framework comprises: (1) laws, regulations, and technical standards; (2) national and subnational government plans and strategies; and (3) mechanisms for implementation.

Laws, regulations, and technical standards

Governments may or may not have laws, regulations, and technical standards that govern road geohazard risk management. If they exist, the laws and regulations stipulate the responsibility and authority of the actors involved, such as the road management authorities and traffic police, to ensure the implementation of road geohazard risk management.

National and subnational plans and strategies

The development of national and subnational plans and strategies is essential to promote proper road geohazard risk management, and therefore, such development is an essential target of national and subnational governments. When national governments formulate development plans and strategies, the management plan for road geohazards must be incorporated as well. The government or road management authorities also formulate specific investment programs and projects to support geohazard risk management.

Mechanisms for implementation

Because geohazard management is part of the road authority’s overall management activities, the organizational structure will not be determined solely by geohazard management risk requirements. The recommended practice is that geohazard risk management is fully integrated into every practice of the organization.

In terms of implementation mechanisms in developing countries, limited capacity for disaster risk management at the local level is a common challenge. National governments have various roles to support local governments, who have the primary responsibility in disaster risk management, to prepare for and respond to disasters. Similarly, local offices in the road authorities are in a position to be the first responder. It might take some time for road authorities to accumulate experience and develop institutional and technical capacity at the local level. Delegation of responsibilities and decision-making authority to a lower organizational level would be required at a certain point to promote road geohazard risk management (Asian Development Bank Institute 2013).

3.3.3. Institutional capacity review

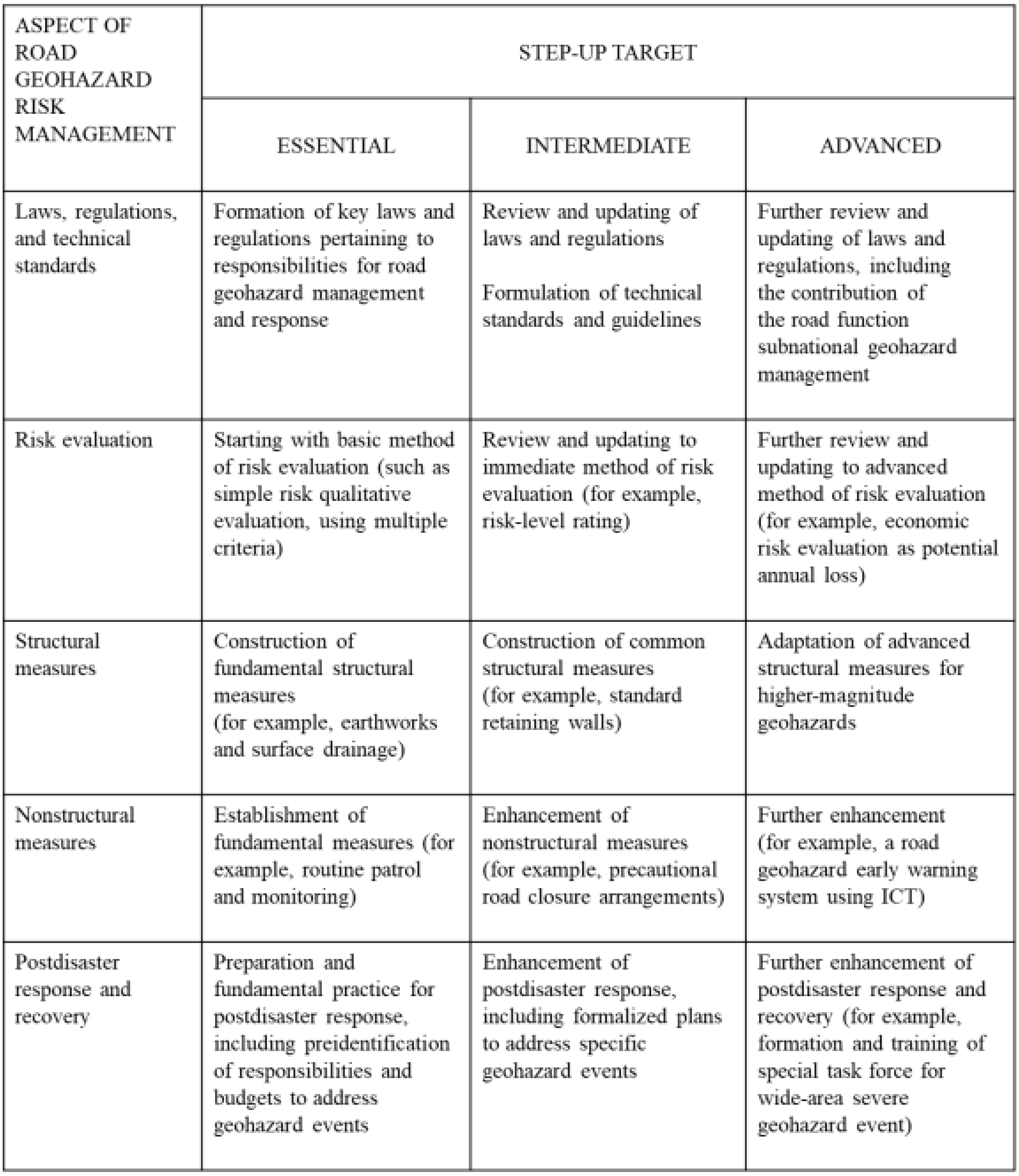
One of the most important aspects of geohazard risk management is the institutional capacity review, which measures how the road authority addresses geohazard risk and risk mitigation at the national and subnational levels, considering the following aspects:

- Existence and level of maturity of the legal framework, institutions, and plans or strategies.
- Institutional capacity and capability.
- Implementation level of plans or strategies.
- Situation and effectiveness of projects on road geohazard risk management.

The results of an institutional capacity review reach an official consensus on weaknesses, targets for institutional strengthening, and investment priorities and their financing strategy.

The authors propose three step-up targets on road geohazard management. First, essential targets are the initial requirements for instituting road geohazard risk management and setting up road geohazard management. Second, intermediate targets are the next level of requirements to operationalize road geohazard risk management. Finally, advanced targets enhance road geohazard risk management through more rigorous review, elaboration, and enhancement using advanced technologies. Each government reviews its institutional capacity and budget constraints and sets a target as a first step. Examples of the items and activities of each target are shown in Table 3.3.

Table 3.3 Setup targets for strengthening road geohazard risk management



ASPECT OF ROAD GEOHAZARD RISK MANAGEMENT	STEP-UP TARGET		
	ESSENTIAL	INTERMEDIATE	ADVANCED
Laws, regulations, and technical standards	Formation of key laws and regulations pertaining to responsibilities for road geohazard management and response	Review and updating of laws and regulations Formulation of technical standards and guidelines	Further review and updating of laws and regulations, including the contribution of the road function subnational geohazard management
Risk evaluation	Starting with basic method of risk evaluation (such as simple risk qualitative evaluation, using multiple criteria)	Review and updating to immediate method of risk evaluation (for example, risk-level rating)	Further review and updating to advanced method of risk evaluation (for example, economic risk evaluation as potential annual loss)
Structural measures	Construction of fundamental structural measures (for example, earthworks and surface drainage)	Construction of common structural measures (for example, standard retaining walls)	Adaptation of advanced structural measures for higher-magnitude geohazards
Nonstructural measures	Establishment of fundamental measures (for example, routine patrol and monitoring)	Enhancement of nonstructural measures (for example, precautional road closure arrangements)	Further enhancement (for example, a road geohazard early warning system using ICT)
Postdisaster response and recovery	Preparation and fundamental practice for postdisaster response, including preidentification of responsibilities and budgets to address geohazard events	Enhancement of postdisaster response, including formalized plans to address specific geohazard events	Further enhancement of postdisaster response and recovery (for example, formation and training of special task force for wide-area severe geohazard event)

Source: Data from the World Bank (2020).

National road authorities formulate institutional, technical coordination, and a funding mechanism for the efficient implementation of road geohazards risk management. When setting up targets in developing countries, it should be noted that a limited capacity at the local level must be taken into consideration. The checklists for the institutional capacity review added to the annex of the handbook would help developing countries to assess their current capability. Knowledge and insight are required to identify and recommend ways to address any deficiencies between the assessed and target competencies. Governments of developing countries must have a thorough consultation with experts and leaders as well as institutions and stakeholders to set targets for each item where the target capability is above the current assessed capability.

3.4. Systems planning

3.4.1. Systems planning

The systems planning stage covers the activities that are necessary to be in place to support the overall geohazard risk management process. It comprises two main aspects: risk evaluation and risk management planning. Although the geographic scope of any geohazard risk evaluation will inherently be different between studies on existing roads or potential new-road alignments, the underlying methods are the same. For existing roads, the approach may be constrained to a single site, a single road, or expanded to the entire network of roads. For new-road alignments, the approach needs to ensure full coverage of all potential road alignments.

For existing roads, the outcome of the geohazard risk evaluation is to develop a prioritized list of sites for subsequent mitigation. For new-road alignments, the risk evaluation process should ensure that there is a basis for proper planning to avoid cost overruns, construction delays, and costly operation and maintenance outcomes. The workflow for risk evaluation of geohazards consists of two steps: (1) identification and mapping of geohazards, and (2) assessment of geohazards.

3.4.2. Risk evaluation

Depending on the capacity and financial constraints of the project-implementing country, the authors propose three options for the identification and mapping of geohazards and assessment of geohazards:

Identification and mapping of geohazards

Basic method. The road maintenance staff identifies any abnormality or deformation of the road by using their maintenance experience, on-site visual inspections, and information provided by road users.

Intermediate method. Geotechnical engineering experts conduct an identification survey of hazard-prone road locations by collecting data of historical geohazard damage events and screening hazard-prone road locations via on-site observations.

Advanced method. Engineering geology experts conduct detailed hazard mapping along with the intermediate method. A detailed hazard map to identify hazard-prone locations is prepared through the analysis of contour maps, and interpretation is conducted using either aerial photographs or satellite images.

The fundamental principle is that experienced road authority staff investigate and monitor hazards through routine maintenance. In developing countries, there are few or no road authority staff with experience in inspecting geohazards and abnormalities. There is no other choice but to gain this experience at the local level since the staff members are responsible for activities and decision making on risk management. In the meanwhile, there is no problem with outsourcing identification surveys to fill out inventory sheets for each hazard-prone road location. Detailed hazard mapping would be conducted depending on the available funds and risk level. It is important that executive officers periodically check inventory sheets, including (1) location type; (2) simple observation results; and (3) sketches and photographs, to prevent overlooking potential road geohazard risks.

Assessment of geohazards

In principle, new-road planning aims to ensure that the true long-term costs of the different alignments are appropriately assessed, which typically results in avoidance of high-risk hazardous locations. In contrast, for existing roads, risk evaluation and planning are intended to ensure that funds to mitigate risks are appropriately prioritized and that contingency plans can be put in place. Three options for the assessment of geohazards are proposed:

Basic method. For the initial assessment, rather than undertaking a quantitative evaluation of both the likelihood and consequence of a risk event occurring, a simpler qualitative evaluation may be used. Likelihood may be defined in terms of occurrence probability, for example: low (more than 20 years between failure events), medium (5–20 years between failure events), and high (less than 5 years between failure events). A consequence may be defined in terms of the duration and magnitude of damage, for example, low (would not cause a loss of human life or significant safety issues), medium (may have an impact on human life), and high (could have a significantly negative impact on human life).

Intermediate method. This approach builds on the basic method. The risk rating of an endangered road location is calculated by evaluating the likelihood and magnitude of damage on a number of subcategories, with a score assigned to each. These scores are then multiplied to generate an overall score of the risk level.

Advanced method. A risk index is calculated as a potential annual economic loss. The potential annual economic loss is the result of the integral computations of the economic losses of several extents of road damage and their probabilities. This index is useful for understanding, from an economics perspective, the prioritization of studies for these measures among different hazard-prone road locations. Its biggest advantage as a risk index is that it can be used for the benefit estimation of investments for road geohazard risk management, which in turn is used in the cost-benefit analysis.

The governments of developing countries would tend to take a reactive approach by retrofitting existing roads after disasters. While the countermeasures against natural disasters seem costly, the investment pays off. There is a lack of understanding of the importance of investing in the promotion of proactive disaster prevention. The assessment of geohazards is a critical part of road geohazard risk management in terms that objective evaluation is used as the basis for the budgetary provision required for structure and nonstructure measures. The budgeting process in the governments of developing countries being based on evaluation results would lead to a better understanding that funding for preparedness and prevention contributes to reducing the amount of damage caused by disasters (Inter-American Development Bank 2017).

3.4.3. Risk management planning

Risk management planning requires recognizing, understanding, and addressing all potential risks, which are identified and assessed in the risk evaluation process, to prioritize hazard-prone road locations for the subsequent application of risk mitigation measures (Singh 2017). Although the techniques for risk management planning vary from country to country, the underlying methods are the same. In the framework, network-level analysis and project-level analysis, either of which can be applicable to most developing countries, are proposed to prioritize the roads for investment. In the subsequent paragraphs, project-level option selection will be discussed to illustrate the decision-making process for specific solutions at specific locations.

There is a need for proper investment of time and money in project-level option selection. The first stage in selecting the preferred option is to define the evaluation approach. Typically, for existing roads, the different options can be compared using life-cycle cost analysis on the presumption that each option will broadly offer the same benefits to road users, and the decision is primarily a technical one as to which solution can be delivered for the lowest cost. The life-cycle costs include the initial investment costs of each option, along with the corresponding annual maintenance cost. The evaluation period for determining the life-cycle cost should align with established practices within the road authority, which typically range between 15 and 50 years. Where no guidance is provided within a country on the period to analyze, a good approach is to consider the life expectancy of the longest-life option.

For new-road alignments, the decision will typically involve multiple factors, including many nongeohazard factors such as cost (initial construction and ongoing maintenance), safety, social and environmental impacts, property impacts, cultural issues, vehicle operating costs, and so on. For such scenarios, road authorities will often revert to the use of multicriteria analyses (MCAs) or similar techniques. Where the benefits or disbenefits between solutions are not broadly the same, then comparison on a basis other than just cost will be required. MCAs enable such a comparison to be made, wherein the options are ranked across a range of user-defined factors. The challenge in applying MCAs is to determine the relative weighting between the different factors being assessed. Once the rating criteria have been set, each option is then scored across the criteria and the sum (often weighted) of the criteria is determined.

DRR investments, in particular, infrastructure projects, may decrease viability from a short-term perspective, but these pay off from a long-term perspective. While many developing countries have made some progress on formulating a DRR policy framework, the implementation of DRR including road geohazard risk reduction still needs further progress. It is recommended that the governments of developing countries formulate planning guidelines on road geohazards risk management since risk management planning is used as the basis for funding for preparedness contributing to reduce the damage caused by catastrophic disasters. The guidelines would help the national and local governments of developing countries to institutionalize planning principles and practices, thus resulting in mainstreaming DRR in the transport sector.

3.5. Design & construction, maintenance & operation, and contingency programming

3.5.1. Design & construction

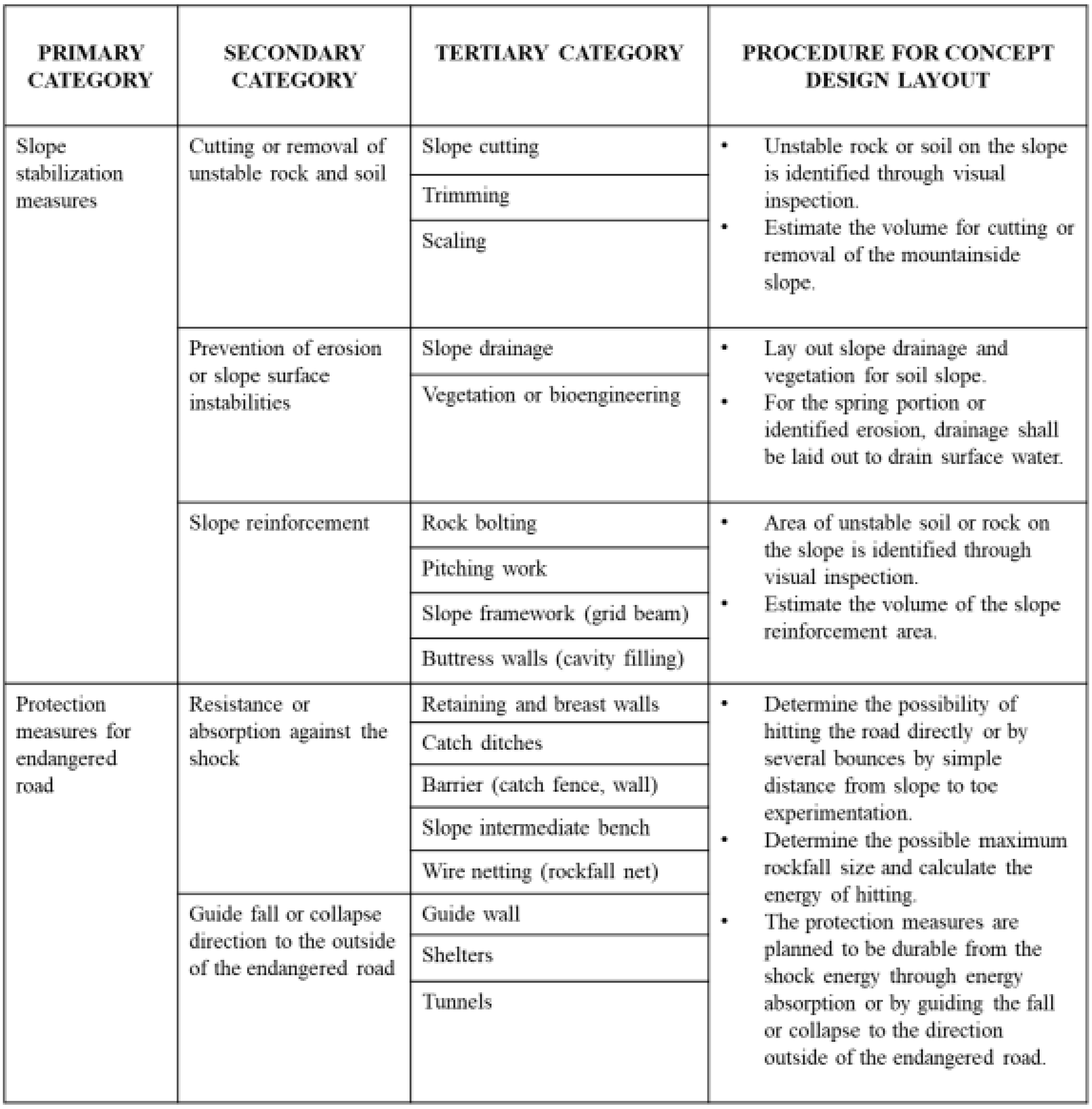
Engineered (or structural) measures are engineering solutions to prevent or protect from road damage due to geohazards. They include measures implemented as: (1) preventive (proactive) measures implemented to lower the risk of geohazard failure; (2) emergency works, in highly susceptible areas or during geohazard events, that are subject to engineering design; and (3) recovery conducted as secondary damage protection or recovery works in a post-disaster stage that are subject to engineering design. Although the trigger to implement an engineered measure may vary, the fundamental approach is often similar, particularly when the solution to be implemented is a long-lived one, such as a concrete retaining wall. A well-engineered road with a functionally efficient geohazardproof system will have more or less negligible vulnerability. The same road, if badly designed and constructed, may be 100% vulnerable. In other words, vulnerability depends on the level of exposure, susceptibility, and degree of preparedness.

Structural measures include structures made of concrete or mortar, steel, wood, asphalt, geosynthetics, earth, and vegetation or bioengineering as well as their composites. Geosynthetics refers to any synthetic material, such as geotextiles (permeable material) and geomembranes (impermeable material). Earth structures include engineered slopes (cutting slopes) and embankments used as a counterweight of a sliding slope toe. Engineered measures can increase the robustness of roads. They are usually implemented during the stages of road construction and operation and maintenance based on the priority of the countermeasures required on road hazard-prone locations. They are measures for geohazard risk management, but they can also be implemented as post-disaster recovery measures.

The types of structural measures are selected depending on the type of geohazard on the road. Earth work with surface drainage and vegetation (bioengineering) is always the basic countermeasure to consider for each type of geohazard. Depending on the method of construction and materials, it is necessary to account for economic efficiency, the availability of construction materials and machines, social or environmental negative impacts, and the difficulty of maintenance. Structural measures comprise four types: (1) structural measures for mountainside fall or collapse, (2) structural measures for valley-side collapse or river erosion, (3) structural measures for slide-type geohazards, and (4) structural measures for flow-type geohazards. Structural measures for a fall or collapse (slope stabilization) are shown as an example in Table 3.4.

Tasks of design and construction are straightforward: investigate the cause of failure at the project site, estimate the likelihood and cost of future events, analyze mitigation options, and complete a detailed design and associated documentation. At the local office level, many countries including developing countries fully outsource physical works to the private sector. The handbook offers standard templates for terms of reference (TOR) that can be adapted for the procurement of design consultants and technical assistance projects with international development partners. The road authority staff can refer to details of the approaches and methodologies defined in the handbook.

Table 3.4 Example of structural measures for mountain fall or collapse



PRIMARY CATEGORY	SECONDARY CATEGORY	TERTIARY CATEGORY	PROCEDURE FOR CONCEPT DESIGN LAYOUT
Slope stabilization measures	Cutting or removal of unstable rock and soil	Slope cutting	• Unstable rock or soil on the slope is identified through visual inspection. • Estimate the volume for cutting or removal of the mountainside slope.
		Trimming	
		Scaling	
	Prevention of erosion or slope surface instabilities	Slope drainage	• Lay out slope drainage and vegetation for soil slope. • For the spring portion or identified erosion, drainage shall be laid out to drain surface water.
		Vegetation or bioengineering	
	Slope reinforcement	Rock bolting	• Area of unstable soil or rock on the slope is identified through visual inspection. • Estimate the volume of the slope reinforcement area.
		Pitching work	
		Slope framework (grid beam)	
		Buttress walls (cavity filling)	
Protection measures for endangered road	Resistance or absorption against the shock	Retaining and breast walls	• Determine the possibility of hitting the road directly or by several bounces by simple distance from slope to toe experimentation. • Determine the possible maximum rockfall size and calculate the energy of hitting. • The protection measures are planned to be durable from the shock energy through energy absorption or by guiding the fall or collapse to the direction outside of the endangered road.
		Catch ditches	
		Barrier (catch fence, wall)	
		Slope intermediate bench	
		Wire netting (rockfall net)	
	Guide fall or collapse direction to the outside of the endangered road	Guide wall	
		Shelters	
		Tunnels	

Source: Data from the World Bank (2020).

3.5.2.Maintenance & operation

In contrast to structural measures, nonstructural measures for road geohazards, which enhance road geohazard risk management in the operations and maintenance stage, are any measures not involving physical construction. They are less expensive than structural measures and include: (1) routine maintenance of previously constructed structural measures, (2) monitoring of geohazards (potentially using automatic measuring devices, linked to automated warning systems), and (3) road closures to prevent injury before (or during) a geohazard event.

Routine maintenance of previously constructed structural measures

Appropriate maintenance of structural measures guarantees the measures' proper effect. Proper maintenance requires preparation of an inspection schedule, maintenance procedures, materials, and machinery. Maintenance includes the removal of sediments in debris flow protection dams or sand traps and the preservation of slope vegetation. Maintenance costs and their availability are considered during the planning stage. A feasibility assessment of the structural measures is commonly included in the maintenance costs.

The maintenance of structural-measure methods is often not limited to the operation of road maintenance entities. Such methods (for example, removal of earth and debris from a dam or a sedimentary sand place) are established in road crossings outside the road management sites or valley streams and rivers to the side against flow-type disasters such as earth and debris flows, floods, and flash floods. Therefore, the road management authorities adjust their plans and budgets with disaster management authorities as well as with the organizations, local governments, communities, and other entities that manage maintenance entities such as water utilization and conservation of mountains, river improvement, erosion control, and irrigation.

Monitoring of geohazards

Nonstructural measures include risk avoidance methods, such as advanced warning, to prevent vehicle damage and loss of human life even if a geohazard event occurs. The early detection of anomalies is important to prevent disasters and avoid damage for road users. The early detection of anomalies is important to prevent disasters and avoid damage for road users. Both visual inspections and specific geohazard monitoring have their place in this effort. The visual inspections are conducted using a range of tools and techniques and are carried out either by vehicle or on foot. Based on their frequency, they are subdivided into the following:

- Routine patrol: visual observation conducted from vehicles daily, weekly, or at some other time interval. These are typically undertaken by staff with limited geohazard technical expertise but who often have significant experience on the road network and are aware of how the network performs and where high-risk locations are.
- Inspection patrol: inspection of endangered road locations—before and after the rainy season, earthquakes, or other potentially hazardous

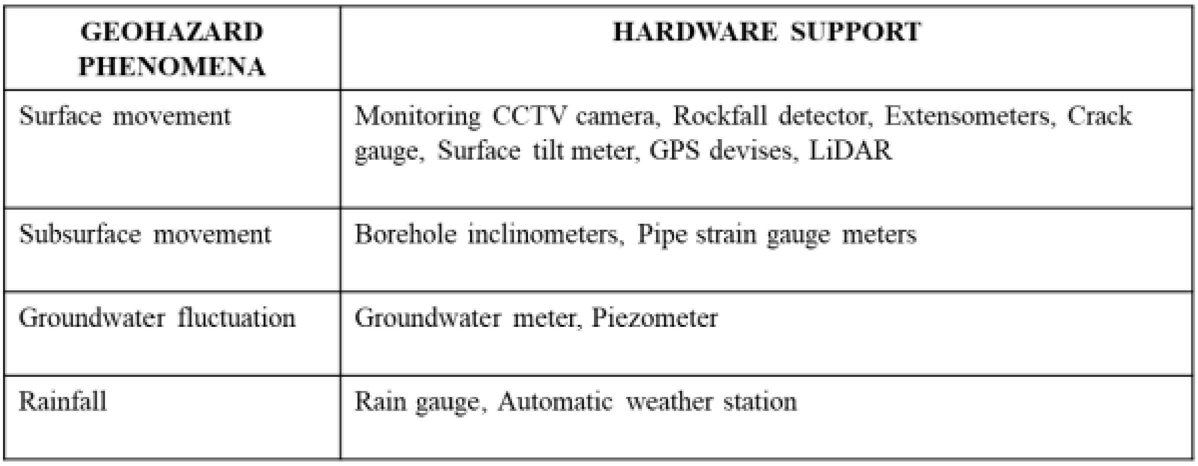
events—is performed with the aid of the hazard inspection record format and past records including photos or sketches.

- Emergency patrol: inspections during highly disaster-susceptible situations or in response to complaints of abnormalities from road users or other observers. The initial emergency patrol may then generate the need for a specialist's inspection.

Road agencies also have been successfully using automated geohazard monitoring, for example, monitoring of failing slope ground movement and geohazard triggers, such as heavy rainfall or the rise of groundwater tables, as shown in Table 3.5. The monitoring is conducted at prioritized endangered road locations where structural measures have not been implemented owing to budgetary or technical difficulties. The monitoring results are used as criteria for early warning and precautionary traffic closures to avoid damage to road users.

How innovation and technology for geohazard monitoring can be effectively utilized to monitor risk roads in developing countries is the key to success. The monitoring results, such as displacement and distortion, are indispensable for the maintenance cycle to retrofit the risk roads. It is worth noting that monitoring mechanisms and measuring units of output data are different between monitoring devices in the global market. Technical standards must be developed in each country to adopt and diffuse road geohazards monitoring devices.

Table 3.5 Geohazard monitoring types and equipment used



GEOHAZARD PHENOMENA	HARDWARE SUPPORT
Surface movement	Monitoring CCTV camera, Rockfall detector, Extensometers, Crack gauge, Surface tilt meter, GPS devises, LiDAR
Subsurface movement	Borehole inclinometers, Pipe strain gauge meters
Groundwater fluctuation	Groundwater meter, Piezometer
Rainfall	Rain gauge, Automatic weather station

Source: Data from the World Bank (2020).

As noted in Section 3.4, geohazard risk management is part of the overall asset management practice within a road authority. Although climate change is not the same as geohazard management, there are significant overlaps between the two subjects, and it is worth reflecting on the specific actions proposed by Henning, Tighe, and Greenwood (2017), who reviewed the asset management process and proposed specific additional activities that should be incorporated into each stage of the process to ensure climate change was appropriately addressed. Their proposed approach includes a series of specific initiatives that should be implemented to ensure that road geohazard management is considered in each part of the road asset management framework (Table 3.6).

Table 3.6 Actions for integrating geohazard management into asset management

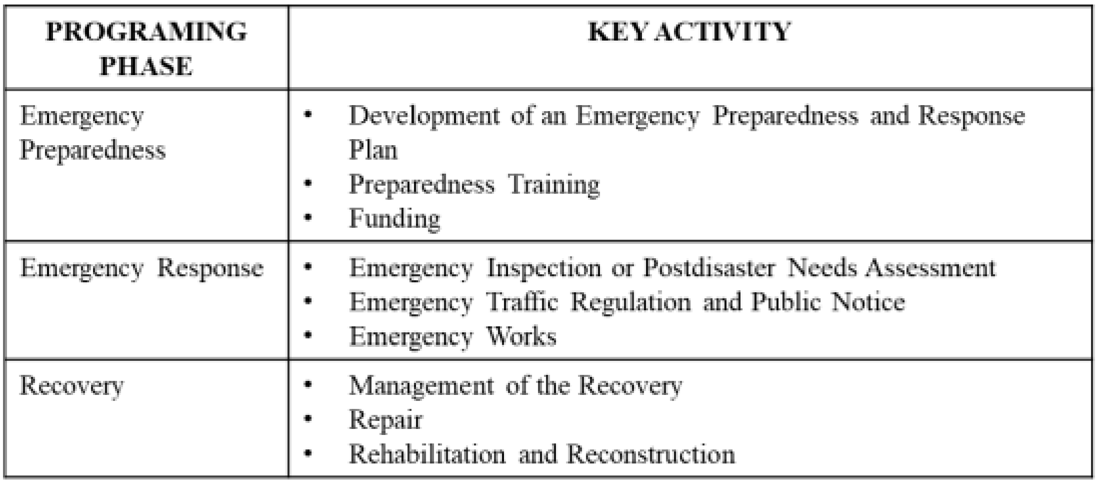
Framework of Asset Management	Key additional actions
Improve Asset Performance	● Specifically address geohazard risk management within the AM policy statement, and have agreements in place on how the damage from major events will be funded ● Effective integration of geohazard management and asset management must be driven from executive management levels within organizations
Improve Asset Value	● Operational plans should include specific allowances for identifying and addressing deficient adaptation measures, such as making sure drainage structure are cleaned and without blockages ● Identify improvements necessary for geohazard management, and integrate these into the overall improvement plan for the road authority
Efficiently Manage Risk	● Data collection should include measuring and recording of specific geohazard risk effects on road networks ● Information management systems should include the recording of specific geohazard data for planning purposes
Enhance Business Growth and Improvement	● Future demand forecast such as demographic changes and traffic-loading increases should be integrated with geohazard impacts on the expected performance of infrastructure ● Financial and funding strategies should investigate the impacts of different investment scenarios on geohazard mitigation
Reliable Decision Making	● Risk and vulnerability assessments—already commonly used for geohazard management—should be integrated with risk management from an organizational risk perspective ● Current analytical processes need to incorporate multi-objective capabilities and often need refinement to include risk-based costs
Grow Stakeholder Confidence and Reputation	● Ensure that network resilience measures (for example, restore all major roads within 12 hours of the end of a 1-in-100-year flood) are included into the level-of-service framework ● More emphasis on community involvement in decision making is required when bringing geohazard management into the asset management decision making, as often the solution is to reduce the reliability of access

Source: Data from the World Bank (2020).

3.5.3.Contingency programming

Contingency planning addresses contingency programming issues, such as post-disaster response and recovery, and the important issue of funding arrangements. As shown in Table 3.7, contingency programming consists of three distinct phases: (1) emergency preparedness before a geohazard event, (2) emergency response during and in the immediate aftermath of an event, and (3) recovery following the emergency to restore full functionality to the road network.

Table 3.7 Contingency programming activity



PROGRAMING PHASE	KEY ACTIVITY
Emergency Preparedness	• Development of an Emergency Preparedness and Response Plan • Preparedness Training • Funding
Emergency Response	• Emergency Inspection or Postdisaster Needs Assessment • Emergency Traffic Regulation and Public Notice • Emergency Works
Recovery	• Management of the Recovery • Repair • Rehabilitation and Reconstruction

Source: Data from the World Bank (2020).

Emergency preparedness

A key outcome from all the prior phases of geohazard risk management described in this handbook is that of understanding the nature of existing risks across the network. From this information, it is necessary to develop an emergency response plan covering what actions should be taken, and by whom, if various risks were to occur. Two key activities underpin the successful completion of emergency preparedness:

- Having in place an emergency preparedness and response plan.
- Undertaking preparedness training to ensure that the plan can be deployed.

Emergency response

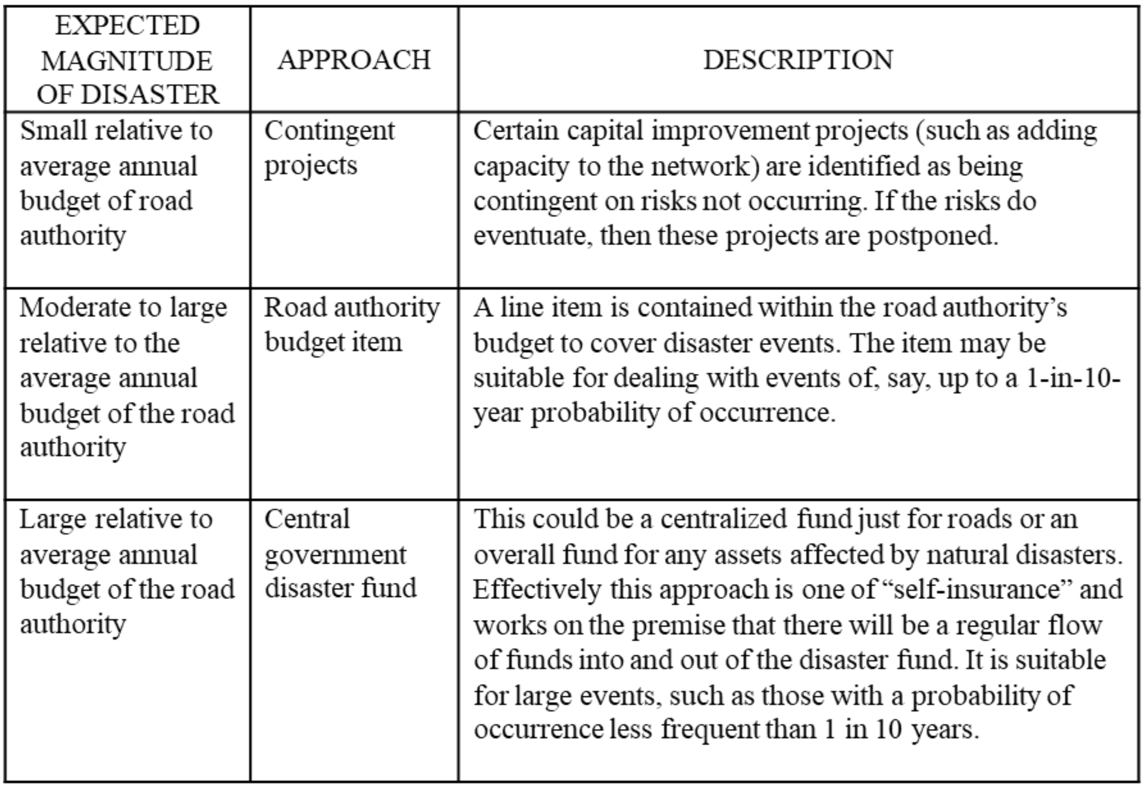
Immediately after a significant geohazard risk event, it may be necessary to trigger an emergency response procedure. The highest priority during the initial emergency response phase is life-saving services. The role of the road network in such life-saving services is critical, whether it be for access to sites by emergency responders or for the transport of the injured from sites to hospitals. The focus of the emergency response phase is therefore about making rapid decisions in the field, using limited information, to restore key critical routes as quickly as possible, before moving on to the remainder of the network. For large-scale geohazard events (those caused by major climatic events or earthquakes), it is often the role of emergency response crews (those of either the road authority or contractors) to both clear the road and to provide an initial assessment of the scale of work required at sites.

Recovery

Reactive measures involve the recovery of the road asset to reinstate traffic flow, along with the concept of "build back better," which is the concept of "recovery with improvements" such that the geohazard risk is lower after the event than it was beforehand. Reactive measures are subdivided into emergency recovery (covered earlier), repair, rehabilitation, and reconstruction—as expanded on further below. Although the emergency response phase is, by definition, undertaken rapidly to restore basic functionality, it is important that the subsequent phases be undertaken more holistically considering the long-term costs and benefits of options. It is quite possible that, under major events, restoring the existing road is not the best solution and that rather than recovering the existing road, the solution may be to make substantial changes to the alignment to lessen the future exposure of the network to risk.

The funding of post-disaster recovery is an essential element of the risk management process. The approach taken to the funding of disaster recovery should be directly related to the expected magnitude of disaster events, as shown in Table 3.8. The option of cutting back on maintenance standards (that is, stopping the maintenance of the rest of the road network to fix up geohazards in one area) is not recommended, because the long-term consequences of doing so can significantly increase the overall cost to the nation of the original hazard.

Table 3.8 Post-disaster funding approaches



EXPECTED MAGNITUDE OF DISASTER	APPROACH	DESCRIPTION
Small relative to average annual budget of road authority	Contingent projects	Certain capital improvement projects (such as adding capacity to the network) are identified as being contingent on risks not occurring. If the risks do eventuate, then these projects are postponed.
Moderate to large relative to the average annual budget of the road authority	Road authority budget item	A line item is contained within the road authority's budget to cover disaster events. The item may be suitable for dealing with events of, say, up to a 1-in-10-year probability of occurrence.
Large relative to average annual budget of the road authority	Central government disaster fund	This could be a centralized fund just for roads or an overall fund for any assets affected by natural disasters. Effectively this approach is one of "self-insurance" and works on the premise that there will be a regular flow of funds into and out of the disaster fund. It is suitable for large events, such as those with a probability of occurrence less frequent than 1 in 10 years.

Source: Data from the World Bank (2020).

Putting emergency preparedness, emergency response, and recovery into practice is a great challenge for national and local road authorities of developing countries. Many developing countries lack the institutional, technical, and financial capacity to effectively cope with disasters. National road authorities must formulate the mechanisms for the implementation of contingency programming, which would preferably be expressed as operation guidelines. These mechanisms comprise institutional, technical coordination, and funding mechanisms. For example, the national road authority should support local road authorities by coordinating the organizations concerned (meteorological agency, police, rescue agency, and so on) and deploying specialized teams to respond to catastrophic disasters. What is most important is how contingency funds are allocated when geohazard events occur because such emergency events would require funding beyond that of the road authority's day-to-day activities.

3.6. Case studies

Case studies in Brazil and Serbia were conducted to verify the applicability of the framework to developing countries. Key elements for developing a road geohazard risk management framework were identified so that the framework is applicable to any country's context. Documents and information about road geohazard risk management practices were reviewed to cover all technical areas defined by the proposed framework. The case studies identified gaps that can be improved:

Brazil case study

The study summarizes the institutional capacities of geohazard risk management at different government levels in Brazil, focusing particularly on the federal government and state government. The study selected the São Paulo state as a case study for two reasons: (1) it is a state vulnerable to landslide disasters and (2) the World Bank is implementing an investment operation in the road sector, including disaster risk management. There is no comprehensive approach to road geohazard risk management in order to protect the road infrastructure from geohazard events. Such an approach should be coordinated and implemented by relevant stakeholders. However, road administrators and other relevant institutions often work individually, and any official coordination mechanism on geohazard risk does not exist. An integrated, multi-institutional approach is essential to enhance the geohazard risk management of road infrastructure.

The case study's findings and recommendations for the enhancement of road geohazard risk management in Brazil include, but are not limited to:

- Ad hoc methodology for geohazard risk assessment. Road administrators are identifying and assessing road geohazard risks substantially depending on the experience of local engineers, normally through the visual inspection of roads. Though the experience in local situations helps to identify problems, this approach has certain limitations, not being based on any geological or statistical assessment. For example, it is difficult for the local engineers to conduct a proper geological survey or inspection of risky slopes. Many of the occurrences start outside of the right-of-way or are in inaccessible areas where the human eye cannot observe. This obstacle could be overcome by using advanced technology such as unmanned aerial vehicles (UAVs) to observe the terrain and identify critical spots. Also, an additional assessment by experts in geology with the support of local geological institutes would enrich the engineer's evaluation and provide a better solution, combining the transport and geological points of view. In Japan, the 10th nationwide road geohazard risk Inspection (2006) focused on the identification of hazard-prone road locations (mostly outside the right-of-way under the jurisdiction of road management authorities) missed during the 9th inspection (1996) using "Road Geohazard Risk Inspection Guidebook", which was upgraded by a committee of public, academic, and private expert members.

- No cost-benefit assessment for geohazard mitigation measures. Specific funding for mitigation measures is almost nonexistent in the federal and state roads throughout Brazil. Although geohazard mitigation could bring a substantial economic benefit by preventing a chronic need for the recuperation of roads after disasters, the economic assessment of geohazard mitigation measures from the life-cycle viewpoint has rarely been conducted. This often leads to a low priority of these works given to the serious budget constraints. In Japan, the nationwide inspections identify the hazardous road locations where proactive measures can be applied to prepare the concepts and rough cost estimates of the required measures needed. The Japanese government consolidates the inspection results and formulates the nationwide road geohazard risk management program using the list of hazard-prone road locations selected for proactive measures and the corresponding draft budget allocations.
- Little data-sharing among stakeholders in geohazard management. Brazil does not have a law or plan that relates and directly integrates disaster risk management into the country's transport sector. Environmental and geohazard risk-related information is not yet integrated with the transport sector. Each branch has been considered separately over the years without looking at each other's data or information. For successful road geohazard risk management, data are one of the most valuable assets, and as such, it becomes fundamental that every institution involved in the area is aware and knowledgeable about all the available data. As discussed in Section 3.2, geohazard risk management activities must fit within the road authority's asset management practices. Effective asset management systems collect data that are valuable in understanding which road assets are vulnerable to natural hazard risks. American Association of State Highway and Transportation Officials (AASHTO) published a guideline on integrating

extreme weather risks into transportation asset management (AASHTO 2012). Sharing key information, being aware of the other institutions' actions and plans, and keeping a continuous relationship are fundamental for effective prevention of and rapid response to natural disasters.

- No strategic contingency program. Although a certain protocol exists at the local unit level of road agencies for preparing for geohazard events, no official and written procedures or contingency plan has been developed, which is key to reduce potential losses of life or assets under a natural disaster threat. In Japan, there are three focus points of contingency programming: (i) emergency inspection and post-disaster needs assessment; (ii) emergency traffic regulations and public notice arrangements pertaining to the closure of roads; and (iii) emergency recovery activities. A more protocolized contingency plan is recommended to establish clear guidelines and criteria of the preparedness actions based on the historical disaster data in Brazil. Such plan will be able to promote close coordination between the involved stakeholders to carry out the appropriate actions in the most efficient way possible.

Serbia case study

It was found that road geohazard risk management is still a new terminology, for which there is not yet a specific law or clause in Serbia. The case study's findings and recommendations include, but are not limited to:

- There are no separate technical standards, guidelines, or operational manuals for road geohazard management. Risk evaluation and prioritization is ad hoc, depending on the affected road category and level of damage. Risk evaluation of endangered road locations is provided by experienced road agency's maintenance staff by visual inspection. Landslides, flash floods, and floods are the primary natural hazards affecting roads in Serbia, but until recently, there was no turning point in road geohazard risk management. A significant turning point in road geohazard risk management in Japan was the 1968 "Hida River Bus-Fall Incident," in which debris from a slope collapse hit two buses, pushing them from a mountainside into a river and killing 104 people. The debris flow occurred outside of the road management area (the right-of-way) and was triggered by extremely heavy rains. Until this accident occurred, the road management authority had targeted only road structures (such as roads, bridges, tunnels, engineered slopes and embankments), and did not deal with geohazard risks outside its area. Since then, the evaluation procedure has been updated so as not to miss any hazard-prone road locations, including those that may be damaged by geohazards occurring far from the road.

- No data are available on cost-benefit analysis for road geohazard risk reduction in Serbia. The responsible authority repairs the damaged section of the road whatever the cost may be, considering the importance of the road. In other words, the assumption is that all roads must be maintained, and the only decision concerns which repair solution offers the lowest life-cycle-cost solution and what priority each repair is given. The road agency estimates the cost of repairs yearly, and includes these in its investment plan submitted to the national government. The agency focuses primarily on reactive measures after a geohazard event, so a cost-benefit analysis of investment is sometimes out of context. As is the case with developing countries, the governments would tend to take reactive approach by retrofitting existing roads after disasters. There is a lack of understanding of the importance of investing for the promotion of proactive disaster prevention.
- No geohazard risk reduction strategy. Although geohazard risk management planning for new roads is performed to minimize the total life-cycle cost of the new infrastructure, there were no geohazard risk reduction plans for existing state roads within operational maintenance programs. Disaster risk management plans for existing roads are part of road maintenance activities such as reconstruction and rehabilitation. Road geohazard risk management planning starts with a risk assessment by the road agency's maintenance staff based on visual inspections and geohazard risk related data from the field. Although countermeasure planning and strategies for road disaster risk reduction are prepared annually within Serbia's regular road maintenance budget, the agency focuses mainly on emergency response and repair activities after a geohazard event.

After the 2014 floods caused damage estimated at 5% of the Serbian gross domestic product (GDP), the National Disaster Risk Management Program for Serbia was officially launched in 2015. The program has created a common platform for managing risks associated with various types of disasters by identifying potential hazard risks and reducing them in the long term. It emphasizes a dual view of risk management on transport, not only as an exposed infrastructure but also as a key part of preparedness, response, rescue, and reconstruction. The program also provides an open platform to enable various sectoral actors and donors to coordinate and avoid replication of similar activities.

3.7. Conclusion

This study developed an institutional and technical framework for road geohazard risk management in developing countries through the review of best practices for disaster prevention measures in the world. The adopted management approach aligns with the risk management practices in the ISO 31000. Since developing countries lack sufficient funds and knowledge to implement full-scale disaster prevention measures, it was required to convey necessary institutional and technical know-how in an understandable manner for policy makers and practitioners in national and local governments. This road geohazard risk management framework covers: (1) institutional setup, (2) road geohazard risk management for new roads, and (3) road geohazard risk management for existing roads. These three activities are institutionalized in governments and road agencies as road assets are financed by the government budget in most cases. The road geohazard management activities fit within the infrastructure asset management practices, such as the AASHTO's Transportation Asset Management.

The proposed framework is comprised of the stages of: (1) institutional capacity and coordination, (2) systems planning, (3) engineering and design, (4) operations and maintenance, and (5) contingency planning. The framework would be put in place in a step-by-step manner depending on the capacity and financial constraints of the project-implementing countries. It also enables these countries to select simple/low-cost technology or high-cost technology case by case. One of the most important aspects of geohazard risk management is the institutional capacity review, which measures how the road authority addresses geohazard risk and risk mitigation at the national and subnational levels. The applicability of the framework was verified by conducting the case studies to collect information about disaster risk management practices in Brazil and Serbia and by consulting with the World Bank task team leaders and experts in the field of transport and disaster risk management.

Japan is one of the developed countries that have set up systematic approaches from the aspects of geohazard risk management, such as governance and laws; evaluation and design, construction and maintenance of countermeasures; and engagement with a wide range of stakeholders such as traffic police and meteorological agencies. Japan has its own history of expanding the mandate and planning for geohazard risk management in the road sector across various national and subnational governments by experiencing turning points in geohazard risk management such as serious road geohazard incidents. This implies that developing countries should also develop their own disaster risk management frameworks through continuous efforts, while accumulating management practices in the field. For those just commencing implementation of geohazard risk management practices, a long-term commitment is required.

4. Project evaluation and trip estimation

4.1. Evaluation of transport systems in disasters

4.1.1. Evaluation of transport systems

It is necessary for road networks to have enough capacity to prepare for low-frequency, high-damage disasters, as described by Harada et al. (2017). The road network system can be degraded not only by direct damage caused by the disaster itself, but also by indirect damage, such as route disruptions, long detours, and severe traffic congestion, which may lead to greater damage. For example, road disruptions could make it difficult to transport goods to isolated communities in mountainous areas. A major detour during life-saving emergency operations could cause serious, life-threatening problems. This highlights the importance of road networks that do not become seriously dysfunctional in times of disaster.

As many parts of the world have suffered from large-scale natural disasters for a long time, Kinuma et al. (2012) stated that there has been a shift in thinking from "disaster prevention" to "disaster mitigation". In other words, increasing trends in natural disasters have caused a change in mindset from preventing disasters to minimizing the damage caused by disasters. They argue that by applying this concept to transportation networks, a resistant transportation network is not a network that is "unbreakable" by natural disasters, but rather a network that can be restored and reconstructed using multiple means and routes (more importantly, a network that can never be completely disrupted). Emphasis should be placed on building a network that can always survive with alternative and multiple routes.

Therefore, it is vital that the impacts of disasters on transport systems be evaluated in line with the disaster life cycle phase consisting of mitigation, preparedness, response, and recovery, as described by Faturechi et al. (2015). The first two phases and the latter two phases are categorized into pre-disaster and post-disaster, respectively. In the context of transport systems, they are illustrated as follows.

- The major mitigation actions can be described as (1) retrofitting system components, (2) expanding the system to include new links or nodes, and (3) adding capacity to the existing system.
- Preparedness actions may include, for example, implementing awareness campaigns, training response teams, or pre-positioning equipment and/or

other resources.

- Post-disaster emergency response includes short-term response actions in the aftermath of a disaster with the aim of restoring system performance.
- Recovery action continues until the actions to improve system performance are terminated.

Evaluation of these actions in the disaster life cycle needs to be undertaken to assess the effectiveness of disaster risk management actions.

The systems planning stage in the framework for road geohazard risk management provides a comprehensive discussion on component-level geohazard risk evaluation, but doesn’t include network-level analysis on a full scale. The systems planning stage includes risk evaluation activities for existing roads and potential new-road alignments, as discussed in Section 3.4. For existing roads, the outcome of the geohazard risk evaluation is to develop a prioritized list of sites for subsequent mitigation. For new-road alignments, the risk evaluation process should ensure that there is a basis for proper planning to avoid cost overruns, construction delays, and costly operation and maintenance outcomes. But road management authorities are responsible for evaluating related risks to their road systems (or road network).

There are a number of studies on evaluating transport system performance in disasters, as discussed in Section 2.2. Some of them have been applied to the road sector of developing countries. The World Bank disseminates road geohazard risk management by outlining its techniques and practices in a handbook that includes a network-level evaluation method for road geohazard risk management. Its techniques and practices will be discussed in the next subsection.

4.1.2.Network-level analysis

For either a new road where the range of risks may be limited or an existing road network that is relatively short, the traditional “predict, then act” methodology -with associated option selection based on cost-benefit analysis- is relatively simple and effective, as discussed in Section 3.4.2. However, for longer road sections or road networks that are often tens to hundreds of kilometers in length, for the purpose of geohazard risk assessment, the cost-benefit approach is much more difficult to apply. Geohazard risk management at the network level consists of a range of uncertainties that make it practically impossible to precisely define a future scenario to design for.

A range of factors (climatic, geological, structural, and so on) have a distribution of probabilities of occurrence and magnitude of events. These events can then trigger a range of geohazards in terms of location and magnitude, which in turn will have a distribution of impacts on road users and road networks. Such a range of unknowns is ideally suited to the decision making under deep uncertainty (DMDU) approach that provides an analysis framework for making decisions when there is a high level of uncertainty (Espinet 2018).

The nature of geohazard risks and associated decision making is closely aligned with the above DMDU description. Under DMDU, the decision-making process is reversed from a normal "predict, then act" methodology (identify a scenario, develop solutions, sensitivity-test the solutions) to one that must develop a range of strategies, identify the vulnerabilities of each strategy, and finally identify strategy adaptations to reduce the vulnerabilities. The DMDU methodology is divided into five steps (Espinet et al. 2018):

- Determine the criticality of a road link.
- Determine the exposure of the road link to geohazard events.
- Determine the vulnerability of the road link to geohazard events.
- Determine the risk to the infrastructure (expected annual damage to the infrastructure).
- Calculate the resultant priority of the road link.

Determine the criticality of a road link

The measure of criticality could include aspects such as the change in the total road user costs, total kilometers traveled, total travel time, and total journey time to the nearest school or hospital. The approach to determining criticality is to analyze the network, first with the assumption that all road links are fully functional, and then one-by-one remove a road link from the analysis and recalculate the metric assuming that road users will divert to their next best route. In this analysis, a "road link" is any length of road that the analyst wishes to consider. The criticality being determined could be that of a single road, a subnetwork of roads, or some other combination such as a key route between cities.

For each road link, the resulting difference in the metric between the "fully functional" and "without link" results are used to define whether the impact is very low, low, medium, high, or very high. The exact definition of these ratings is not that important, because it is more about relativity than the absolute value. However, a road authority may have in place an existing definition for criticality, and this should be used if available.

Determine the exposure of the road link to geohazard events

The next stage is to assess the impact of a range of different magnitude events on the road network. Exposure could be related to rainfall, earthquakes, or any other trigger of a geohazard event. A typical analysis should consider 5–10 different exposure levels for each geohazard risk category under consideration (such as rainfall, earthquake, and so on). The more exposure levels analyzed, the more reliable the results will be when subsequently determining the risk rating of a road link.

Ideally, the lowest exposure level should yield little damage to the road network. If the calculation of the vulnerability (Step 3) for the lowest exposure levels indicates otherwise, then a new lower level of exposure should be considered until such a scenario is found. Alternatively, it may be possible to assume that a high-exposure event, such as a 1-in-1-year rainfall, will have zero impact (low vulnerability) on infrastructure for the purpose of this analysis.

For instance, it may be that the exposure is being assessed on the impact of a range of return-period rainfall events—from 1-in-5-year events to 1-in-1,000-year events. Under each exposure scenario, each road link is assessed as to what impact such an event would have on that particular road link, measured in terms of water depth across the road. As with the criticality analysis, the water depths are then grouped into bands ranging from very low, low, medium, high, or very high levels of exposure.

Determine the vulnerability of the road link to geohazard events

Having identified the range of exposure levels that each road link could be exposed to, the vulnerability is then assessed on the basis of the assumed financial cost to the road authority to repair the damage. As with the exposure analysis, there will be a vulnerability for each return period being analyzed. For practical application, it may be necessary to make assumptions about the likely impact of different exposure levels that can be readily applied across the road network.

For instance, a rainfall exposure event of “very low” impact may be assumed to cause only minimal damage to the unpaved portions of a road, while a "very high" exposure may result in the loss of paved surfacing, among other things.

Because the analysis is on the basis of a road link, and because roads will be affected differently at different locations along the road, the vulnerability assessment is the arithmetic sum of the vulnerabilities along each road link. For instance, using the aforementioned rainfall example, the vulnerability of a road link can be estimated based on the length of road with "very low" impact multiplied by the unit rate to undertake minor repairs, plus the length of road with "low" impact multiplied by its unit rate, and so on.

Determine the risk to the infrastructure (expected annual damage to the infrastructure)

The risk to any given road link is then the expected annual loss based on the combination of the exposure level and the vulnerability costing (Espenit et al. 2018). This is calculated using the trapezoidal rule, where the probability of an event is the inverse of its return period. Based on the resultant expected annual loss, the risk of the road link is categorized as very low, low, medium, high, or very high. Again, the exact definitions of these categories are not so important, because it is more about determining the relative risk levels between road links.

Calculate the resultant priority of the road link

The final step is to combine the criticality with the risk ratings to calculate the priority of each road link. This is undertaken using a matrix (Table 4.1). Once the priority rating of each road link is determined, the highest-rated links are then subjected to further detailed analysis. If the initial definition of a road link was a relatively long length of road (or even a subnetwork of roads), it may be appropriate to rerun the DMDU analysis on the high-priority road links, with each road link split into a number of small links. This will then provide further guidance as to the best portion of the network on which to focus subsequent efforts.

Table 4.1. Determining the Priority Rating

		RISK RATING				
		VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH
CRITI-CALITY	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	LOW
	LOW	VERY LOW	LOW	LOW	LOW	MEDIUM
	MEDIUM	LOW	LOW	MEDIUM	MEDIUM	HIGH
	HIGH	MEDIUM	MEDIUM	HIGH	HIGH	VERY HIGH
	VERY HIGH	MEDIUM	HIGH	HIGH	VERY HIGH	VERY HIGH

Source: Data from the World Bank (2020).

4.1.3. Analysis of traffic conditions after disasters

A variety of performance indicators have been proposed in the disaster literature for evaluating disaster impacts on transportation systems. Faturechi et al. (2015) categorized them into functional and topological:

> *Functional measures focus on serviceability of the transportation system as categorized by: travel time/distance, flow or throughput, and accessibility. Topological measures consider the transportation system as a pure network and characterize it based on concepts of graph theory. Measures such as connectivity, betweenness, and centrality fall into this category. These measures focus on the relative location of network nodes and links and their interconnections rather than operations.*

For the former, it would be useful to study the characteristics of travel time, traffic flow, and other factors after a disaster in order to consider measures to minimize the functional deterioration of the transportation network. But, traditional traffic statistics do not allow us to grasp such actual circumstances.

There is a high level of uncertainties associated with evaluating and analyzing disaster impacts on transport systems, as discussed in Section 4.1.2. Uncertainty is natural and unavoidable when coping with the geographic location, severity, and other impacts of a disaster event. Faturechi et al. (2015) found the following:

> *Several different approaches have been applied within this literature for modeling possible disasters and their consequences. Such models are employed in providing input for system optimization and analysis. These approaches can be generally categorized as falling under scenario, simulation, probability distribution, and worst-case performance-based techniques.*

As uncertainties remain with regard to the evaluation of transport systems in disasters, it is important to analyze real traffic in the event of disasters. As a result of traffic analysis, a scenario and/or simulation for evaluating transport system performance in disasters will be verified.

Although travel surveys, such as the Person Trip Survey in Japan, the National Person Transportation Survey in the United States, and German Mobility Panel in Germany, have been applied in many cities in the world to understand traffic flow (Ministry of Land, Infrastructure, Transport and Tourism 2018; Bureau of Transportation Statistics U.S., Department of Transportation 2018; German Aerospace Center 2018), they have faced challenging problems: low continuity (e.g., surveyed every 7-10 years), unavailability of trends and up-to-date statuses including in disasters, and incapability of tracking short-distance trips (e.g., within 1km).

The advancement in recent years of information, communication, and technology (ICT) services offers increasing opportunities to use pervasive ICT devices (e.g., smartphones) to collect traveler location information in real-time. Transport Big Data may be defined as traveler location information converted into traffic flow through data processing. Methods of using transportation big data are applicable to developing countries where similar services are provided. The use of big data in the field of disaster management has been progressing, and there have been several reports on the use of location data from cell phones. In the area of big data-related assistance to developing countries, the most anticipated use is for cell phone location information data, and there are many technical assistance projects to utilize this information.

When a large earthquake occurs, traffic flow occurs for rescue, emergency, medical care, supply of supplies, restoration work of the facility, confirmation of family safety, volunteers, and so on. Imai (2020) discussed practical applications of disaster prevention and disaster mitigation information using probe data from communication-type car navigation systems to generate information on road traffic in the area affected by the Great East Japan Earthquake in 2011. The morning after the earthquake, this information was released to the public, and the information was used to support people heading to the affected areas. Trip estimation for large and small areas through transport big data will be discussed in the next section.

4.2. Trip estimation for large and small areas through transport big data analysis

4.2.1. Trip estimation through transport big data analysis and evaluation on disaster risk management actions

As discussed in Section 4.1.1, it is necessary to assess the impact of a disaster on the transportation system, and the results of the assessment will indicate whether the measures taken during the risk mitigation, preparedness, emergency recovery, and reconstruction phases were effective in terms of overall management. As described in Section 4.1.3, the indicators used in the evaluation can be categorized into those related to the service function of the transportation system and those related to the geometric network, although the former, such as travel time, traffic flow, and accessibility, are applied in many cases. (Faturechi et al.) A disaster resilient transportation network is one that can be recovered and rebuilt using multiple means and routes. The effectiveness of disaster risk management is assessed by analyzing whether the transportation system as a whole fulfilled required functions in the event of a disaster, that is, by analyzing the actual state of transport functions after the disaster using transportation big data. Figure 4.1 shows the relationship between road geohazard risk management actions, the evaluation of the transportation system in disasters (Section 4.1), and the analysis of traffic conditions using transport big data (Section 4.2).

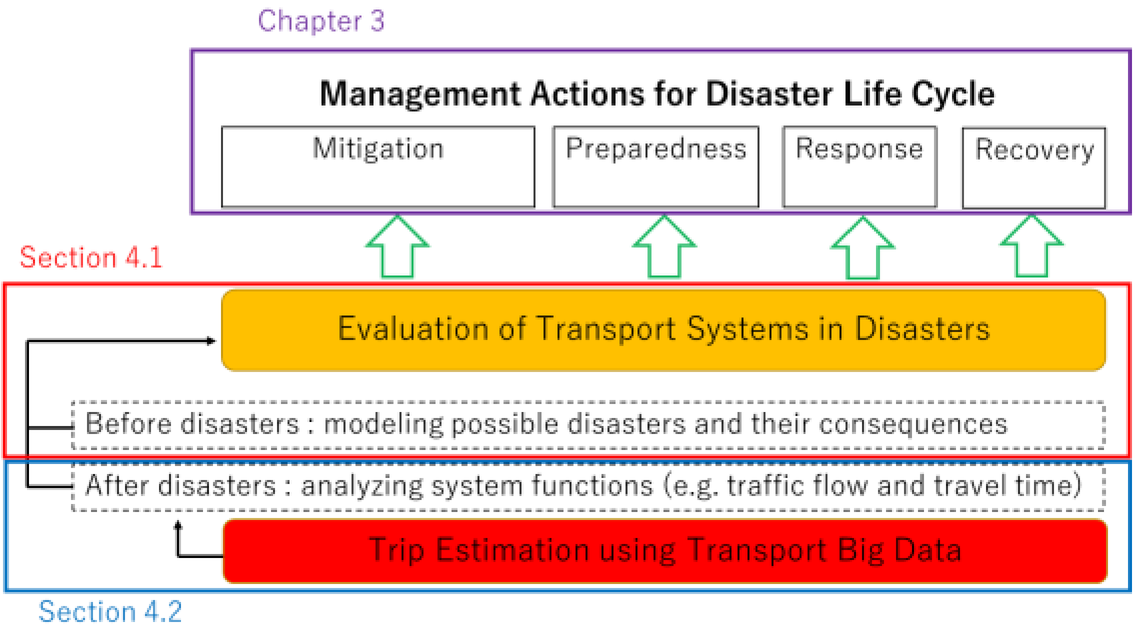


Figure 4.1 Relationship between risk management actions, transport system evaluation, and transport big data analysis

The analysis of post-disaster traffic conditions using traffic big data differs slightly depending on large areas and small areas, but this study focuses on the latter and develops a method for it. Table 4.2 summarizes the contents of road geohazard risk management actions evaluated by analyzing traffic in large and small areas. First, as for the former, when evaluating risk measures on arterial roads, it may be sufficient to analyze macroscopic trip estimation using transport big data. Risk mitigation measures for arterial roads, risk monitoring, road closures and detours, emergency route planning, and recovery planning for wide-area disasters can be evaluated by analyzing inter-regional traffic flows. For example, Yoshioka et al. (2018) analyzed the characteristics of inter-regional traffic flow after the Kumamoto earthquake occurred in 2016 by using mobile spatial statistics, which is transport big data, and evaluated the recovery status of wide-area transport functions such as highways, railroads, and airlines, as well as the disaster response of related organizations. As mobile phone penetration in developing countries is not that different from developed countries, as a similar example, Shibasaki et al. collaborated with Bangladesh Grameenphone (the largest cell phone company in Bangladesh) to transfer technology for spatial information analysis to utilize cell phone data for disaster response support (Center for Spatial Information Science of the University of Tokyo 2014).

Table 4.2. Evaluation contents and trip estimation for large and small areas

○ Useful、◇ Partially useful

Evaluation Content (road geohazard risk management actions)	Trip estimation with transport big data		Note
	Large area (>R=5km)	Small area (<R=5km)	
Mitigation Retrofitting system Adding new links	 ○ ※ 1 ○ ※ 1	 ◇ ※ 2 ◇ ※ 2	※ 1 Arterial roads, ※2 Minor roads
Preparedness Risk monitoring DRR planning	 ○ ※ 1 ○ ※ 3	 ○ ※ 2 ○ ※ 4	※ 3 Emergency routes, ※ 4 Evacuation plan
Emergency response Response plan Road closure, Detour	 ○ ※ 5 ○ ※ 1	 ○ ※ 6 ○ ※ 2	※ 5 Large-scale disasters, ※ 6 Localized disasters
Recovery Reconstruction plan Revitalizing economy		 ○ ※ 7 ○ ※ 8	※ 7 Reconstruction planning before disasters, ※ 8 Traffic flow recovery

Macro analysis Micro analysis

Next, as for the latter, there are risk management actions, the effectiveness of each of which can only be assessed by analyzing traffic after disaster on a microscopic level through transport big data. As for preparedness, risk monitoring on minor roads and evacuation plans included in disaster prevention plans require analysis of resident behaviors at district level (i.e., trip flow in walking distance) during and before a disaster, in line with particular disaster risks faced at the district. Also, as for disaster response, recovery plans, road closures, and detour measures in the case of localized disasters require identifying roads that need to be addressed urgently, and collecting real-time and micro traffic data related to those roads. In other words, continuous monitoring of traffic conditions using transport big data will enable effective and efficient disaster response and the ex-post evaluation.

Examples of the above-mentioned cases are discussed as follows. In the flow-type disaster occurred in 2021 in Atami City of Shizuoka Prefecture, Japan, a large mudslide mounted in the Izuyama district flowed down a steep sloping land for about two kilometers through a residential area. The Izuyama district is designated as the Landslide Hazard Area, but the disaster killed 26 people of passersby and residents who delayed evacuation. This is a case where preparedness actions such as evacuation planning should be implemented based on microscopic trip analysis within the district prior to the occurrence of the disaster. In addition to the prior trip analysis, post-disaster trip analysis can be useful for emergency response including the rapid formulation of a recovery plan and its accountability to local residents. In developing countries, there are many cases where settlements inhabited by the poor are formed in such landslide disaster risk areas, and it is extremely useful to evaluate the content of management actions through microscopic trip estimation.

In addition, as shown in Table 4.2, microscopic trip estimation is useful for reconstruction measures in cases that prior reconstruction plans are formulated in response to an anticipated major disaster. It took more than three years before work executions at full scale in the reconstruction of the Great East Japan Earthquake. In the reconstruction project, each municipality will manage at district level the planning, progress the work execution, and local economy revitalization within its jurisdiction with the financial and technical support of the national government. Therefore, it is useful to analyze the traffic flow before the disaster at a microscopic level for the reconstruction. Sharing information on the traffic flow in the affected areas (i.e., communities and walking-distance areas) among the parties and stakeholders involved in the recovery project management can be used to enhance productivity and project management. In developing countries, large-scale disasters occur every year, and early recovery from disasters is an urgent issue for sustainable development. Japan should contribute to sustainable development of developing countries by transferring technology that utilizes transport big data analysis, together with the lessons learned from the reconstruction of the Great East Japan Earthquake.

The knowledge gained from the post-disaster evaluation based on traffic estimates for large and small areas using transport big data analysis should be used to improve the upcoming road geohazard risk management. It is because risk management against natural disasters inherent to a particular region can be overcome by accumulating knowledge and experiences over many years. Trip estimation for large areas using cell phone location data will be discussed as a typical example of trip estimation for large areas using transport big data in the next section.

4.2.2. Trip estimation for large areas using mobile phone location data

Operational data from mobile phone base stations are provided using communication records between mobile phones and base stations. The mobile phone location data obtained from these service providers are converted into traffic flow through data processing. In Japan, with the aim of applying mobile phone operation data (showing where mobile phone devices are located) to urban and transport planning, a method of generating statistical data showing the amount of people's movement between areas (population flow statistics data) has been developed, as shown in Figure 4.2 (National Institute for Land and Infrastructure 2018).

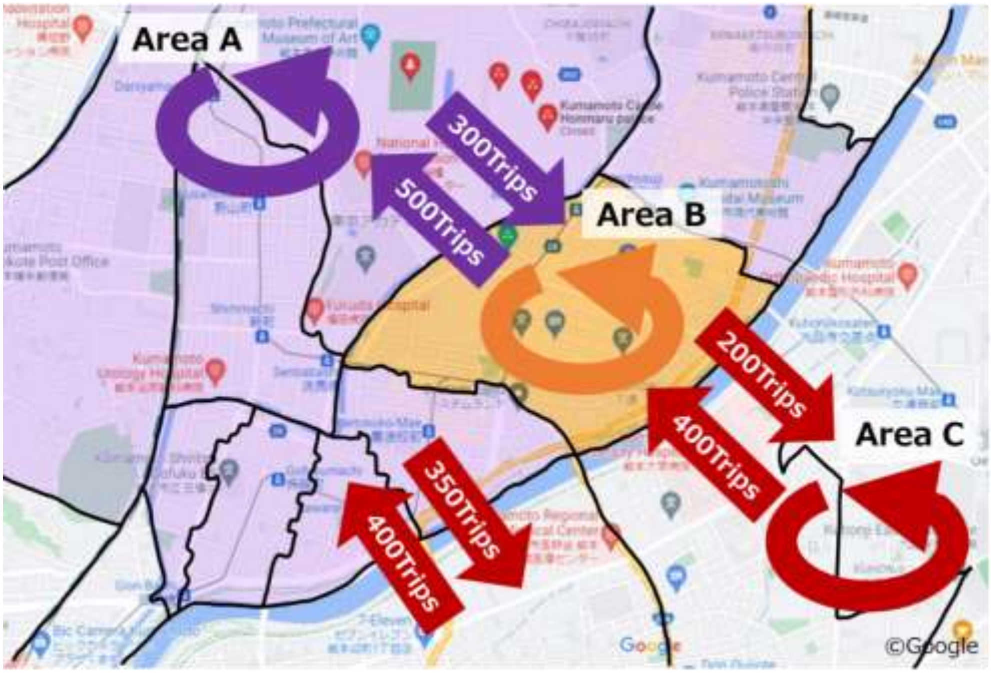


Figure 4.2 Illustration for the estimation method of population movement

(Source: National Institute for Land and Infrastructure 2018.)

The statistical data on people's movements obtained from the operational data of mobile phone base stations (for example, population flow statistics are one of the mobile spatial statistics provided by NTT DoCoMo Company) are as follows.

- Mobile phone base stations periodically monitor the number of mobile phones located in each radio wave coverage area so that they can receive calls anytime and anywhere.
- By generating statistical information on the movement of people based on the operation data, it is possible to determine the number of trips between areas across Japan as well as the number of people moving and staying in each time zone.
- Statistical information is characterized by its high statistical reliability due to the large number of samples (operational data on approximately 80 million cell phones).
- Data can be generated 24 hours a day, 365 days a year, and day-of-week, weekly, and monthly variations are available.

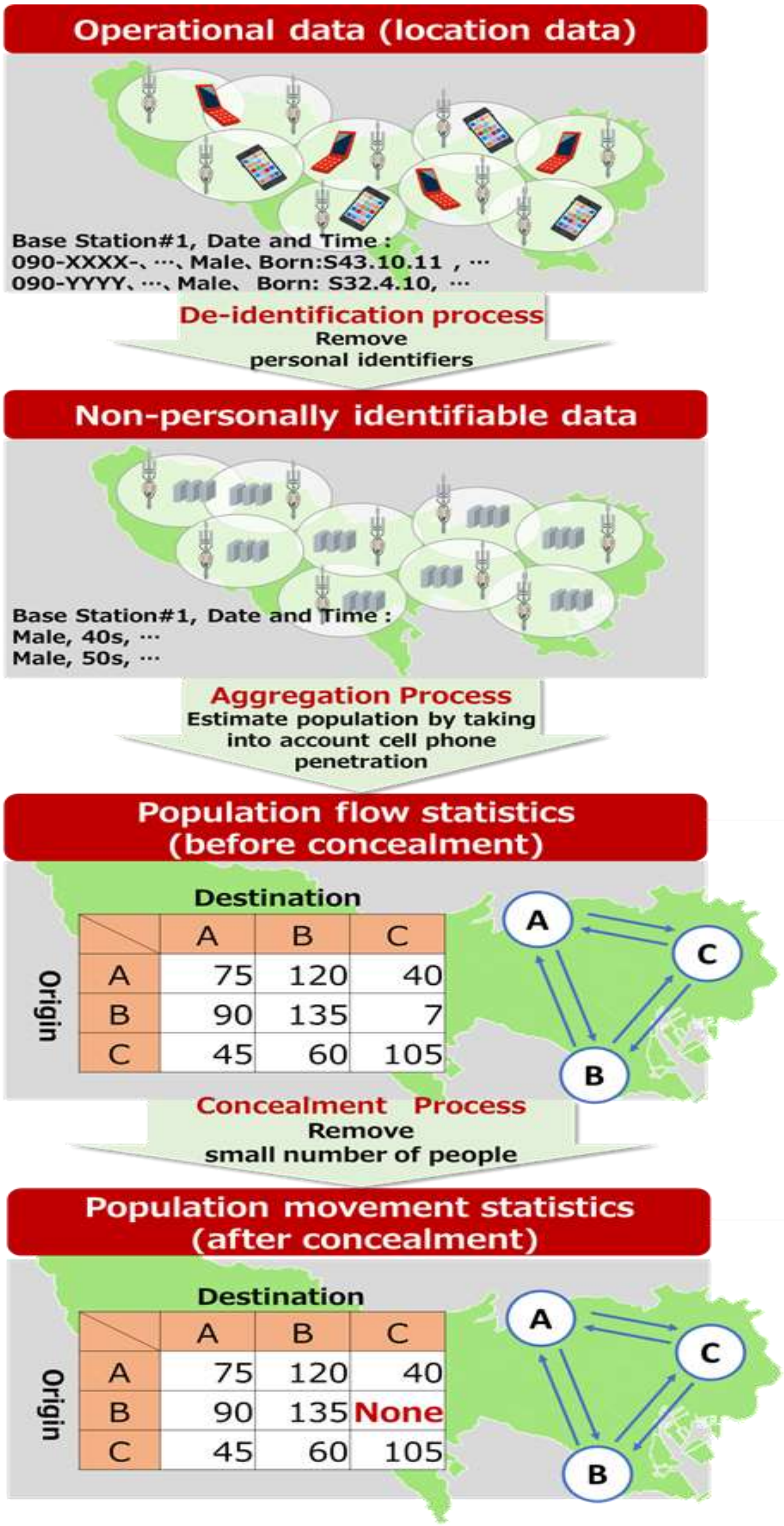
The population flow statistics are produced based on the operation data for providing mobile phone services, using the process that protects the personal information and privacy of mobile phone users. As shown in Figure 4.3, the population flow statistics are provided through a "de-identification process" that removes unnecessary personal identifiers from the operational data, an "aggregation process" that estimates the population moving between areas during a certain time period on a certain day, and a "privacy protection process" that removes a small portion of the estimated population. In the aggregation process, the ratio of the number of NTT DOCOMO mobile phones to the Japanese resident register is used to estimate people’s movement on a real population basis.

As the population flow statistics are based on operational data, they depend on the structure of the mobile phone network. The service area of the mobile phone network covers 100% of the municipalities in Japan, and it is possible to estimate the population flow at least between the municipal areas.

The spatial resolution depends on the density of base stations of the mobile phone network. In urban areas, where many people flow, the density of installed base stations is so high that estimation can be made in medium to small zones. In suburban and rural areas, where the density of base stations is low, estimation would be made in large zones (for example, a municipal area).

The temporal resolution of population flow statistics is set to one hour to ensure the reliability of the estimation because the mobile phones located in the base station area are recorded every hour. It is possible to generate population flow statistics 24 hours a day, 7 days a week, on a continuous basis. It is also possible to estimate population flow statistics separately by gender, age group, and place of residence.

Furthermore, by algorithmically processing the operational data, it is possible to estimate the population by travelling route and means of transport (airplane, bullet train, or expressway), as shown in Figure 4.4 and 4.5. It is possible to analyze people's movements 24 hours a day, 365 days a year, throughout Japan, including after disasters. Thus, it has become possible to analyze inter-regional traffic flow (i.e. traffic flow analysis for large areas) after occurrence of the disasters using transport big data.



	A	B	C
A	75	120	40
B	90	135	7
C	45	60	105

	A	B	C
A	75	120	40
B	90	135	**None**
C	45	60	105

Figure 4.3 Illustration for the generation process of population movement statistics

(Source: National Institute for Land and Infrastructure 2018.)

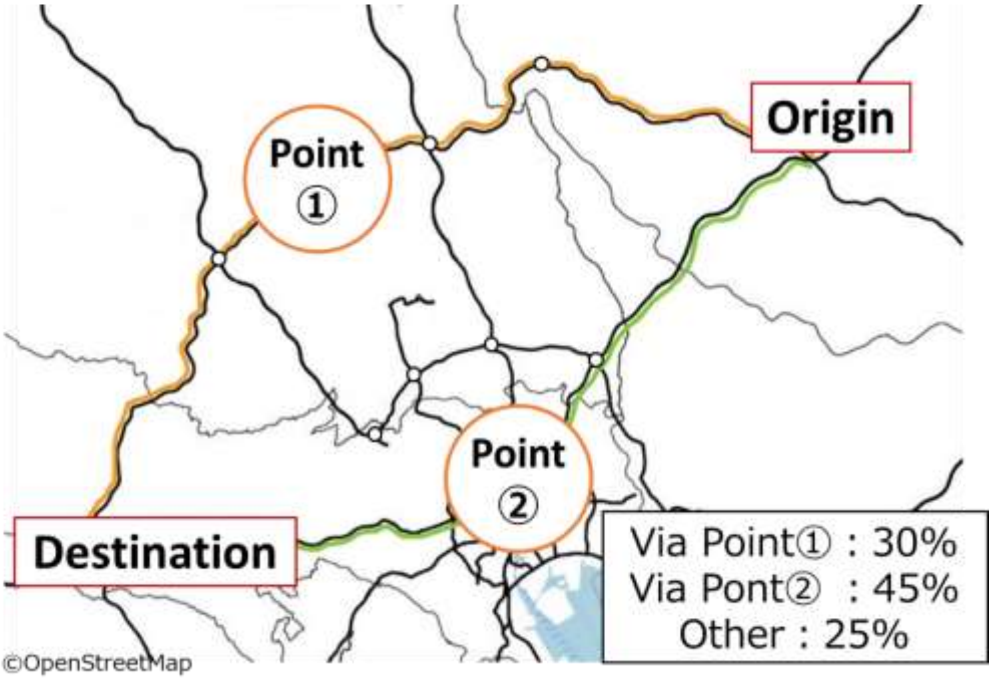


Figure 4.4 Illustration for the estimation method of trip routes

(Source: National Institute for Land and Infrastructure 2018.)

Figure 4.5 Illustration for the estimation method of transport modes

(Source: National Institute for Land and Infrastructure 2018.)

4.2.3.Trip estimation for small areas using transport big data

Studies on traffic flow analysis for small areas have been conducted by collecting transport big data from public transport IC cards, Wi-Fi, and mobile phone networks. Liu et al. (2019) conducted an overview on the studies of Wi-Fi probe data used in transportation analysis. Wi-Fi probe is preferable to existing traffic data collection equipment for several reasons, including comprehensive data, flexible application, and easy operation.

As for public transport surveys, Wang et al. (2018) provided a method to evaluate the interchange quality from bus to metro in both time and space dimensions by calculating the transit time from a bus to a metro, as well as the direct distance and route distance between bus stops and metro stations using smart card data and geographic information system (GIS) tools. Dong et al. (2018) verified that bus passenger flow and running status, including average transit velocity and the waiting time at bus stations, could be monitored by analyzing a combination of MAC address data obtained from Wi-Fi devices and bus GPS data. Ricord et al. (2020) presented a cost-effective and simple way to collect travel time data across multiple modes using the technology, which detects personal electronic devices to determine people's movements. A new travel-time calculation method for pedestrians, bicycles, and automobile travelers is a linear model, which distributes the travel time between different modes by weighting the travel time based on the highest, lowest, and most likely speeds. Hidayat et al. attempted to capture the media access control (MAC) addresses of paratransit passengers in Makassar City, Indonesia. The objective of the study is: to produce a cleaning procedure to clean Wi-Fi raw data from non-passenger data, to match data between ground truth and Wi-Fi, and to make OD data based on Wi-Fi estimation.

As for pedestrian movement surveys, Danalet et al. (2014) proposed a methodology, which was a probabilistic method due to the uncertainty of Wi-Fi localization, to use Wi-Fi traces to detect the sequence of activity episodes visited by pedestrians. The number of episodes and the activity-episode locations and durations were estimated by merging information about the activity locations on a map, W-Fi measurements, and prior information about schedules and the attractivity in pedestrian infrastructure. Jiang et al. (2019) proposed a passenger trajectory reduction framework for an urban rail transit system, which is composed of trip trajectory division, trajectory noise data cleaning, and semantic trajectory extraction. Trajectory mining through Wi-Fi probing data is mature in an outdoor environment, but for indoor environments, the noise in Wi-Fi probing data significantly interferes with the preciseness of trajectory reduction. Shi et al. (2017) conducted an evaluation on the performance of a Bluetooth/Wi-Fi-based smartphone sensing approach for estimating pedestrian walking characteristics. Pedestrian walking trajectories and the corresponding motion properties were calculated using the proposed algorithm and validated by comparison with the ground truth data obtained from the video recordings.

Pu et al. (2020) conducted a study on the feasibility and reliability of the Wi-Fi CSI (channel state information)-based sensing method for pedestrian existence and moving direction recognition. The proposed Wi-Fi CSI signal is highly effective for pedestrian existence detection and moving direction recognition. Soundararaj attempted to overcome the two major challenges when using probe requests for estimating human activity: filtering the noise generated by the uncertain field of measurement and clustering anonymized probe requests generated by the same devices together without compromising the privacy of the users. Wi-Fi ‘probe requests’ generated by mobile devices can act as a cheap, scalable, and real-time source of data for the accurate measurement of human activity with high spatial and temporal granularity. Alekseev et al. (2019) developed a framework for the processing and analysis of the data from WIFI scanners, particularly electronic devices with unique MAC addresses, for estimation of the pedestrian flow and walking time. Experiments were conducted on the campus of The Hong Kong Polytechnic University to collect relevant data and to investigate the detection performance of the WIFI scanners. A comparison was made between the estimated number of pedestrians using WIFI data with the actual number of pedestrians extracted from video records.

As for other traffic surveys, in light of the COVID-19 pandemic impact on transport behaviors, Patra et al. attempted to understand the short-term changes in road traffic patterns, using data from two Wi-Fi MAC Scanners deployed at strategic locations in Chennai, India. The results indicated that the road traffic activities significantly reduced due to the restrictions in non-essential trips, workplace suspensions, and strict surveillance during lockdowns. Dang et al. (2019) developed a low-cost and flexible system that utilizes an IOT device for traffic data collection from MAC address-based data. Common problems, like detecting the capacity of the system and data processing, are discussed. Arreeras et al. (2019) analyzed travel patterns by employing Wi-Fi probe data, which were collected in the Asahikawa and Furano tourism areas. The results indicated that the association rule mining calculation is useful for sequential travel patterns illustrated to identifying significant locations toward sustainable tourism development.

However, to the best of the authors' knowledge, few existing studies have investigated the continuous monitoring of passenger flow near stations and in central business districts, which is increasingly becoming indispensable for the evaluation of urban and transport planning and disaster risk management. This paper introduces a method for acquiring trip behaviors within walking distance by means of multiple kinds of big data. First, an optimal set of big data is selected from possible sets of big data in the transport sector to estimate trip behaviors. Second, the authors propose a method for estimating trip volume. Finally, the proposed method is applied to a case study in order to validate the accuracy of estimating walking trip behaviors.

Selection of transport big data

This study investigated big data that can be useful in measuring actual traffic flow in small areas such as central business districts. This subsection reviews widespread transport big data in the world, and items of the big data were summarized from the viewpoint of how they are collected and utilized.

Public transport IC cards: A public transport IC card is a method of cashless payment by charging the card with some money and allowing IC readers to scan it when getting on a train or a bus. While such IC cards are becoming widespread over the world, Japanese IC cards are used not only as a fare card for public transport services but also as electric money for general purchases. As of March 2019, the East Japan Railway Company has issued 75 million cards called “Suica” which are widely used in metropolitan areas (East Japan Railway Company 2019). Similarly, trip data can be collectable from IC cards over the world including Oyster Cards in London, England; SMARTRIP Cards in Washington D.C., USA; and T-money Cards in Seoul, South Korea. However, there are very few cards like Suica and PASMO cards in Japan, which have interoperability for multiple transportation companies and have a credit card function (Shimamoto et al. 2014). IC cards are useful to collect personal trip data such as the traveled sections and riding time using public transport. However, the usage of such big data is limited from viewpoints of personal information protection, and consequently continuous data acquisition on a long-term basis is very challenging.

Wi-Fi: The Wi-Fi packet sensor (see Figure 4.6) is capable of collecting data, such as unique ID (MAC address), time history, and radio wave intensity, from ICT devices, such as smartphones, in which the Wi-Fi function is activated within a radius of 100 to 200 meters from the sensor (Fukuda et al. 2017). In

Japan, approximately 40% of smartphone users activate Wi-Fi all the time. Although there is no difference in the Wi-Fi services between Japan and other countries, the utilization rate is higher in Western countries because more free Wi-Fi spots have already been made available (NTT Communications Corporation 2015). The Wi-Fi data can be used to survey OD traffic volumes, traveler attributes, length of stay, and other traffic trends.

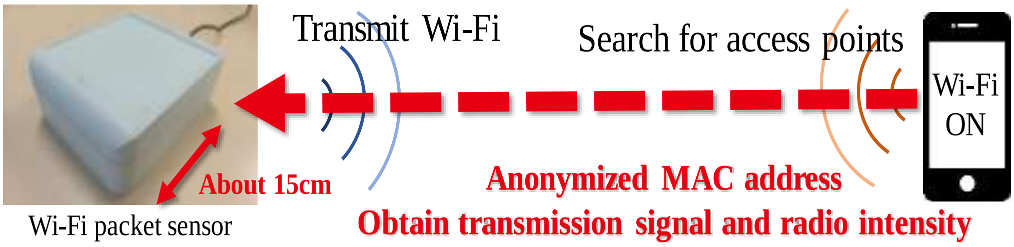


Figure 4.6 Wi-Fi packet sensor and image of data collection

Smartphone GPS data: Smartphone GPS data is trip information including the time, geographic coordinates, and positioning accuracy recorded by GPS sensors mounted in smartphones. A large number of data samples can be collected as transport big data, since the use of the opt-in method in many smartphone applications is pervasive in Japan. However, the EU has strict regulations that prohibit some methods of taking personal data outside the EU region data, and restrictions are applied as to how to use the personal data (Nomura Research Institute Ltd. 2019).

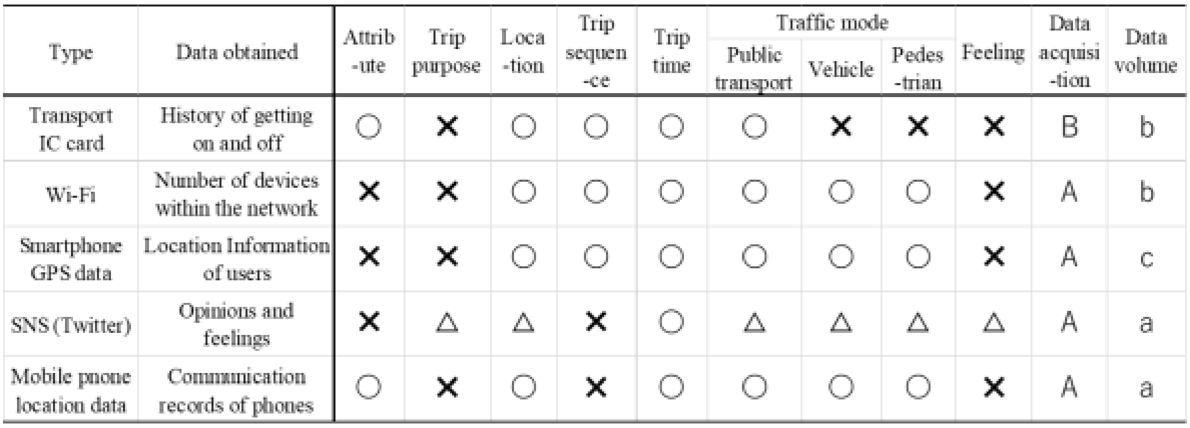
SNS: Communication via SNS (Social Networking Services) is generally more common as smartphones are owned by an overwhelmingly large majority of people around the world. Twitter has 134 million accounts over the world, and when a user tweets a message, they can optionally add location information. SNS, such as Twitter, Facebook, and Instagram, are becoming mainstream around the globe, and these communications can be tracked in real time. Nikolaidou et al. (2018) reviewed about 70 papers on the utilization of SNS in the transport sector, and concluded with recommendations to facilitate the process of collecting transport-related information from social media, the use of social media in transport planning and operation, and potential use of qualitative indicators on public transport services.

Mobile phone location data: Operational data from mobile phone base stations are provided using communication records between mobile phones and base stations. The mobile phone location data obtained from these service providers are converted into traffic flow through data processing. In Japan, mobile phone providers have developed population distribution statistics as well as population flow statistics (DOCOMO Insight Marketing Inc. 2019). It is also possible to generate similar kinds of data in any country, where mobile phone networks are operated, to be utilized as transport big data (Japan Transport and Tourism Research Institute 2018). A small zone size helps to understand person trips precisely, and therefore the spatial resolution is higher than that of traditional statistical surveys such as the Person Trip. Furthermore, since statistical surveys allow for understanding only daytime traffic flow and the nighttime population, mobile phone location data are extremely useful as they have a higher time resolution as required for urban planning and project evaluation.

Selection and comparison of transport big data

As shown in Table 4.3, a series of transport big data as described in the subsection were summarized according to criteria such as successive trips, traffic modes, data acquisition, and data volume. As a result, in order to analyze trip behaviors within walking distance, Wi-Fi data have been selected as they can easily collect the sequential data of person trips. Also, mobile phone location data have been selected as they cover the largest population distribution in the study area.

Table 4.3 Transport big data for estimating people's movements



Type	Data obtained	Attrib-ute	Trip purpose	Loca-tion	Trip sequen-ce	Trip time	Traffic mode			Feeling	Data acquisi-tion	Data volume
							Public transport	Vehicle	Pedes-trian			
Transport IC card	History of getting on and off	○	×	○	○	○	○	×	×	×	B	b
Wi-Fi	Number of devices within the network	×	×	○	○	○	○	○	○	×	A	b
Smartphone GPS data	Location Information of users	×	×	○	○	○	○	○	○	×	A	c
SNS (Twitter)	Opinions and feelings	×	△	△	×	○	△	△	△	△	A	a
Mobile pnone location data	Communication records of phones	○	×	○	×	○	○	○	○	×	A	a

Legend: ○: available △: partially available ×: not available
A: easy B: difficult
a: large b: medium c: small

From the perspectives of “in disasters”, when mobile phone base stations are stricken, mobile phone location data cannot be temporarily collected but may be soon obtained by mobile base stations substituted by mobile phone companies. As for Wi-Fi packet sensors, trip monitoring will be carried out anywhere by locating mobile-type Wi-Fi packet sensors immediately after disasters. Even in case of no power supply due to disasters, some Wi-Fi packet sensors are operated by mobile battery for a couple of days.

4.3. Trip estimation for small areas

4.3.1.Method for estimating short distance trips

In this paper, the authors developed a method for estimating trip volume and trip modes within walking distance using the big data selected in the previous chapter. The data sets used for estimating the trip volume are both Wi-Fi data collected from Wi-Fi packet sensors and the statistics of population distribution obtained through the processing of mobile phone location data. This method is distinctive in that short distance trip behaviors that cannot be found by traditional travel surveys can be estimated by simple surveying and easy data processing.

Trip volume is the number of people who move between 2 different points every hour. As indicated in Figure 4.7 and 4.8, the analytical procedure is divided into (a) calculation of the trip coefficient, (b) calculation of the outgoing, incoming, and floating populations for every point, and (c) calculation of the hourly trip volume between 2 points. First, using the OD (origin-destination) volume calculated based on the collected Wi-Fi data, the distribution ratio of each trip volume (hereinafter referred to as the "trip coefficient"), from a particular starting point (hereinafter referred to as the "origin") to the next point (hereinafter referred to as the "destination") can be calculated. Second, the incoming ratio, outgoing ratio, and floating ratio per hour for each point can be calculated from the OD volume between the points. The outgoing population for each point is calculated by multiplying the outgoing ratio by the number of visitors at the origin. In cases where the number of visitors cannot be counted, the number of people for each point can be calculated using statistics of the population distribution. Finally, sets of trip volumes between 2 points can be calculated by multiplying the outgoing population by the trip coefficient.

Trip modes indicate walking, vehicles, and bicycles and other transport modes, by which people move from one point to another. The analytical procedures are divided into (d) share of different trip modes between two points, and (e) trip volume for different trip modes. First, after calculating the trip time for each OD trip, the share of different trip modes can be identified according to the shortest time for different trip modes between points. Second, sets of trip volumes between 2 points for different trip modes can be calculated by multiplying the trip volume between 2 points by the share of different trip modes. Details of the calculation for each step will be described in the following subsections.

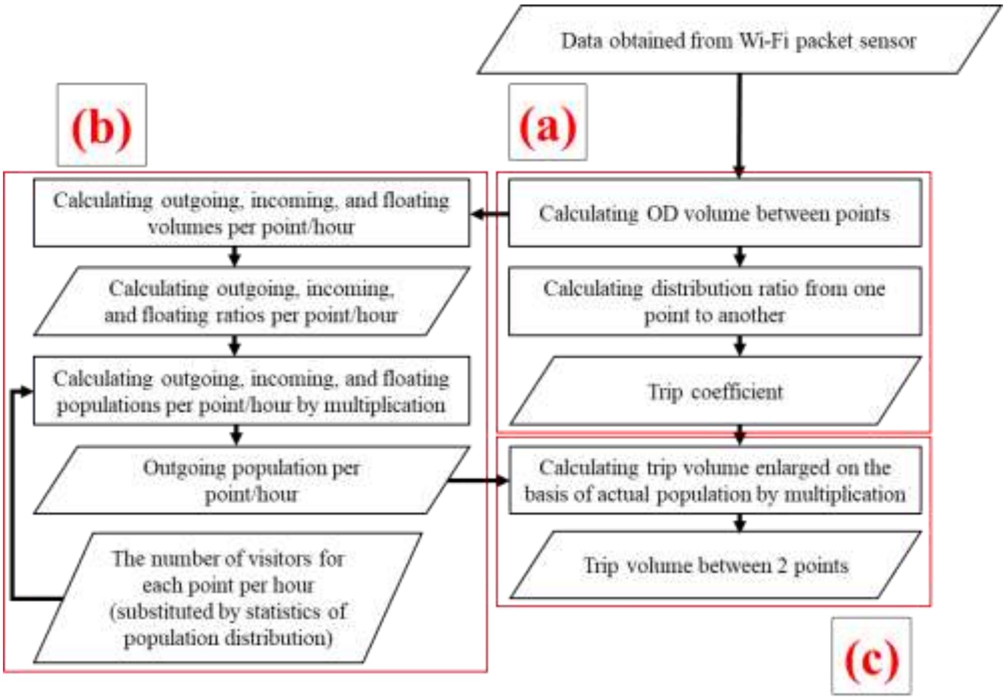


Figure 4.7 Analytical procedure to estimate trip volume

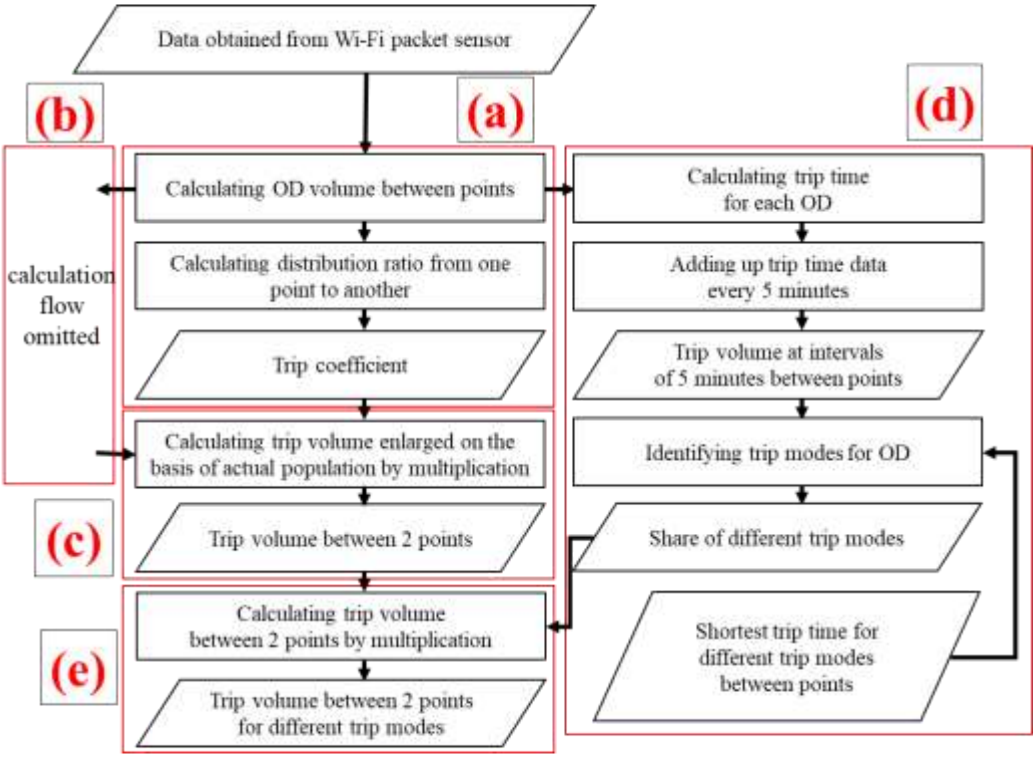
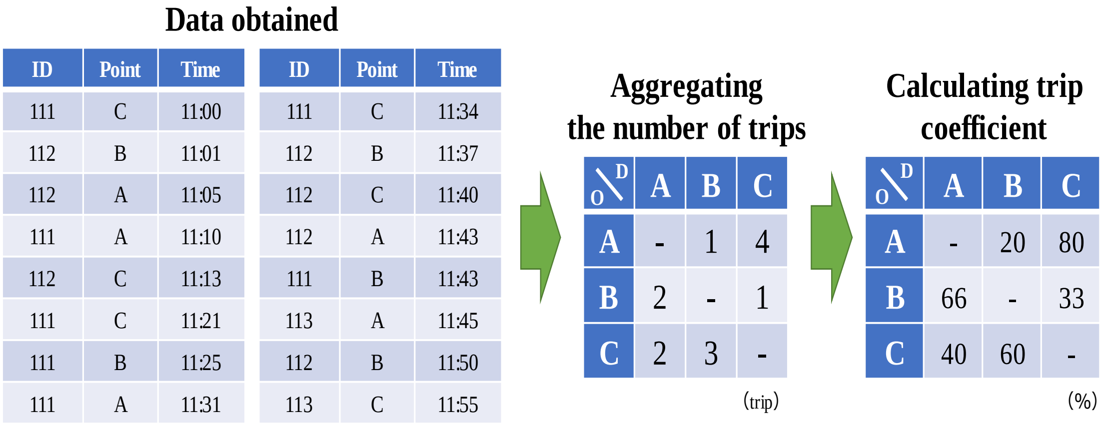


Figure 4.8 Analytical procedure to estimate trip modes

Calculation of trip coefficient

Figure 4.9 shows an illustration for how to calculate the trip coefficient, which indicates the distribution rate of smartphone devices moving from a particular point to the next points. First, the number of devices moving between 2 points is calculated by aggregating the Wi-Fi data linked with user IDs. Second, the trip coefficient is hourly calculated by dividing the calculated number of OD trips by the total number of trips generated at the origin.



Data obtained

ID	Point	Time
111	C	11:00
112	B	11:01
112	A	11:05
111	A	11:10
112	C	11:13
111	C	11:21
111	B	11:25
111	A	11:31

ID	Point	Time
111	C	11:34
112	B	11:37
112	C	11:40
112	A	11:43
111	B	11:43
113	A	11:45
112	B	11:50
113	C	11:55

Aggregating the number of trips

O \ D	A	B	C
A	-	1	4
B	2	-	1
C	2	3	-

(trip)

Calculating trip coefficient

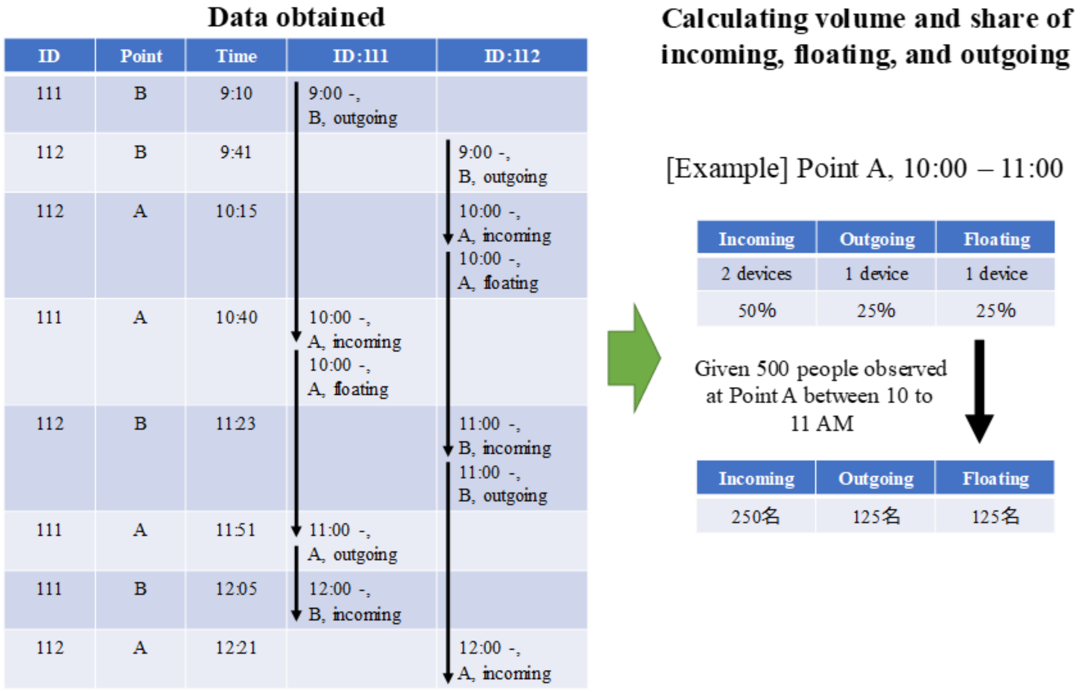
O \ D	A	B	C
A	-	20	80
B	66	-	33
C	40	60	-

(%)

Figure 4.9 Illustration for calculating the trip coefficient

Calculation of outgoing, incoming, and floating populations for every point

The outgoing population, incoming population, and floating population are the number of people who start, arrive, and stay at every point, respectively, enlarged on the basis of the actual population in the respective time zones of a day. Figure 4.10 shows an illustration for how to calculate them. First, trips that moved from one point to another would be extracted by linking them with user IDs. Incoming and outgoing volumes for a particular point are calculated for every hour (from 00 to 59 minutes for each hour). If the same ID is observed in a particular point for two consecutive times before and after the hour (00 minutes), the device is regarded as being in the floating population. Second, the hourly outgoing, incoming, and floating ratios can be calculated by dividing the outgoing, incoming, and floating volumes by the total population. Finally, the outgoing, incoming, and floating populations for a particular point can be calculated by multiplying the number of visitors (or statistics of the population distribution) by their respective ratios.



Data obtained

ID	Point	Time	ID:111	ID:112
111	B	9:10	9:00 -, B, outgoing	
112	B	9:41		9:00 -, B, outgoing
112	A	10:15		10:00 -, A, incoming 10:00 -, A, floating
111	A	10:40	10:00 -, A, incoming 10:00 -, A, floating	
112	B	11:23		11:00 -, B, incoming 11:00 -, B, outgoing
111	A	11:51	11:00 -, A, outgoing	
111	B	12:05	12:00 -, B, incoming	
112	A	12:21		12:00 -, A, incoming

Calculating volume and share of incoming, floating, and outgoing

[Example] Point A, 10:00 – 11:00

Incoming	Outgoing	Floating
2 devices	1 device	1 device
50%	25%	25%

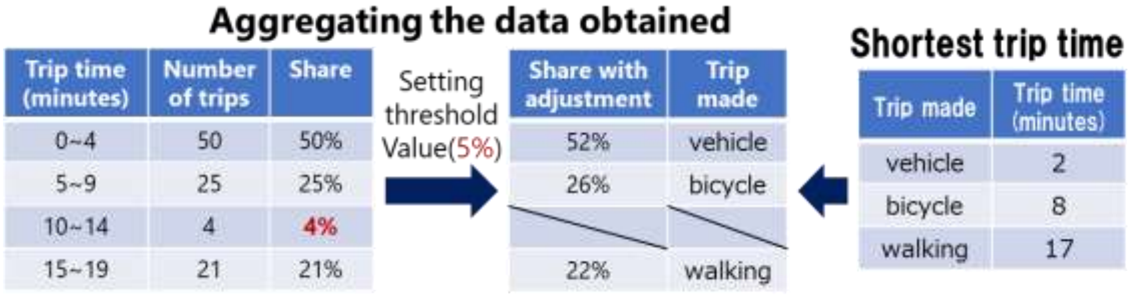
Given 500 people observed at Point A between 10 to 11 AM

Incoming	Outgoing	Floating
250名	125名	125名

Figure 4.10 Illustration for calculating the outgoing population

Calculation of trip mode share

Figure 4.11 shows an illustration for how to calculate the share of different trip modes such as walking, vehicles, and bicycles. First, after calculating the trip time for each device moving from a particular point to the next point, the number of devices is added up for every 5 minutes. Second, the share of trips calculated at intervals of 5 minutes is adjusted by removing “trip shares” less than the threshold value (5%), which is statistically set up. Finally, the share of different trip modes is calculated by identifying trip modes for each 5-minute-interval trip according to the shortest trip time mode between two points.



Trip time (minutes)	Number of trips	Share
0~4	50	50%
5~9	25	25%
10~14	4	4%
15~19	21	21%

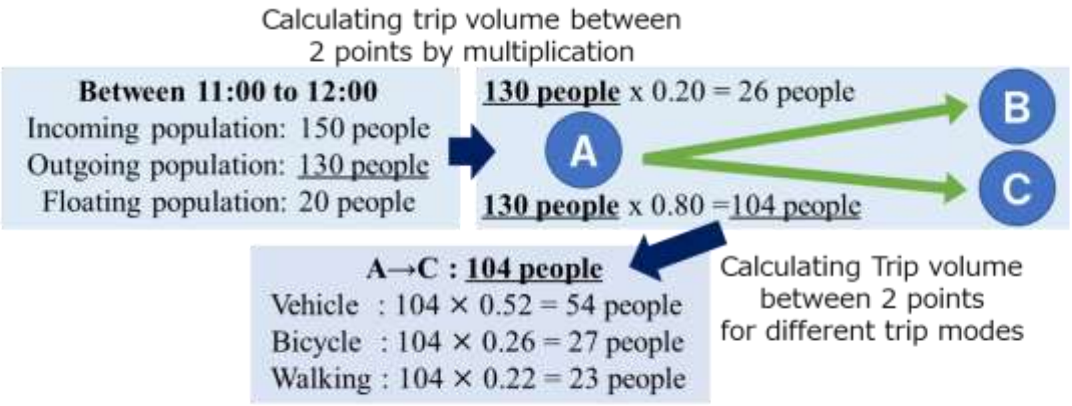
Share with adjustment	Trip made
52%	vehicle
26%	bicycle
22%	walking

Trip made	Trip time (minutes)
vehicle	2
bicycle	8
walking	17

Figure 4.11 Illustration for calculating the trip mode share

Calculation of trip volume between two points

The trip volume is the number of people traveling between 2 points, enlarged on the basis of the actual population. The trip volume between the 2 points can be estimated by multiplying the outgoing population calculated by the trip coefficient. Also, the trip volume between 2 points for different trip modes is calculated by multiplication with the trip mode share.



Between 11:00 to 12:00
Incoming population: 150 people
Outgoing population: 130 people
Floating population: 20 people

130 people x 0.20 = 26 people
130 people x 0.80 =104 people

A→C : 104 people
Vehicle : 104 × 0.52 = 54 people
Bicycle : 104 × 0.26 = 27 people
Walking : 104 × 0.22 = 23 people

Figure 4.12 Illustration for calculating the trip volume between 2 points

4.3.2.Case study

Overview of the study area

A case study has been carried out in Tachikawa City, located about 40 kilometers west of central Tokyo. The study area is in the area of Tachikawa Station in the center of Tachikawa City, where some urban renewal projects have been ongoing. As the national Showa Memorial Park and the Mitsui Shopping Park are located within 1 kilometer and 2 kilometers of the station, respectively, many visitors come from a relatively long distance. The flat land allows people to travel on foot or by bicycle easily in the central district of Tachikawa City, where the sizes of the zones and blocks are similar to those of other countries. Monorail (light rail transit) services from Tachikawa Kita Station (B) to the north are also available for visitors to this area (see Figure 4.13).

The data obtained from the Wi-Fi packet sensors on September 1 (Saturday) and 5 (Thursday), 2018, and statistics of the population distribution (i.e., mobile phone location data) have been used to validate the proposed method. Population distribution statistics can be used to understand the floating population by the time period, age group, and sex in 500m × 500m square zones in the study area. "Mobile spatial statistics" provided by NTT DOCOMO were employed as population distribution statistics data. Data were collected using Wi-Fi packet sensors installed around Tachikawa Station, as shown in Figure 4.13, from 10:00 to 18:00 on September 1.

The number of mobile phones detected at each of the Wi-Fi sensor locations is shown in Figure 4.14 and 4.15. It was found that the number of detected mobile phones is larger in the shopping areas, in particular on September 1 (weekend). The total number of mobile phones detected in each of the time periods is shown in Figure 4.16 and 4.17. It was found that the total number of detected phones increased from morning to evening.

【Source of the background map】 Google Map

Figure 4.13 Detection points by Wi-Fi packet sensors

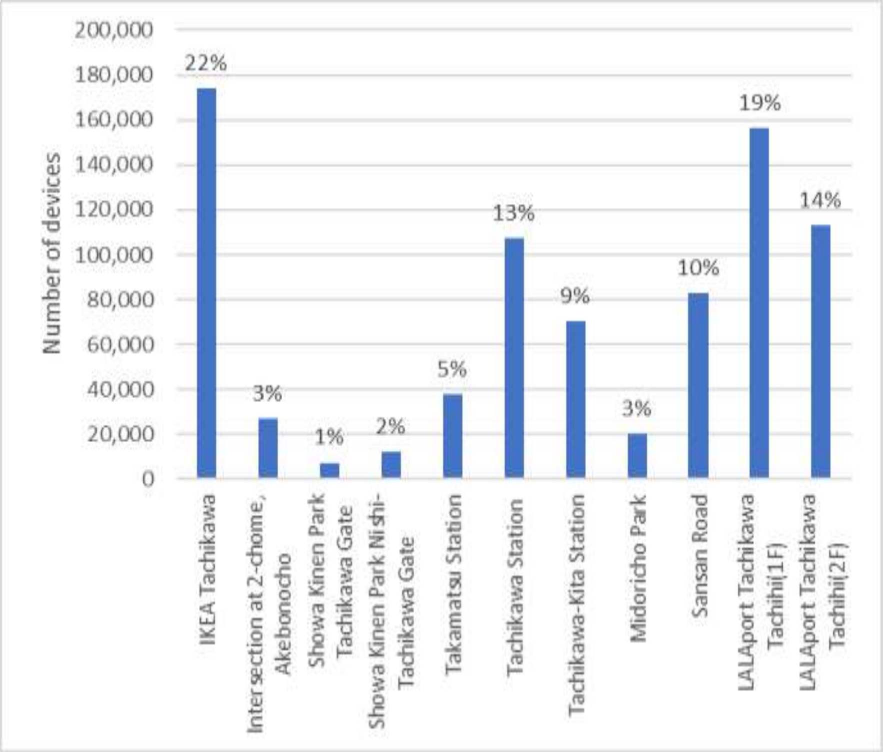


Figure 4.14 Number of mobile phones detected (September 1)

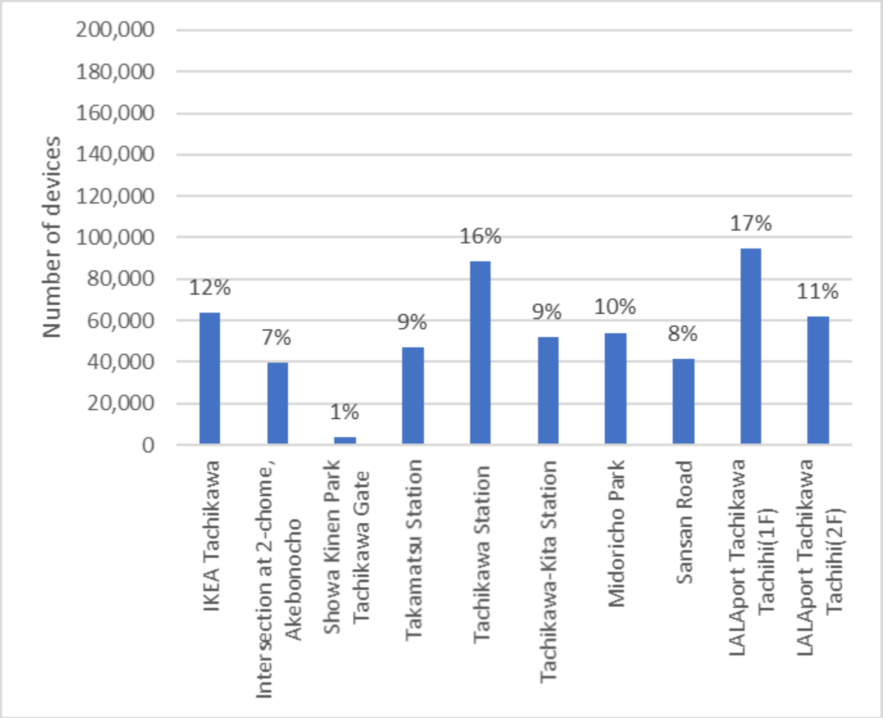


Figure 4.15 Number of mobile phones detected (September 5)

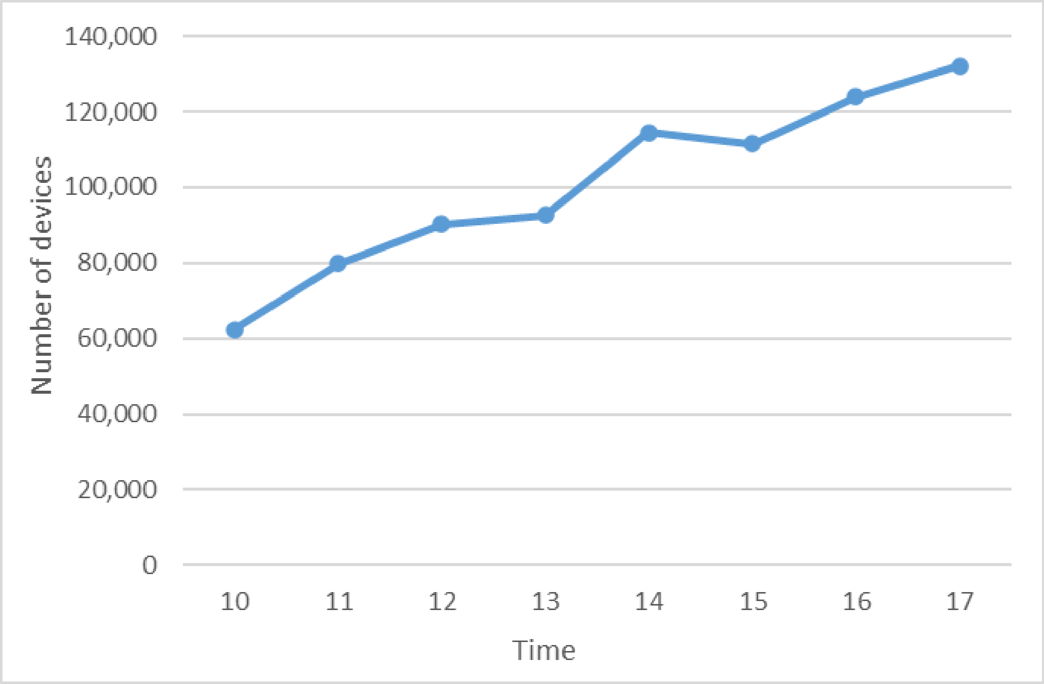


Figure 4.16 Number of detection records (September 1)

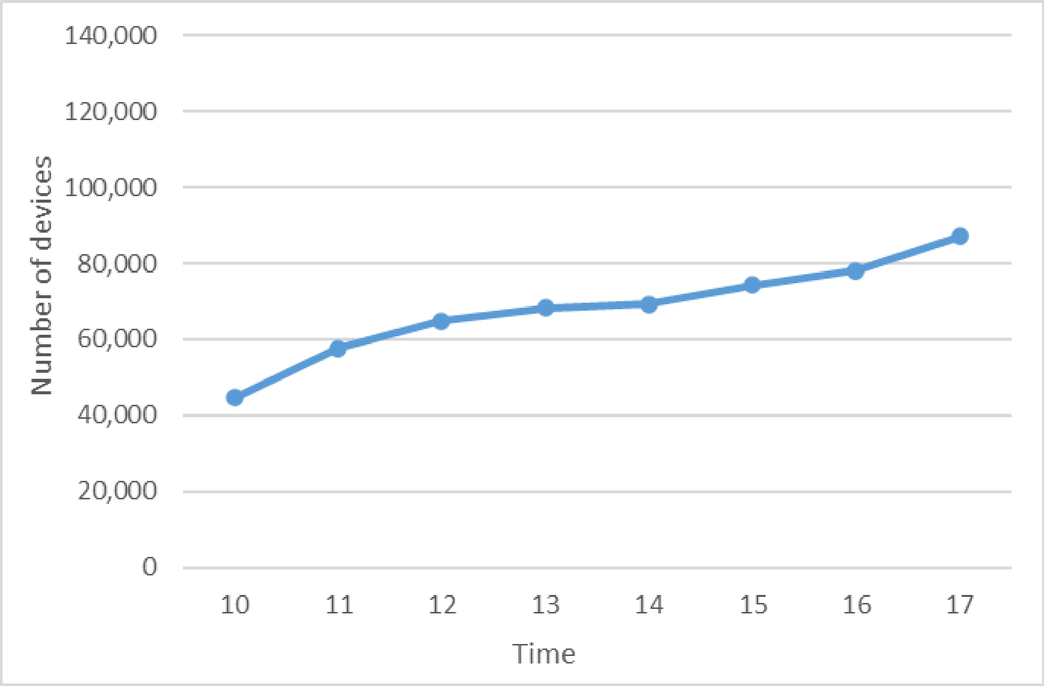


Figure 4.17 Number of detection records (September 5)

Estimation of trip volume

Table 4.4 and 4.5 shows part of the hourly number of trips calculated using the data obtained from Wi-Fi packet sensors (between 10:00 and 11:00) on September 1 and 5, respectively. Weekend trip patterns, such as shopping trips, are found in the OD matrix for September 1, and weekday trip patterns, such as commuting trips, are found in the OD matrix for September 5. Although many trips were confirmed between the two sites closely located (Tachikawa-Kita Station (B) - Sansan Road (I), and IKEA Tachikawa (D) - Midoricho Park (J)), there is a possibility that travelers could be detected by both sensors while they were staying in the area between the two sites; excessive trips may have been estimated. With regard to the observation points, a great number of trips were found at traffic nodes such as Tachikawa Station (A) and Tachikawa-Kita Station (B). On the other hand, sufficient numbers of trips were not seen at some points such as Showa Kinen Park Nishi-Tachikawa Gate (H). An application using a GPS function called “Profile Passport” was used to check the accuracy of the data, and it was confirmed that the collected data are correct.

In this case study, the hourly number of visitors was calculated using statistics of the population distribution at every site. The population in a 500m×500m square zone in Figure 4.18 is an estimated population through data processing according to the market penetration of NTT DOCOMO in Japan. In consideration of the detection range (100 meters to 200 meters) of the sensor where the Wi-Fi packet sensor can collect data from personal devices, a circle of 150 meters radius is made for each point (Ichii et al. 2018). However, it is known that the sensor detection rates may be influenced by the location of the sensors and surrounding conditions, such as indoor/outdoor and crowded/non-crowded. Estimation results influenced by the detection rates will be discussed in the concluding chapter. The circle is divided into 4 portions according to the intersection of the 500m × 500m square zones and the circle. The total population (outgoing population + incoming population + floating population) can be calculated according to each of the intersectional areas of the circle (Terada et al. 2012). As discussed in the analytical procedure shown in Figure 4.18, the outgoing population, incoming population, and floating population for each point can be calculated by multiplying the total population for each point by the outgoing ratio, incoming ratio, and floating ratio for every hour, respectively.

Table 4.4 Number of trips between two points (between 10:00 and 11:00, Sep 1)

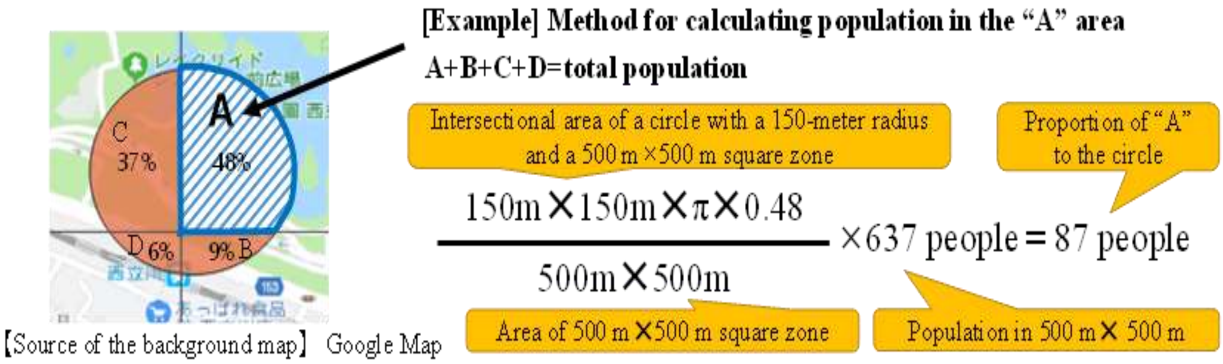
	Arrival Start	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	
		Tachikawa Station	Tachikawa-Kita Station	Takamatsu Station	IKEA Tachikawa	LALAport Tachikawa Tachihi(1F)	LALAport Tachikawa Tachihi(2F)	Showa Kinen Park Tachikawa Gate	Showa Kinen Park Nishi-Tachikawa Gate	Sansan Road	Midoricho Park	Intersection at 2-chome, Akebonocho	Total
(A)	Tachikawa Station		160	20	75	64	51	31	5	128	11	85	630
(B)	Tachikawa-Kita Station	102		53	30	23	42	27	1	258	8	13	557
(C)	Takamatsu Station	24	65		55	38	34	3	1	46	28	14	308
(D)	IKEA Tachikawa	36	14	26		44	33	39	6	39	581	10	828
(E)	LALAport Tachikawa Tachihi(1F)	31	0	0	0		0	0	0	0	0	0	31
(F)	LALAport Tachikawa Tachihi(2F)	15	0	0	0	0		0	0	0	0	0	15
(G)	Showa Kinen Park Tachikawa Gate	30	20	14	52	15	9		11	51	5	6	213
(H)	Showa Kinen Park Nishi-Tachikawa Gate	3	2	0	2	2	2	3		2	0	0	16
(I)	Sansan Road	86	216	26	43	11	26	19	0		31	34	492
(J)	Midoricho Park	6	11	31	265	9	4	3	0	27		7	363
(K)	Intersection at 2-chome, Akebonocho	66	8	2	17	6	9	7	1	24	15		155

	Arrival Start	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
		Tachikawa Station	Tachikawa-Kita Station	Takamatsu Station	IKEA Tachikawa	LALAport Tachikawa Tachihi(1F)	LALAport Tachikawa Tachihi(2F)	Showa Kinen Park Tachikawa Gate	Showa Kinen Park Nishi-Tachikawa Gate	Sansan Road	Midoricho Park	Intersection at 2-chome, Akebonocho
(A)	Tachikawa Station		25%	3%	12%	10%	8%	5%	1%	20%	2%	13%
(B)	Tachikawa-Kita Station	18%		10%	5%	4%	8%	5%	0%	46%	1%	2%
(C)	Takamatsu Station	8%	21%		18%	12%	11%	1%	0%	15%	9%	5%
(D)	IKEA Tachikawa	4%	2%	3%		5%	4%	5%	1%	5%	70%	1%
(E)	LALAport Tachikawa Tachihi(1F)	11%	0%	0%	0%		0%	0%	0%	0%	0%	0%
(F)	LALAport Tachikawa Tachihi(2F)	7%	0%	0%	0%	0%		0%	0%	0%	0%	0%
(G)	Showa Kinen Park Tachikawa Gate	14%	9%	7%	24%	7%	4%		5%	24%	2%	3%
(H)	Showa Kinen Park Nishi-Tachikawa Gate	19%	13%	0%	13%	13%	13%	19%		13%	0%	0%
(I)	Sansan Road	17%	44%	5%	9%	2%	5%	4%	0%		6%	7%
(J)	Midoricho Park	2%	3%	9%	73%	2%	1%	1%	0%	7%		2%
(K)	Intersection at 2-chome, Akebonocho	43%	5%	1%	11%	4%	6%	5%	1%	15%	10%	

Table 4.5 Number of trips between two points (between 10:00 and 11:00, Sep 5)

Arrival Start		(A)	(B)	(C)	(D)	(E)	(F)	(G)	(I)	(J)	(K)	
		Tachikawa Station	Tachikawa -Kita Station	Takamatsu Station	IKEA Tachikawa	LALAport Tachikawa Tachihi(1F)	LALAport Tachikawa Tachihi(2F)	Showa Kinen Park Tachikawa Gate	Sansan Road	Midoricho Park	Intersection at 2-chome, Akebonocho	Total
(A)	Tachikawa Station		179	20	14	20	3	2	44	25	106	413
(B)	Tachikawa-Kita Station	145		50	8	12	17	0	28	19	16	295
(C)	Takamatsu Station	26	77		23	21	31	0	13	60	12	263
(D)	IKEA Tachikawa	8	4	12		7	5	2	17	106	9	170
(E)	LALAport Tachikawa Tachihi(1F)	16	6	16	10		110	0	5	8	5	176
(F)	LALAport Tachikawa Tachihi(2F)	5	3	8	5	108		0	8	3	4	144
(G)	Showa Kinen Park Tachikawa Gate	1	0	0	0	0	0		1	0	0	2
(I)	Sansan Road	37	34	10	15	6	4	2		38	22	168
(J)	Midoricho Park	23	9	38	177	13	7	1	37		36	341
(K)	Intersection at 2-chome, Akebonocho	89	13	11	14	4	4	0	31	34		200

Arrival Start		(A)	(B)	(C)	(D)	(E)	(F)	(G)	(I)	(J)	(K)
		Tachikawa Station	Tachikawa -Kita Station	Takamatsu Station	IKEA Tachikawa	LALAport Tachikawa Tachihi(1F)	LALAport Tachikawa Tachihi(2F)	Showa Kinen Park Tachikawa Gate	Sansan Road	Midoricho Park	Intersection at 2-chome, Akebonocho
(A)	Tachikawa Station		43%	5%	3%	5%	1%	0%	11%	6%	26%
(B)	Tachikawa-Kita Station	49%		17%	3%	4%	6%	0%	9%	6%	5%
(C)	Takamatsu Station	10%	29%		9%	8%	12%	0%	5%	23%	5%
(D)	IKEA Tachikawa	5%	2%	7%		4%	3%	1%	10%	62%	5%
(E)	LALAport Tachikawa Tachihi(1F)	9%	3%	9%	6%		63%	0%	3%	5%	3%
(F)	LALAport Tachikawa Tachihi(2F)	3%	2%	6%	3%	75%		0%	6%	2%	3%
(G)	Showa Kinen Park Tachikawa Gate	50%	0%	0%	0%	0%	0%		50%	0%	0%
(I)	Sansan Road	22%	20%	6%	9%	4%	2%	1%		23%	13%
(J)	Midoricho Park	7%	3%	11%	52%	4%	2%	0%	11%		11%
(K)	Intersection at 2-chome, Akebonocho	45%	7%	6%	7%	2%	2%	0%	16%	17%	



【Source of the background map】 Google Map

Figure 4.18 Illustration for calculating the total population

The study estimated a real trip volume on September 1 by enlarging the Wi-Fi-based trip volume with the statistics of population distribution. Table 4.6 shows part of the trip volume (between 10:00 and 11:00) calculated by multiplying the hourly outgoing population by the trip coefficient between points. Table 4.7 shows the calculated results of the number of people incoming for each point. The accuracy of the estimated trip volume can be confirmed by comparing the hourly incoming volume for each point with the hourly number of visitors to the sites. The hourly number of visitors to some of the sites should have been collected, for example, by manual counting or automated surveying, which was not conducted due to resource constraints. Instead, based on interviews with the managers of the shopping sites observed by the Wi-Fi packet sensors, it was confirmed that the estimated trips were nearly the same as the actual situation. For example, the hourly incoming volume are larger for major points such as the stations and IKEA (a famous company based in Sweden). The number of hourly incoming people to each of the major points was nearly the same as the number observed by the managers in the day-to-day business operation.

Table 4.6 Hourly trip volume between two points (10:00 - 11:00, September 1)

Start \ Arrival		(A) Tachikawa Station	(B) Tachikawa -Kita Station	(C) Takamatsu Station	(D) IKEA Tachikawa	(E) LaLaport Tachikawa Tachihi(1F)	(F) LaLaport Tachikawa Tachihi(2F)	(G) Showa Kinen Park Tachikawa Gate	(H) Showa Kinen Park Nishi-Tachikawa Gate	(I) Sansan Road	(J) Midoricho Park	(K) Intersection at 2-chome, Akebonocho	Total
(A)	Tachikawa Station		427	49	188	165	131	80	13	319	33	219	1,624
(B)	Tachikawa-Kita Station	186		104	54	42	81	52	2	652	17	25	1,214
(C)	Takamatsu Station	15	40		27	23	21	2	1	28	24	9	189
(D)	IKEA Tachikawa	23	11	18		28	21	24	4	28	112	7	276
(E)	LaLaport Tachikawa Tachihi(1F)	26	12	11	22		107	8	0	21	4	6	216
(F)	LaLaport Tachikawa Tachihi(2F)	13	8	12	20	136		2	2	6	2	7	208
(G)	Showa Kinen Park Tachikawa Gate	32	19	15	53	16	10		12	52	8	6	223
(H)	Showa Kinen Park Nishi-Tachikawa Gate	25	17	0	17	17	17	25		17	0	0	136
(I)	Sansan Road	182	274	54	84	25	54	44	0		71	71	860
(J)	Midoricho Park	2	5	16	396	4	2	2	0	12		4	443
(K)	Intersection at 2-chome, Akebonocho	493	60	15	127	45	67	52	7	179	112		1,159
Total		999	873	294	987	502	510	290	40	1,315	384	353	6,547

Table 4.7 Hourly incoming volume for each point (September 1)

	Name of location	10:00 -	11:00 -	12:00 -	13:00 -	14:00 -	15:00 -	16:00 -	17:00 -
(A)	Tachikawa Station	999	1,341	1,357	1,388	1,516	1,705	1,802	1,970
(B)	Tachikawa-Kita Station	873	1,211	1,435	1,510	1,656	1,742	1,695	1,651
(C)	Takamatsu Station	294	389	519	579	480	575	666	596
(D)	IKEA Tachikawa	987	1,050	1,335	1,303	1,272	1,161	1,271	1,221
(E)	LaLaport Tachikawa Tachihi(1F)	502	611	656	773	843	781	790	617
(F)	LaLaport Tachikawa Tachihi(2F)	510	716	690	796	754	677	614	325
(G)	Showa Kinen Park Tachikawa Gate	290	138	73	72	52	24	12	7
(H)	Showa Kinen Park Nishi-Tachikawa Gate	40	52	77	82	73	36	43	53
(I)	Sansan Road	1,315	1,323	1,445	1,436	1,636	1,552	1,071	1,128
(J)	Midoricho Park	384	489	735	733	799	823	495	742
(K)	Intersection at 2-chome, Akebonocho	353	467	435	531	506	534	743	655

(Number of people)

Table 4.8 and 4.9 are the sample results of the trip mode share and hourly trip volume for different trip modes. As indicated in Section 4.1, there are monorail (light rail transit) services from Tachikawa Kita Station (B) to LaLaport Tachikawa Tachihi (E, F). Therefore, some trips classified as “Walking” and “Tour” might use monorail services. As trip modes are identified according to the shortest trip time between two points, in the case of traffic congestion, some vehicle trips might be classified as the walking mode or other trip modes. The authors will treat such situations as future challenges.

Table 4.8 Sample results of the trip mode share (September 1)

Start	Arrival	Trip Time (minutes)	Share	Trip mode
(A) Tachikawa Station	(C) Takamatsu Station	5～9	40%	Bicycle
		10～14	40%	Bicycle or Walking
		15～19	20%	Walking
	(G) Showa Kinen Park Tachikawa Gate	0～4	21%	Bicycle
		10～14	26%	Walking
		15～19	53%	Tour
		20～24		
	(D) Lalaport Tachikawa(1F)	0～4	39%	Vehicle
		20～24	30%	Walking
		55～59	30%	Tour
	(E) IKEA Tachikawa	0～4	38%	Bicycle
		5～9	29%	Bicycle or Walking
		10～14	33%	Walking

Table 4.9 Sample results of hourly trip volume for different trip modes (September 1)

Start	Arrival	Trip Time (minutes)	Trip mode	10:00~	11:00~	12:00~	13:00~	14:00~	15:00~	16:00~	17:00~
(A) Tachikawa Station	(C) Takamatsu Station	5～9	Bicycle	20	13	8	16	16	28	9	13
		10～14	Bicycle or Walking	20	13	8	16	16	28	9	13
		15～19	Walking	10	7	4	8	8	14	5	7
	(G) Showa Kinen Park Tachikawa Gate	0～4	Bicycle	17	8	4	4	3	1	1	0
		10～14	Walking	21	10	5	5	3	2	2	0
		15～19	Tour	42	21	10	11	7	3	3	0
		20～24									
	(D) Lalaport Tachikawa(1F)	0～4	Vehicle	65	52	39	68	61	72	67	36
		20～24	Walking	50	40	30	52	47	55	52	28
		55～59	Tour	50	40	30	52	47	55	52	28
	(E) IKEA Tachikawa	0～4	Bicycle	72	71	83	92	71	61	68	105
		5～9	Bicycle or Walking	54	53	62	68	53	45	50	78
		10～14	Walking	62	61	71	79	61	52	58	90

As discussed in Section 4.2 (Selection of transport big data), the Wi-Fi packet sensor is capable of collecting MAC address or unique ID for a device to identify a smartphone user. There is an issue called "MAC address randomization" that MAC addresses for some devices can be changed for privacy protection, resulting in double/multiple counting that the number of smartphones excessively recorded by Wi-Fi packet sensors (Hino et al. 2021). However, the case study in Tachikawa City was carried out in 2018, the authors did not correct Wi-Fi data because it was confirmed that such double/triple counting rarely happened, and could be identified by reading the part of the device unique ID where the first few digits are common. Miyaji et al. (2021) developed a method that correct the influence of an excessive number of smartphones due to the MAC address randomization based on the analysis of radio wave intensity data recorded from smartphones. When recording MAC addresses, the radio strength of the probe request weakens depending on the reach distance. Their correction method to set the threshold of the radio strength data is the same approach as the case study method to expand Wi-Fi data with the statistics of the population distribution data.

4.4. Conclusion

There are a number of practical studies on the evaluation of transport systems (road networks) in disasters using performance indicators such as risk, reliability, vulnerability, robustness, and resilient. Some of them have been applied to the road sector of developing countries. Section 4.2 discussed an example of a network-level evaluation method, called decision making under deep uncertainty (DMDU), for road geohazard risk management. A range of factors (climatic, geological, structural, and so on) have a distribution of probabilities of occurrence and magnitude of disaster events, which in turn will have a distribution of impacts on road users and road networks. The DMDU approach provides an analysis framework for making decisions when there is a high level of uncertainty

A variety of performance indicators have been proposed for evaluating disaster impacts on transportation systems. Performance indicators are categorized into transport function measure and topological network measure. The former can be applicable to the serviceability of the transport system such as travel time, traffic flow, and accessibility. The latter focuses on the relative location of network nodes and links and their interconnections rather than transport operations. Therefore, for the former, it would be useful to study the characteristics of travel time, traffic flow, and other factors after a disaster in order to consider measures to minimize the functional deterioration of the transportation network. But, traditional traffic statistics do not allow us to grasp such actual circumstances.

It is necessary to assess the impact of a disaster on the transportation system, and the results of the assessment will indicate whether the measures taken during the risk mitigation, preparedness, emergency recovery, and reconstruction phases were effective. The evaluation indicators such as travel time, traffic flow, and accessibility, are applied in many cases. With the development of ICT in recent years, the use of big data in the field of disaster management has been progressing. The effectiveness of disaster risk management is assessed by analyzing the actual state of transport functions after the disaster using transportation big data. The analysis of post-disaster traffic conditions using traffic big data differs slightly depending on large areas and small areas, but this study focuses on the latter and develops a method for it. The evaluation contents of road geohazard risk management actions and the traffic analysis in large and small areas are discussed have been discussed in details, including the context of technical assistance to developing countries.

The authors reviewed the characteristics of 6 kinds of transport big data, which can be considered useful in analyzing actual trips within walking distance. As a result, two types of data were selected: Wi-Fi data for acquiring successive pedestrian trips and mobile phone location data for surveying the population mobility precisely with a small zone size. The developed method was applied to the case study in Tachikawa City, Tokyo. MAC address data for smartphones measured by Wi-Fi packet sensors and statistics of the population distribution data processed by mobile phone location data have been employed to validate the accuracy of the estimated results of the method. The case study produced various findings, including: (1) it was confirmed by interviews with the managers of the shopping sites that the estimated trip volume was almost the same as the trip volume actually observed each day and (2) the method is useful to evaluate disaster impacts on transportation systems because it is capable of monitoring short distance trips not found by traditional statistical surveys.

5. Conclusion and recommendation

5.1. Summary

Summary of Chapter 2

Key findings from the literature review on mainstreaming of disaster risk reduction in the transport sector of developing countries are as follows:

- Consideration of hazard and risk information at the early stages of the project management process can lead to long-term savings, both in terms of the initial cost of the project and the cost of the maintenance operations over the life of the infrastructure.
- An analytical framework proposed by the World Bank provides two key domains for mainstreaming resilience in transport systems. One is management domains: policies, institutions, and processes; technical expertise; financial arrangements and incentives; operations and maintenance; and technical planning and design. Another is temporal dimensions: predisaster risk assessment and management, emergency response and risk reduction, and postdisaster recovery and reconstruction.
- Most transportation asset management plans do not currently detail causes of failure and risks of hazards that affect condition, performance, and life of the asset and its ability to provide a reliable and safe service.
- Despite the frequency of natural hazards and the threat of more extreme weather as a result of climate change, there are few works on how a systematic approach can be established to address natural disaster risks in the transport sector.

To develop the institutional and technical framework for road geohazard risk management, the authors initially set up six pillars: country capacity review; inspection and identification of road hazards; evaluation and planning; structural measures; non-structural measures; and emergency response, recovery and reconstruction. The literature review provides details of practices and techniques for each pillar.

Evaluation of disaster prevention measures in the disaster life cycle needs to be undertaken to assess the effectiveness of disaster risk management actions. Disaster-related performance evaluation provides direct measurements that can aid in the prioritization of mitigation, preparedness, and adaptive actions. Performance indicators for the evaluation methodologies can be categorized as risk, reliability, vulnerability, robustness, and resilient. As a result of the literature review, the following evaluation methodologies are found:

- to maximize the overall system functionality and the benefit of mitigation investment for transportation infrastructure systems;
- to identify the ways a road network can become partially or completely dysfunctional and identify disaster events that may arise from vulnerable weaknesses;
- to identify optimal protection strategies for networks of significant size;
- to consider congestion in the degraded network for evaluating network reliability as heavy congestion interferes with traffic related to restoration or reconstruction works; and
- to explore optimal allocation of a limited budget between preparedness and recovery activities.

The study has special significance in developing a comprehensive risk management framework for particular risk hazards to mainstream DRR in the transport sector in developing countries. This institutional and technical framework should be phased in stages according to the capacity and financial constraints of developing countries.

Summary of Chapter 3

The study developed an institutional and technical framework for road geohazard risk management in developing countries through the review of best practices for disaster prevention measures in the world. The road geohazard risk management approach proposed in the study aligns with the practices in the ISO 31000 standard.

The framework covers the followings:

- Institutional capacity and coordination cover the institutional arrangements that are necessary for the successful implementation of geohazard management.
- Systems planning covers the planning aspects pertaining to the identification, assessment, evaluation of risks, and risk management,

along with raising awareness of disasters.

- Engineering and design deals with the engineered solutions to address geohazard risks, giving examples of different solutions to particular risk types.
- Operations and maintenance focuses on the operation and maintenance aspects of geohazard management—whether through the maintenance of previously engineered solutions or the nonengineered solutions available to mitigate the impacts of geohazard risks.
- Contingency programming addresses contingency programming issues, such as postdisaster response and recovery, and the important issue of funding arrangements.

The road geohazard risk management processes for new and existing roads differ only in the risk assessment and geohazard risk management planning stages. The measures common to both new and existing roads include (1) proactive structural measures, (2) proactive nonstructural measures, (3) postdisaster response, and (4) recovery.

One of the most important aspects of geohazard risk management is the institutional capacity review, which measures how the road authority addresses geohazard risk and risk mitigation at the national and subnational levels, considering the following aspects:

- Existence and level of maturity of the legal framework, institutions, and plans or strategies
- Institutional capacity and capability
- Implementation level of plans or strategies
- Situation and effectiveness of projects on road geohazard risk management.

Results of an institutional capacity review reach an official consensus on weaknesses, targets for institutional strengthening, and investment priorities and their financing strategy.

The systems planning stage comprises two main aspects: risk evaluation and risk management planning. Although the geographic scope of any geohazard risk evaluation will inherently be different between studies on existing roads or potential new-road alignments, the underlying methods are the same. For existing roads, the approach may be constrained to a single site, a single road, or expanded to the entire network of roads. For new-road alignments, the approach needs to ensure full coverage of all potential road alignments.

Risk management planning requires recognizing, understanding, and addressing all potential risks, which are identified and assessed in the risk evaluation process, to prioritize hazard-prone road locations for the subsequent application of risk mitigation measures.

Structural measures are engineering solutions to prevent or protect road infrastructure damages due to geohazards. They include measures implemented as (1) proactive measures implemented to lower the risk of geohazard failure; (2) emergency works in highly susceptible areas or during geohazard events; and (3) recovery conducted as secondary damage protection or recovery works in a postdisaster stage.

Nonstructural measures for road geohazards, which enhance road geohazard risk management in the operations and maintenance stage, are any measures not involving physical construction. They are less expensive than structural measures and include: (1) routine maintenance of previously constructed structural measures; (2) monitoring of geohazards (potentially using automatic measuring devices, linked to automated warning systems); and (3) road closures to prevent injury before (or during) a geohazard event.

Contingency planning addresses contingency programming issues, such as postdisaster response and recovery, and the important issue of funding arrangements. Contingency programming consists of three distinct phases: (1) emergency preparedness before a geohazard event, (2) emergency response during and in the immediate aftermath of an event, and (3) recovery following the emergency to restore full functionality to the road network.

The case studies in Brazil and Serbia were conducted to verify the applicability of the framework to developing countries. Key elements for developing a road geohazard risk management framework have been identified so that the framework is applicable to any country contexts.

Summary of Chapter 4

A resistant transportation network is not a network that is "unbreakable" by natural disasters, but rather a network that can be restored and reconstructed using multiple means and routes. Road management authorities are responsible for evaluating related risks to their road systems (or road network). However, the systems planning stage in the framework for road geohazard risk management provides comprehensive discussion on component-level geohazard risk evaluation, but doesn’t include network-level analysis on a full scale.

There are a number of practical studies on the evaluation of transport systems in disasters using performance indicators. Section 4.2 discussed an example of a network-level evaluation method, called the decision making under deep uncertainty (DMDU), for the road geohazard risk management. Geohazard risk management at the network level consists of a range of uncertainties that make it practically impossible to precisely define a future scenario to design for.

A variety of performance indicators have been proposed for evaluating disaster impacts on transportation systems. Performance indicators are categorized into transport function measure and topological network measure. The former can be applicable to serviceability of the transport system, such as travel time, traffic flow, and accessibility. The latter focuses on the relative location of network nodes and links and their interconnections rather than transport operations.

It is necessary to assess the impact of a disaster on the transportation system, and the results of the assessment will indicate whether the measures taken during the risk mitigation, preparedness, emergency recovery, and reconstruction phases were effective. The evaluation indicators such as travel time, traffic flow, and accessibility, are applied in many cases. With the development of ICT in recent years, the use of big data in the field of disaster management has been progressing. The effectiveness of disaster risk management is assessed by analyzing the actual state of transport functions after the disaster using transportation big data. The analysis of post-disaster traffic conditions using traffic big data differs slightly depending on large areas and small areas, but this study focuses on the latter and develops a method for it. The evaluation contents of road geohazard risk management actions and the traffic analysis in large and small areas are discussed have been discussed in details, including the context of technical assistance to developing countries.

In Japan, with the aim of applying mobile phone operation data (showing where mobile phone devices are located) to urban and transport planning, a method of generating statistical data showing the amount of people's movement between areas (population flow statistics data) has been developed. It is also possible to estimate population flow statistics separately by gender, age group, and place of residence. Furthermore, by algorithmically processing the operational data, it is possible to estimate the population by travelling route and means of transport (airplane, bullet train or expressway). It is possible to analyze people's movement for large areas (inter-regional trips) 24 hours a day, 365 days a year throughout Japan, including after disasters.

This study introduces a method for acquiring trip behaviors within a walking distance by means of multiple kinds of transport big data. First, an optimal set of big data is selected from possible sets of big data in the transport sector to estimate trip behaviors. Second, the authors propose a method for estimating trip volume. Finally, the proposed method is applied to a case study in order to validate the accuracy of estimating walking trip behaviors.

The authors developed a method for estimating trip volume and trip modes within a walking distance using the big data selected in the previous chapter. The data sets used for estimating the trip volume are both Wi-Fi data collected from Wi-Fi packet sensors and the statistics of population distribution obtained through the processing of mobile phone location data. The methodology is designed to estimate trips and OD matrix based on trip patterns analyzed by aggregating the Wi-Fi data linked with user IDs. The real trip volume is calculated by enlarging the Wi-Fi based OD matrix with the statistics of population distribution.

A case study has been carried out in Tachikawa City, located about 40 kilometers west of central Tokyo. The study area is in the area of Tachikawa Station in the center of Tachikawa City. As the national Showa Memorial Park and the Mitsui Shopping Park are located within 1 kilometer and 2 kilometers of the station, respectively, many visitors come from a relatively long distance. The flat land allows people to travel on foot or by bicycle easily in the central district of Tachikawa City. A monorail (light rail transit) services from Tachikawa Kita Station to the north are also available for visitors to this area.

Accuracy of the estimated trip volume can be confirmed by hourly incoming volume for each point with the hourly number of visitors to the sites, which was not counted. Instead, based on interviews with the managers of the shopping sites observed by the Wi-Fi packet sensors, it was confirmed that the estimated trips were nearly the same as the actual situations. For example, hourly incoming volume are larger for major points such as the stations and IKEA (a famous company based in Sweden). The number of hourly incoming people to each of the major points was nearly the same as the number observed by the managers in the day-to-day business operation.

5.2. Conclusion and further studies

This study developed the institutional and technical framework for road geohazard risk management in developing countries through the review of best practices for disaster prevention measures in the world. The adopted management approach aligns with the risk management practices in the ISO 31000. The framework is comprised of the stages of (1) institutional capacity and coordination, (2) systems planning, (3) engineering and design, (4) operations and maintenance, and (5) contingency planning.

The framework would be put in place in a step-by-step manner depending on the capacity and financial constraints of the project-implementing countries. The applicability of the framework was verified by conducting the case studies to collect information about disaster risk management practices in Brazil and Serbia.

Since developing countries lack sufficient funds and knowledge to implement full-scale disaster prevention measures, it was required to convey necessary institutional and technical know-how in an understandable manner for policy makers and practitioners in national and local governments. The framework is targeted for the developing world where capacity development on road geohazard risk management is needed. The author provides recommendations on how techniques and practices included in the framework can be applied to the developing world as follows.

(1)Road Geohazard Risk Management Incorporated in Asset Management

It is important that geohazard management activities fit within the road authority's overarching asset management framework. For some developing countries that have incorporated road asset management practices into the project life-cycle, it would not be easy for these countries to put road geohazard risk management in place. For developing countries that have not yet started the road asset management, most of the road geohazard risk management activities can be fit in with the traditional management processes in the road authorities. It is recommended to enhance capacity for incorporating DRR into the asset management practice and the traditional management processes with financial and technical support of international organizations and developed countries.

(2)Implementation Mechanism at the Local Level

In terms of implementation mechanism in developing countries, limited capacity on disaster risk management at the local level is a common challenge. National governments have various roles to support local governments, who have the primary responsibility in disaster risk management, to prepare for and respond to disasters. Similarly, local offices in the road authorities are in a position to be the first responder. It might take some time for road authorities to accumulate experience and develop institutional and technical capacity at the local level. Delegation of responsibilities and decision-making authority to a lower organizational level would be required at a certain point to promote road geohazard risk management (Asian Development Bank Institution 2013). Furthermore, it is extremely important to follow-up regularly (for example, annually in a DRR training) to make sure each activity under the framework can be properly implemented before and after disasters at national and local levels.

(3)Expert Consultation for Set-Up Targets

National road authorities formulate institutional, technical coordination, and funding mechanism for the efficient implementation of road geohazards risk management. When setting up targets in developing countries, it should be noted that limited capacity at the local level must be taken into consideration. The checklists for institutional capacity review added to the annex of handbook would help developing countries to assess the current capability. Knowledge and insight are required to identify and recommend ways to address any deficiencies between the assessed and target competencies. Governments of developing countries must have a thorough consultation with experts and leaders as well as institutions and stakeholders to set targets for each item where the target capability is above the current assessed capability.

(4)Staff Responsibility for Geohazard Risk Identification

The fundamental principle is that experienced road authority staff investigate and monitor hazards through routine maintenance. In developing countries, there are few or no road authority staff with experience in inspecting geohazards and abnormalities. There is no other choice but to gain this experience at the local level since the staff members are responsible for activities and decision-making on risk management. In the meanwhile, there is no problem with outsourcing identification surveys to fill out inventory sheets for each hazard-prone road location. Detailed hazard mapping would be conducted depending on the available funds and risk level. It is important that executive officers check inventory sheets, including (a) location type; (b) simple observation results; and (c) sketches and photographs, to prevent overlooking potential road geohazard risks.

(5)Geohazard Risk Assessment and Budgetary Process

The governments of developing countries would tend to take reactive approach by retrofitting existing roads after disasters. While the countermeasures against natural disasters seem costly, the investment pays off. There is a lack of understanding of the importance of investing for the promotion of proactive disaster prevention. Assessment of geohazards is a critical part of road geohazard risk management in terms that objective evaluation is used as the basis for the budgetary provision required for structure and non-structure measures. Budgeting process in the governments of developing countries based on evaluation results would lead to a better understanding that funding for preparedness and prevention contributes to reduce the amount of damage caused by disasters (Inter-American

Development Bank 2017).

(6)DRR Investments and Risk Management Planning

DRR investments, in particular infrastructure projects, may cause to decrease viability from a short-term perspective, but these pay off in a long-term perspective. While many developing countries have made some progress on formulating DRR policy framework, the implementation of DRR including road geohazard risk reduction still needs further progress. It is recommended that the governments of developing countries formulate planning guidelines on road geohazards risk management since risk management planning is used as the basis for funding for preparedness contributing to reduce the damage caused by catastrophic disasters. The guidelines would help the national and local governments of developing countries to institutionalize planning principles and practices, thus resulting in mainstreaming DRR in the transport sector.

(7)Implementation Mechanism for Contingency Programming

To put emergency preparedness, emergency response, and recovery in practice is a great challenge for national and local road authorities of developing countries. Many developing countries lack the institutional, technical, and financial capacity to effectively cope with disasters. National road authorities must formulate the mechanisms for implementation of Contingency Programming, which would preferably be expressed as operation guidelines. These mechanisms are comprised of institutional, technical coordination, and funding mechanisms. For example, the national road authority should support local road authorities by coordinating the organizations concerned (meteorological agency, police, rescue agency, and so on) and deploying specialized teams to respond to catastrophic disasters. What is most important is how contingency funds are allocated when geohazard events occur because such emergency events would require funding beyond that of the road authority's day-to-day activities.

This is the end of my recommendations for developing countries. Next, I will conclude on the evaluation of transport systems in disasters and the method for analyzing real traffic in the event of disasters using transport big data.

Advanced Framework for Road Geohazard Risk Management

The author has upgraded the framework for road geohazard risk management by proposing an additional scheme of the transport system-level evaluation on disaster risk management, as shown in Figure 5.1. The effectiveness of disaster risk management actions in line with disaster life cycle should be evaluated based on whether or not the transport systems would be able to function as required during a disaster. Performance indicators are categorized into transport function measure and topological network measure. The former is used in more evaluation methodologies, as it would be useful to study the characteristics of travel time, traffic flow, and other traffic factors after a disaster in order to consider measures to minimize the functional deterioration of the transportation network.

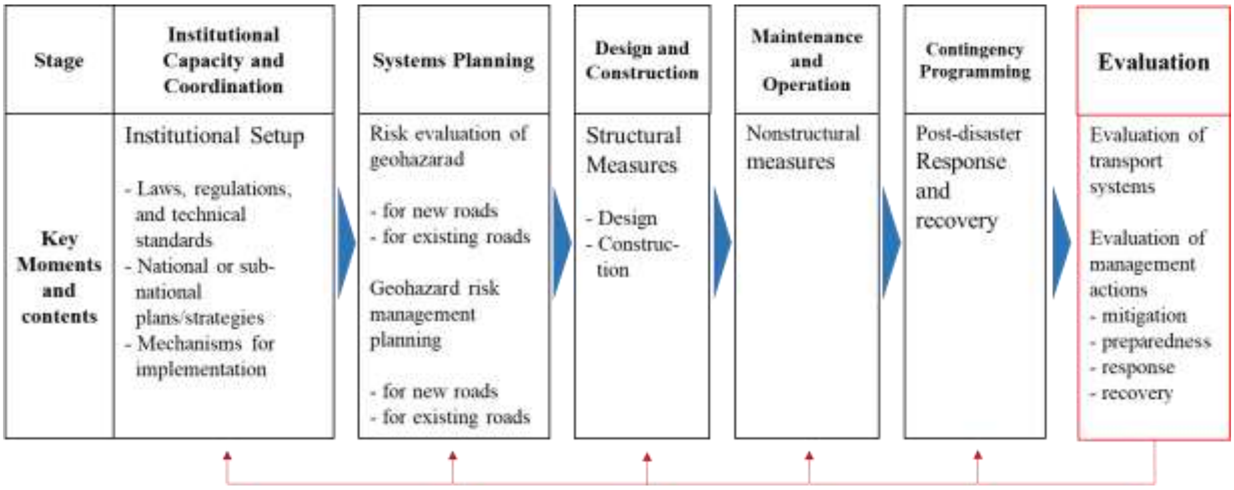


Figure 5.1 Advanced framework for road geohazard risk management

With the development of ICT in recent years, the use of big data in the field of disaster management has been progressing. It has become possible to analyze inter-regional traffic flow after occurrence of the disasters using transport big data. As discussed in Section 4.2.1, contents of road geohazards risk management actions will be evaluated by transport big data analysis including trip estimation for large and small areas. As mobile phone penetration in developing countries is not that different from developed countries, there has been some cases, as for the former, where developed countries transfer technology for spatial information analysis to utilize cell phone data for disaster response support. This study focuses on the latter and develops a method for it. The effectiveness of some risk management actions can only be assessed by analyzing traffic after disaster on a microscopic level with transport big data. In developing countries, large-scale disasters occur every year, and early recovery from disasters is an urgent issue for sustainable development. Japan should contribute to sustainable development of developing countries by transferring technology that utilizes transport big data analysis, together with the lessons learned from our disaster experiences in the past.

The authors developed a method for estimating trip volume and trip modes within a walking distance (i.e. for small areas) using the big data selected in chapter 4. The data sets used for estimating the trip volume are both Wi-Fi data collected from Wi-Fi packet sensors and the statistics of population distribution obtained through the processing of mobile phone location data. The methodology is designed to estimate trips and OD matrix based on trip patterns analyzed by aggregating the Wi-Fi data linked with user IDs. The real trip volume is calculated by enlarging the Wi-Fi based OD matrix with the statistics of population distribution.

A case study has been carried out in Tachikawa City, located about 40 kilometers west of central Tokyo. Accuracy of the estimated trip volume can be confirmed by comparing hourly incoming volume for each point with the hourly number of visitors to the sites, which was not counted. Instead, based on interviews with the managers of the shopping sites observed by the Wi-Fi packet sensors, it was confirmed that the estimated trips were nearly the same as the actual situations. The number of hourly incoming people to each of the major points was nearly the same as the number observed by the managers in the day-to-day business operation.

Further Study

The study developed the institutional and technical framework contributing disaster risk reduction targeted for road geohazards, and the developed framework can be applicable to other fields of infrastructure management and against other natural disasters to a certain degree. For future work, technology transfer to developing countries is required so that more advanced disaster risk management can be realized by adding traffic analysis using transport big data to the developed framework. A road network is comprised of highways, arterial roads, and district roads, and is managed and operated by the national government, local governments, and road authorities, each of which has its own role to play. In the event of a natural disaster, these roads must function as a network to provide the required services such as lifesaving, emergency, medical care, and supply of goods. Disaster risk management must be carried out quickly and efficiently by each organization so that damaged roads could be restored and rebuilt immediately. In order to contribute to disaster risk reduction in developing countries, Japan should provide generous technical cooperation on disaster risk management for other transport infrastructures, such as railroads and ports that are relatively simple compared with roads.

Accuracy of trip estimation results using the developed method has been enhanced by comparing Wi-Fi data with actual numbers obtained through surveyor's manual count in succeeding case studies in 2019-2020 (Hino 2021). For future study on trip estimation for small areas, the authors will improve the method for automating the data processing and continual trip monitoring, and will also develop a methodology to analyze trip attributes, such as sex and age, and estimate trip sequences. Finally, field testing in other cities besides Japanese cities needs to be conducted to improve the usability.

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