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Policy brief

MAINTAINING RESILIENT INFRASTRUCTURE SYSTEMS

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ABSTRACT

Improving maintenance management and increasing investment in infrastructure maintenance makes it possible to boost the resilience of infrastructure against a variety of threats. This has a positive financial return for developed as well as developing countries. Building on the issues outlined in two seminal T20 Policy Briefs *Building Resilient Infrastructure Systems* (ABDI, 2020) and *Evaluating Resilient Infrastructure Systems* (Evans et al., 2020), this Policy Brief: (i) advocates for a global maintenance framework addressing the specificities of developed and developing countries, (ii) calls for the development of infrastructure bonds and standardised ratings that include maintenance issues, capable of securing financial resources for maintenance and (iii) draws G20 members' attention to the issue of human resilience and the human factor to ensure the long-term maintainability of Quality Infrastructure.

CHALLENGE

RESILIENCE IN THE LONG RUN IS A MATTER OF WELL EXECUTED MAINTENANCE AND STEADY ADAPTATION TO A CHANGING ENVIRONMENT

The rising risks of disasters, amplified by climate change, pose threats to infrastructure resilience and might bring suboptimal economic and social benefits over time (Lu, 2019). Extreme events as well as prolonged disruptive hazards – such as sea level rise, heavy and/or prolonged rain, wind and heat impact, with effects on materials and equipment, and also loss of connectivity and damaged data transmission – can shut down essential facilities and impede the efficient movement of goods and people. These hazards can adversely impact the well-being of whole communities and of local, regional and global economies. As an example, among so many others, a resilience pilot study investigating culverts in an area of New Jersey, USA prone to flooding partially due to topography, determined that "flooding was not due to undersized culverts but due to a lack of maintenance" (Russo, 2019). In eroding areas, "the multibillion-dollar question is: what is maintenance versus upgrade?" (Ruppert, 2019).

There is a need to consider the whole picture in a holistic sense and to determine the wider impacts for transport, planning and emergency relief whereby resilience plays a key role in maximising the economic, social and environmental aspects of transport infrastructure and network operations. This not only applies to climate change events, but can also cover multi-hazard events such as natural disasters, man-made threats and pandemics (WRA, 2020a). More, when the infrastructure is not properly maintained, deterioration due to ageing is likely to amplify the adverse effects of these incidences, especially when they occur concurrently. For example, hazards such as landslides, floods, storms or earthquakes are still occurring in the face of COVID-19 (Buchoud et al., 2021), leading to further complexities for owners, operators and society (WRA, 2020a).

According to OECD (2021), the impact of COVID-19 on infrastructure will be long lasting, both by accelerating trends that were already underway and by leaving an imprint on societies more generally. The COVID-19 pandemic has raised awareness of the critical nature of infrastructure systems and services, often overlooked before. Furthermore, the pandemic has highlighted the importance of regional infrastructure in facilitating the smooth provision of transport, connectivity and utility services (UNESCAP, 2020). Due to the increasing risks and uncertainties from climate change, a number of disasters happened during the pandemic period and put infrastructure and public facilities under extreme pressure. For example, Japan suffered from unprecedented heatwaves last year which resulted in nearly 20,000 hospitalisations, on top of the hospital occupancy from COVID-19. From the governmental perspective, the enormous amount of stimulus needed to weather the impact of the pandemic has left governments with more limited fiscal space to be allocated to the development of infrastructure. WRA (2020a), also notes that as governments have redirected resources to attend the emergency due to COVID-19, and this has reduced their capacity to face other types of natural emergencies. On the other hand, infrastructure that has already been built and is not resilient incurs higher cost due to more expensive operation and maintenance. Thus, the need for resilient infrastructure becomes more apparent as we foresee the need to cope with other potential unprecedented crises in the future.

RESILIENCE IS UNDERFUNDED BUT ADDS VALUE

Infrastructure development is critical in supporting the economic growth and sustainable development of any country. However, the higher risks of disasters, amplified by the existence of climate change, pose threats to the resilience of infrastructures. This might bring a suboptimal impact in terms of economic and social benefits over time as less resilient infrastructures result in higher maintenance costs and more time-consuming rebuilding processes. Nevertheless, in terms of resilience, current infrastructures are still underfunded, with investment deficit estimated to reach USD 3.7 trillion annually for developing countries alone (Runde, 2019). An estimate for developed countries can be made indirectly referring to Woetzel et al. (2016), who considered at that time that emerged economies accounted for 40 per cent of the world investment needs in infrastructure (and emerging economies for 60 per cent) to support the expected rates of growth.

Climate-resilient infrastructures are beneficial as they reduce the impact of natural hazards and climate change in the form of damaged assets which affect the financial and economic performance of the infrastructures (ABDI, 2020). Moreover, they potentially improve the reliability of service provision, increase asset life and protect asset returns. In terms of economic benefits, investing in the resilience of infrastructures in developing countries is estimated to bring a net benefit of USD 4.2 trillion over the lifetime of new infrastructures, or USD 4 for each dollar invested (Evans et al., 2020). Rozenberg and Fray (2019) proved in a very large study that without good maintenance, infrastructure capital costs could increase by 50 per cent for the transport sector and by 60 per cent for the water sector. Indeed, it is clearly established that efficient and adapted maintenance is able to increase the life span of an asset, as well as to significantly increase its capacity to support extreme events. An analysis of member countries of the OECD suggests that each additional USD 1 spent on road maintenance saves USD 1.5 in new investments, making better maintenance a very cost-effective option (Kornejew et al., 2019).

More resilient infrastructures also offer social benefits, ranging from saving human life in the face of natural hazards and climate change to achieving a better and more equitable life quality across regions.

THE HUMAN FACTOR IS OFTEN OVERLOOKED

Resilience is not a neutral concept and is influenced by conflicting views and values. The human factor is often overlooked in infrastructure maintenance strategies. Indeed, the resilience approach is most often limited to infrastructures themselves and rarely includes human resilience. Typically, humans are considered as system weaknesses or sources of mistakes, and a common strategy is to exclude them from the decision processes. Most often, when a maintenance failure occurs, the subsequent decision is to create new regulations in order to prevent it occurring again. However, although it may be necessary to establish these new regulations, it is not sufficient. This is because there will always be unpredictable events for which no regulation yet exists.

It is thus of utmost importance to develop human resilience, i.e., adaptation skills vis-à-vis unknown situations, by informing and training all the actors involved in the infrastructure maintenance process, both in developing and developed countries. Experiences related to the adaptation of teams in charge, for example, of the maintenance and operation of transport networks during the COVID-19 crisis can be an important source of information (WRA, 2020b).

POLICY MAKERS AND INFRASTRUCTURE OWNERS NEED A STRONGER SUPPORT

Infrastructure owners facing changes in the management of infrastructure may need additional financing mechanisms, transfer of knowledge on best practices, innovative solutions based on nature, and environmental, economic and financial sustainability. Agencies that are at the forefront of asset management are developing processes to introduce resilience into their decision making, both for maintenance and for capital investment. Education, awareness and training to allow informed decisions to be made is critical for ensuring stronger support across all levels of an organisation.

Good infrastructure management is the necessary basis for resilient infrastructure, but targeted actions are also needed. Unfortunately, no single intervention will make infrastructure systems resilient. Instead, a range of coordinated actions will be required (Buchoud et al., 2020).

PROPOSAL

In short, improving maintenance management and increasing investment for infrastructure maintenance makes it possible to boost the resilience of the infrastructure against a variety of threats and has a positive financial return for developed and developing countries: it should be a no-regret action.

1. PROVIDE A GLOBAL MAINTENANCE FRAMEWORK ADDRESSING THE SPECIFICITIES OF DEVELOPED AND DEVELOPING COUNTRIES

In order to address vulnerabilities, all economic actors – citizens, cities and regions, the business sector and governments – need to avoid exacerbating threats to infrastructure systems. Therefore, policy makers and infrastructure companies should create a strong foundation for infrastructure planning and convey clear objectives related to resilient infrastructure to all parties or levels of management (Japanese Ministry of Finance, 2019). Tam and Johnson (2020), proposed to "adopt a statewide functional recovery building standard so that more buildings will be usable and easily repaired after a disaster". This could be achieved by establishing a set of common principles on the sustainability of resilient infrastructure. In order to make these holistic principles more practical on a more micro level, the principles could be derived into set of rules that would be more technical and detailed to ensure better adaptations on all levels.

The PIARC Framework (WRA, 2015) and the related methodologies and strategies report (WRA, 2019) provide a methodological process and tools for the identification of potential risks/impacts of a road infrastructure. They develop an assessment of the vulnerability to climate change, potential impacts (exposure and sensitivity) and the risks (probabilities and consequences). The framework's user obtains a prioritised list of risks/impacts that can be addressed through response/adaptation measures which can be integrated into the decision-making process, including education, awareness and training. The enhancement of maintenance is among the actions that increase the resilience of the infrastructure (WRA, 2015).

In order to initiate these types of country-wide approaches, a coherent set of measures, regulations and financial incentives can be put in place with the objective of aligning the interests of service providers and the public interest (users and territories). To do this, it is necessary to identify, for each hazard and for each infrastructure system, a minimum level of "resistance", i.e., the intensity of a hazard below which the system must not suffer any damage or disruption. Then, the public authorities must define what will be called the level of *force majeure*, or level of acceptable risk – the level at which failures will be tolerated. Beyond this level, risk damages are generally supported by public authorities. Below this level, but above the level of unacceptable risk, risk is shared between the public authorities and the owners/operators of the infrastructure system. Finally, it is necessary to create the right incentives to align the interests of infrastructure service providers and the public. This includes, for example, fines for disruptions. Based on these definitions and regulations, infrastructure owners and operators are able to define the right level of maintenance adapted to their strategy and to the desired level of resilience (critical or non-critical infrastructure).

Nature-based solutions allow addressing problems with an alternative approach (not engineering), where through natural, green and comprehensive infrastructure, problems such as floods, erosion, etc., that affect the resilience of the infrastructure can be addressed. There are multiple case studies termed “Green Infrastructure” that help reduce the vulnerability of the infrastructure through the management of rainwater. These include soft engineering solutions such as the creation of wetlands and barrier islands to reduce the vulnerability of infrastructure to rainfall events. The magnitude of costs and benefits for nature-based solutions to build resilience for local contexts and alleviate the need for ordinary maintenance, vary widely according to geography and scale, but make an important contribution to sustainability. Normal planning processes offer opportunities to define suitable roles for nature-based solutions to work in harmony with conventional Disaster Risk Management project components, such as “Gray Infrastructure” (based in engineering) (World Bank, 2018).

A common framework developed by an institution with strong global leadership – such as the G20 – to assess disaster and climate risks to infrastructure would be crucial in identifying the gap between the current level and the ideal level of infrastructure resilience, and also by taking into account the unique characteristics of each country in terms of its exposure to climate change and disaster risks. Infrastructure building codes should be regularly updated regarding maintenance as well as adaptation to a changing environment and more focused on nature-based solutions (Congressional Research Center, 2020). Using such a global framework together with properly updated infrastructure building codes would help more facilities remain usable or easily repaired after a disaster/emergency.

Policy Options:

a. The G20 should encourage the implementation at national levels of effective systems of infrastructure maintenance, strong institutions with clearly established missions and responsibilities, with transparent funding and distribution mechanisms. These institutions could be in charge of developing and implementing appropriate maintenance standards, establishing functional recovery standards and post-incident response strategies.

b. In order to ensure equitable access to resilient infrastructures, governments should identify critical infrastructures at local, national and regional levels, define what the acceptable and intolerable risk levels are, define minimum maintenance standards (intolerable risks), identify basic/minimum key ordinary and extraordinary maintenance indicators, develop incentives based on these levels, and promote nature-based solutions that alleviate ordinary maintenance.

2. DEVELOP INFRASTRUCTURE BONDS AND STANDARDISE RATINGS INCLUDING MAINTENANCE ISSUES

Implementing resilient infrastructure helps manage natural shocks and complements the infrastructure quality of services generally. But given the high infrastructure cost, governments' budget alone can't fulfil their infrastructure needs. Banks with short-term liabilities are also not well-suited to hold long-term infrastructure assets. On that view, the economy is looking for alternative infrastructure financing, particularly from the private sectors. Investors are constantly searching for a clear and steady asset of investment that can match their interest (OECD, 2018). Currently, investors have been increasingly participating in infrastructure projects such as sustainable and resilient infrastructure building, especially in emerging markets (OECD, 2020). Environmental, social and governance (ESG) factors have been playing a more important role in driving investors to increase their investment allocation, even though ESG practices are still at an early stage of development. The use of ESG investment approaches has been driven by increasing appetite among investors to make better use of non-financial information to guide asset allocation to improve long-term value and align their portfolios with societal values. At the same time, the conduct of such investment practices is expected to minimise the cost imposed on society and the environment. Investors tend to consider ESG factors in their investment decisions as such factors can show the underlying risks in infrastructure projects, from the preconstruction phase to the operational phase, which is an important measure for investors considering these projects. The implementation of an ESG framework in investment allocation also supports SDG goals, especially goal 9 which calls for the development of "quality, reliable, sustainable, and resilient infrastructure". The ESG framework would also tend to encourage investors to prioritise infrastructure projects in their investment selection.

To this end, there is a need for bonds that are more applicable to financing long-term infrastructure projects in terms of construction, operation and maintenance. However, the existence and development of infrastructure bonds remains far below its potential (Inderst, 2016). Several vital challenges are hampering the development of these bonds, including the underdeveloped domestic bond markets, regulatory and institutional issues, and the few number of rating agencies and guarantors, among other challenges. Since the local bond markets in developing countries are still underdeveloped and mostly dominated by government bonds, infrastructure bonds could contribute to solving the domestic infrastructure investment gap by attracting foreign investors.

A multinational rating and guarantee agency would play a vital role in the development of infrastructure bonds by providing information and protection on the risks. Most project or infrastructure bonds tend to be riskier than those of corporate issuers given the inherently complex nature of construction and development primarily due to unforeseeable circumstances (such as delay and disruption in construction); hence higher default rates are often presumed (Squires et al., 2016). The agency could step in to solve this issue by offering credible information and assessment regarding the risk of each infrastructure project in a country through issuing ratings. It is worthwhile noting that the risk profile of infrastructure bonds specifically focused on investments for extraordinary maintenance is much lower than for greenfield projects, since the former have neither significant construction risk nor significant traffic (or demand) risk.

Another major problem is the regulatory and legal environments of the country where the projects take place. Foreign investors tend to have limited knowledge of regulatory and legal governance of other countries, which can limit their appetite to invest abroad (Hallegatte et al., 2019). Multinational rating agencies provide standardised ratings and guarantees against political risks such as delays in the processing of permits and licenses, changes in rules and regulations or even default projects. Also multinational guarantee agencies provide protection to capital invested in infrastructure projects. This would help the development of infrastructure bonds by bolstering demand, through improving the willingness of foreign investors to consider infrastructure projects.

Policy Options:

a. Multilateral development banks should issue G20 infrastructure bonds to attract funds from foreign investors and recover emerging countries' excess savings to finance infrastructure instead of financing debts in advanced economies.

b. The G20 should encourage multinational rating agencies to join their efforts to provide a standardised rating that considers maintenance issues, and resolve the asymmetric information and transparency problems, thereby reducing project risks.

3. SECURE FINANCIAL RESOURCES FOR MAINTENANCE

Governments can establish natural disaster funds as the financial resources to repair and rebuild public infrastructure due to natural disasters. Nevertheless, the need to maintain an adequate level of resilience throughout the service life of the infrastructure also needs to remain an agenda priority (Hallegatte et al., 2019). Governments also need to improve maintenance and operations for boosting the resilience of infrastructure assets and slowly reducing overall costs. An effective strategic maintenance plan can ensure the infrastructure is able to withstand extreme events, and thus will increase the lifetime of the infrastructure.

The key to achieving resilient infrastructure at an affordable cost is to be selective, base investments on comprehensive analysis, and develop contingency plans for cases where increasing resilience is not justified (Hoffmann, 2020). A method could be to invest in infrastructure plans that work well in various possible future scenarios. An analysis with different possible future scenarios can identify infrastructure investments that are expected to be profitable in any future scenario and that avoid modifications that incur extremely high costs or disastrous interruptions of services, including maintenance cost.

The maintenance aspect of resilient infrastructure must therefore include a stable mechanism for providing on a regular basis the resources necessary to carry out these activities. Tam and Johnson (2020) proposed to "establish a regional resilience trust fund for future climate adaptation and hazard management needs". A stable mechanism is crucial in ensuring the sustainability of funds needed to maintain infrastructure quality and resilience (ABDI, 2020). It is also necessary to internalise the costs and introduce an incentive mechanism such that the cost of "damaging" infrastructure is paid by the users. Here, there are many options that can be introduced including tax on logistics/traffic of light and heavy commercial vehicles, vignette, pay per trip, pay per pollution, and pay-as-you-go. Such options can earmark toll revenues and spillover economic revenues to finance maintenance and adaptation. The idea is to set up a specific and regular source of revenues aimed both at avoiding the creation of the backlog in the extraordinary maintenance of infrastructure network and/or specific sensible components (e.g. bridges, viaducts, tunnels) and at tackling the needs defined by the climate change mitigation agenda.

Maintenance funding could also be financed by public-private partnerships (PPPs) specifically for maintenance, to ensure a fixed multi-year budget. For PPPs to work, both parties need to clarify the allocation of responsibilities regarding project planning, management and response (Vallejo and Mullan, 2017). Creating a blended finance system to build and maintain resilient infrastructure systems can help to address capacity constraint and improve the risk-return profile of the infrastructure investment (Passacantando and Bilotta, 2020). The funding split between public and private resources varies; usually the share of public finance is estimated at 60–65 per cent in developing countries but 40 per cent in developed countries. In order to influence the participation of private funding, government or public institutions can conduct risk screening as one of the ways to mitigate the project risks.

Policy Options:

a. Governments should organise a steady revenue allocation from the infrastructure to maintain it and increase its lifecycle in the long term; and clarify the allocation of responsibility in public-private partnerships.

b. Internationally recognised bodies should establish standards to evaluate the quality of the infrastructure within the maintenance contracts. This could evolve in international guidelines for assessing ageing infrastructures and detecting strategies to overpass it.

4. *SHARED RESPONSIBILITIES IN INFRASTRUCTURE MAINTENANCE OPERATIONS*

Resilience must consider a level of risk acceptable to organisations responsible for infrastructures, based on the human factor. Additionally, community self-resilience and social resilience is an important adaptive measure, whereby communities at risk have developed preparations in anticipation of foreseeable climatic events.

The phenomenon of diffusion of responsibility was grasped by Darley and Latané (1968): the more people share a responsibility, the less they will feel individually responsible. When talking about maintenance of large infrastructures, the attribution of responsibilities is often sprawling and shared by a large number of actors (public bodies, local communities, etc.). Moreover, interactions between actors may induce even more responsibility diffusion: for instance, when one of the actors involved considers other actors' inaction, it may be comforted in its decision not to intervene itself. Finally, the multiplication of complex regulations, aggravated by each new failure and new regulations introduced to avoid reoccurrence, may also induce a lower individual feeling of responsibility. Indeed, when an actor is more or less taken out of the decision loop by the implementation of these complex regulations (e.g., when requested to apply strict safety protocols), they might feel like the protocol itself is responsible for the good maintenance of the infrastructure and thus be inhibited in their will to take initiative. In the case of system failure, they will be able to say that they followed the protocol and observed the regulations.

The human factor cannot be neglected in the analysis of potential cascading and connected hazards. Ouyang (2019) reported on a simulation case study conducted in the Manila National Capital Region that "incorporates complex uncertainty systems into disaster management planning" to "analyze and predict human behaviors under emergencies to assist in the decision-making process". To ensure the fulfilment of responsibilities, policy makers and infrastructure owners could implement a community-based development approach to encourage their participation and responsibility in building and maintaining resilient infrastructures (principles of participation and subsidiarity). Moreover, through such a community-based development approach, local communities and local government would also be able to directly communicate their infrastructure needs and problems faced.

Policy Options:

a. Policy makers and infrastructure owners/operators should foster resilience from a system perspective and therefore invest in policies and preventive actions to enhance the resilience of physical assets as well as human assets (e.g., managers, engineers, economists, maintenance personnel, planners).

b. With regard to the diffusion of responsibility for maintaining infrastructure, policy makers and infrastructure companies should clearly define the responsible parties for that undertaking and, moreover, provide those individuals with the effective means (i.e., funds, training, time and a real negotiating power with local communities or local governments) to fulfil their infrastructure maintenance obligations.

c. The more complex an infrastructure system is, the more attention policy makers should pay to preserving the possibility of human initiatives at every level (from operational management to upper management).

5. TRAIN MAINTENANCE EXPERTISE AND IMPROVE CAPACITY BUILDING

An issue is the lack of technical capacity and know-how (Hallegatte, 2019). This gap could be addressed by the provision of technical assistance towards investing, building and maintaining resilient infrastructures to ensure a good transfer of knowledge between contractor and operator. Technical assistance facilities can be provided through a finance approach with combined support (financial and technical support), and thus can provide project preparation support. However, the infrastructure users also need training support or assistance to mitigate and prepare for infrastructure disruptions and minimise costs. This technical assistance should be provided particularly to developing countries. Through such assistance, critical gaps in knowledge between countries could be solved. It is also to be considered that training in the field of climate change and training in the management of ageing infrastructure would imply different profiles.

This issue is relevant in both developing and developed countries. Increasing investment in workforce education bolsters the implementation of technical changes. As Toner (2011) points out, due to their "greater stock of knowledge, more educated and skilled workers learn and develop higher order problem solving skills". While new technologies are expected to reduce maintenance costs and ensure more efficient budget allocation, capacity building is all the more necessary, at both macro and micro levels (OECD, 2021 forthcoming).

Recommendations in a recent report on system resilience concepts for transportation agencies published by the National Academies of Sciences, Engineering, and Medicine (2021) include "develop[ing] a human resource development and succession plan that focuses on preparing the current and future agency staff for resilience-oriented activities". Training local workforce to carry out maintenance would also improve employment opportunities and enhance better employee performance (Hallegatte, 2019). All workers should have equal opportunity to access jobs in the infrastructure industry, and to work in safe and healthy conditions. Also important is encouraging the participation of women and men in the workforce on equal footing, complemented by skills training and occupational safety and health policies, as well as considering training programmes for the existing workforce, including the older employees.

Policy Options:

a. G20 and multilateral development institutions, such as the World Bank, should play a more prominent role in assisting the development of resilient infrastructures, especially in countries with limited technical expertise of their workforce, institutional capacity and regulatory framework.

b. G20 and multilateral development institutions should be more active in encouraging knowledge partnership between countries or between different management levels, and in facilitating learning and co-production of knowledge, particularly in those geographical areas where technical gaps remain critical.

c. The implementation of asset management systems is very important for the scheduling of infrastructure maintenance based on deterioration models that allow scheduling maintenance actions and defining what type of intervention is required. Since the creation of an asset management system is a costly and complex operation, international guidelines to deal with different levels/ambitions would be very useful to improve the efficiency of the investments supported by infrastructure agencies.

CONCLUDING REMARKS

Well-maintained and resilient infrastructure reduces the vulnerability of individuals and communities. In today's context of increasing natural hazards and climate change effects, failure to take resilience into account in investment decision-making, new projects, rehabilitation or adaptation operations can prove extremely costly. Government and infrastructure companies need to ensure long-term adaptability of the infrastructure through disaster risk management and climate-resilient infrastructure design and maintenance. For new infrastructure projects in emerging countries as well as existing infrastructure facilities, integrating maintenance and providing appropriate funding and financing throughout the entire lifecycle can no longer be avoided.

APPENDIX A

INFRASTRUCTURE, MAINTENANCE, DURABILITY AND SUSTAINABILITY

Infrastructure can be defined as “the physical components of interrelated systems providing commodities and services essential to enable, sustain, or enhance societal living conditions“ (Fulmer, 2009). There are several ways to classify infrastructure depending, for example, on its role, services or quality (i.e., hard infrastructure vs. soft infrastructure). In this brief, we focus on the infrastructure that promotes mobility and economic activities and in particular on tangible built infrastructure (a.k.a., hard infrastructure) such as transport facilities and services (roads, railroads, ports, airports), water supply/sanitation, electricity or telecommunications. These infrastructure systems are also called economic infrastructure because of their critical role in empowering economic development and are to be distinguished from “social infrastructure” (hospitals, universities and schools, museums, theatres, public places and so on). Social infrastructure is not discussed in this brief.

Infrastructure is essential to connect communities, shape their economies and support the free flow of ideas, goods, people and services. Subject to numerous natural and human-made hazards, infrastructures, most of which were built in the last century, must also deal with climate change, which increases their vulnerability.

For any government or organisation, infrastructure facilities are major investments that involve complex systems with a long operational life. Implementing methodical maintenance regimes is paramount to preserving those investments. Maintenance refers to all the technical, administrative and management actions during the life cycle of an asset, intended to maintain or restore it to preserving in a state in which it can perform the required function. Maintenance management encompasses all the activities of the management bodies that determine the objectives, the strategy and the responsibilities concerning maintenance and that implement them by means such as the planning, control and monitoring of maintenance, as well as improvement of methods, including economic assessments such as life-cycle costing methodologies. It is also recognised that threats from the climate require identification, analysis and reduction as an integrated part of maintenance, new construction and rehabilitation of roads (Swedish Transport Administration, 2014). Climate change emphasises the need to perform effective maintenance and to reduce maintenance backlog.

According to European standard EN 13306, different types of maintenance can be considered:

- *corrective maintenance*, which is performed after failure has been detected and is intended to restore an asset to a condition in which it can perform a required function;
- *preventive maintenance* which is maintenance performed at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or degradation of the operation of an asset;

- *predictive maintenance* which is conditional maintenance performed according to forecasts extrapolated from the analysis and evaluation of significant parameters of the asset degradation.

Preventive maintenance is also institutionalised. In Mexico this is referred to as “routine maintenance”: this routine maintenance is carried out continuously during the year with the purpose of avoiding the beginning of the deterioration of the infrastructure and ensure its operation. Other countries carry out emergency maintenance during times of distress, such as during rainy or hurricane seasons. In these situations, the maintenance of roads is of high importance to enable them to be reopened as quickly as possible to enable the deployment of services into a region, and to enable the evacuation of the community during times of crisis.

APPENDIX B

RESILIENCE AND QUALITY INFRASTRUCTURE

"Resilience" means to plan and prepare for minimising disruptions in the face of shocks and stresses, recover rapidly when they do occur, and adapt steadily with an optimal economic allocation of resources as part of a cyclical proactive and holistic risk management system. IPCC (2014) defines resilience as "the capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend, or disturbance by responding or reorganizing in ways that maintain their essential function, identity and structure, and the capacity to adapt, learn, and change". This definition expands the traditional notion of resilience related to a specific event, by including the idea that to be resilient, a system must also be adapted to a trend that may result in adverse impacts in the longer term.

Bruneau et al. (2003) establish that resilience for both physical and social systems can be further defined as consisting of the following properties: robustness, redundancy, resourcefulness and rapidity (4R dimensions of resilience).

Applied to infrastructures, this implies that asset owners and managers must ensure that their infrastructures are able not only to withstand a crisis or unforeseen degradation, but also to adapt to chronic degradation (aging), changes in usage, availability of resources, technological innovations, new regulations and, more broadly, to a complex and uncertain future. A prospective approach to resilience makes it possible to anticipate a certain number of risks. The objective is twofold: to avoid possible but undesirable futures, and to provoke the changes and ruptures necessary for the emergence of desirable futures.

Resilience is one of the many aspects that influence the quality of infrastructure. Including resilience in the design and implementation of investments not only helps to manage natural shocks, but also to improve the cost effectiveness, efficiency and broader quality of service provided by the infrastructure.

Hallegatte et al. (2019) propose that resilience can be considered at three levels:

- resilience of *infrastructure assets*. Strictly speaking, resilient infrastructure refers to an asset such as a road, railway or power line that can withstand hazards, whether natural or not. In this case, the main benefit of having a resilient infrastructure is to reduce the cost over the entire life cycle of the asset.
- resilience of *infrastructure services*. Infrastructure systems are interconnected networks. As such, the resilience of a particular component is not a good indicator of the overall resilience of the services provided by the entire network. It is therefore essential to adopt a systemic approach to resilience. This ensures that the infrastructure will provide a reliable service most of the time.
- resilience of *infrastructure users and of territories*. The main objective is ultimately resilience for users, and therefore for the territories. Disruptions in the networks can be

serious or not depending on the ability of the users to cope with them. At this essential level, the advantage of having resilient infrastructures is a reduction of the global impact of hazards, natural or not, on users, territories and their economy.

Investing in resilient infrastructure and implementing effective maintenance programmes is vital to underpin economic growth as part of a decisive transition to Quality Infrastructure.

“Resilience” is not a fashionable equivalent of “durability” or “sustainability”. For example, a bridge can be designed, built and maintained to have a service life of 100 years, and therefore be really durable. But, if that bridge is located in a flood plain, gets flooded, is temporarily unusable and if there is no detour route, then the transportation infrastructure is not very resilient. If construction, operation and maintenance need a lot of energy, a lot of raw materials, and if the roadway is not for instance fitted to accommodate vehicles using renewable energy or lacks digital equipment that enables saving human lives and relieving congestion, then the system is not sustainable. The relationship between durability and resilience is clear, since the latter foresees higher levels of the former, depending on a set of foreseeable adverse events, mostly associated with climate change. The sustainability dimension is strictly associated with the whole process of analysis, but its prioritisation is not always at the top of the agenda.

REFERENCES

ADBI (2020), *Building the Future of Quality Infrastructure*, Tokyo, Asian Development Bank Institute

Buchoud, N.; G. Hartmann; and H. Kuhle (2021), *Intersecting: On Urbanization and Infrastructure / Sustainable Responses to the COVID-19 Pandemic*, The Global Solution Dialogue, e-book series 03/2021

Buchoud, N.; R. Bartlett; L. Benita Kerr; E. Croci; P. Datta Dey; N. Hautière; A. Hijdra; S. Kirpotin; T. Kolesnikova; B. Nofal; M. Silva; and L. B. Wuennenberg (2020), "Shaping the New Frontiers of Sustainable Urban Infrastructure: Reviewing the Long-Term Value of Infrastructure Investments and Enabling System Change", in *T20 Policy Briefs, Saudi Arabia*

Bruneau, M.; S. E. Chang; R. T. Eguchi; G. C. Lee; T. D. O'Rourke; A. M. Reinhorn; M. Shinozuka; K. Tierney; W. A. Wallace; and D. von Winterfeldt (2003), "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities", in *Earthquake Spectra*, Vol. 19

Congressional Research Service (2020), "FEMA Pre-Disaster Mitigation: The Building Resilient Communities and Infrastructure (BRIC) Program", in *CRS Insights*, No. IN11515, Washington, DC

Darley, J. M.; and B. Latané (1968), "Bystander Intervention in Emergencies: Diffusion of Responsibility", in *Journal of Personality and Social Psychology*, Vol. 8, pp. 377-383, DOI 10.1037/h0025589

EN 13306 (2017), *European Norm: Maintenance – Maintenance Terminology*, European Committee for Standardization, Brussels, Belgium

Evans, C.; B. Godart; J. B. Kovarik; J. F. Mendoza; and F. Palhol (2020), "Evaluating Resilient Infrastructure Systems", in *T20 Policy Briefs, Saudi Arabia*

Fulmer, Jeffrey (2009), "What in the World Is Infrastructure?", in *PEI Infrastructure Investor* (July/August), pp. 30-32

Hallegatte, S.; J. Rentschler; and J. Rozenberg (2019), *LIFELINES: The Resilient Infrastructure Opportunity*, Washington DC, International Bank for Reconstruction and Development

Hoffmann, B. (2020), "Resilient Infrastructure Is Crucial When Planning for an Uncertain Future", in Inter-American Development Bank Blog, https://cutt.ly/Qvdu9oW

Hutchison, N.; A. Adair; J. Berry; D. Lo; S. McGreal; S. Organ; and G. Squires (2016), "Financing Infrastructure Development: Time to Unshackle the Bonds?", in *Journal of Property Investment & Finance*, Vol. 34, No. 3, pp. 208-224, DOI 10.1108/JPIF-07-2015-0047

Inderst, G. (2016), *Infrastructure Investment, Private Finance, and Institutional Investors: Asia from a Global Perspective*, Tokyo, https://www.adb.org/publications/infrastructure-investment-private-finance-and-institutional-investors-asia-global

IPCC (2014), Summary for Policymakers", in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge and New York Cambridge University Press

Japanese Ministry of Finance (2019), *G20 Principles of Infrastructure Investment*, https://www.mof.go.jp/english/international_policy/convention/g20/annex6_1.pdf

Kornejew, M.; J. Rentschler; and S. Hallegatte (2019), "Well Spent: How Governance Determines the Effectiveness of Infrastructure Investments", background paper for the report *LIFELINES: The Resilient Infrastructure Opportunity*, World Bank, Washington, DC.

Li, Xianfu (2019), "Building Resilient Infrastructure for the Future", background paper for G20 Climate Sustainability Working Group, Manila, DOI 10.22617/WPS190340-2

Mexican Transport and Communications Secretary (2014), *Guide of Procedures and Techniques for the Maintenance of Roads in Mexico*, Mexico City

National Academies of Sciences, Engineering, and Medicine (2021), *Mainstreaming System Resilience Concepts into Transportation Agencies: A Guide*. Washington DC, The National Academies Press, https://doi.org/10.17226/26125

Organisation for Economic Co-operation and Development (OECD) (2018), *Roadmap to Infrastructure as an Asset Class*, Paris, OECD Publishing

Organisation for Economic Co-operation and Development (OECD) (2020), *OECD Business and Finance Outlook 2020: Sustainable and Resilient Finance, Chapter 7 ESG and Institutional Investment in Infrastructure*, Paris, OECD Publishing, https://doi.org/10.1787/eb61fd29-en

Organisation for Economic Co-operation and Development (OECD) (2021), *COVID-19 and a New Resilient Infrastructure Landscape*, Paris, OECD Publishing

OECD (2021 forthcoming) *Building Resilience: New Strategies for Strengthening Infrastructure Resilience and Maintenance*; *Report for the G20 Italian Presidency 2021*, Paris, OECD Publishing

Ouyang, Y. (2019), "Framework for Incorporating Complex Uncertainty Systems under Post-Disaster Cascading Infrastructure", in *Transportation Resilience 2019: 2nd International Conference on Transportation Resilience to Natural Hazards and Extreme Weather Events (TR2019)*, Washington DC, 13-15 November

Passacantando, F.; and N. Bilotta (2020), "Instruments and Mechanisms to Mobilize Private Investments in Local Infrastructure", in *T20 Policy Briefs, Saudi Arabia*

Rozenberg, J.; and M Fay (2019), *Beyond the Gap: How Countries Can Afford the Infrastructure They Need While Protecting the Planet*, Washington DC, World Bank

Runde, D. F. (2019), "Pursuing Quality of Infrastructure for Sustainable Growth", in *T20 Policy Briefs, Washington DC*, https://www.g20-insights.org/policy_briefs/pursuing-quality-of-infrastructure-for-sustainable-growth/

Ruppert, T. (2019), "Managed Retreat and Infrastructure Planning: Long-Term Challenges of Coastal Communities from a Policy and Legal Perspective", in *Transportation Resilience 2019: 2nd International Conference on Transportation Resilience to Natural Hazards and Extreme Weather Events (TR2019)*, Washington DC, 13-15 November

Russo, M. (2019), "Prioritizing Resilience at State Departments of Transportation: Progress and Challenges", in *Transportation Resilience 2019: 2nd International Conference on Transportation Resilience* *to Natural Hazards and Extreme Weather Events (TR2019)*, Washington DC, 13-15 November

Swedish Transport Administration (2014). *The Swedish Transport Administration's Strategy for Climate Change Adaptation*. Sweden

Tam, L.; and L. A. Johnson (2020), "Safety First: Improving Hazard Resilience in the Bay Area", in *SPUR Regional Strategy Briefing Papers*, San Francisco

Toner, P. (2011), "Workforce Skills and Innovation: An Overview of Major Themes in Literature", in *STI Working Papers*, Paris, OECD

UNESCAP (2020), *COVID-19 Reveals Urgent Need for Resilient Infrastructure*, https://www.unescap.org/blog/covid-19-reveals-urgent-need-resilient-infrastructure

Vallejo, L.; and M. Mullan (2017), "Climate-Resilient Infrastructure: Getting the Policies Right", in *OECD Environment Working Papers*, No. 121, DOI 10.1787/02f74d61-en

Woetzel, J.; N. Garemo; J. Mischke; M. Hjerpe; and R. Palter (2016), "*Bridging Global Infrastructure Gaps*", in *McKinsey Global Institute*, http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/bridging-global-infrastructure-gaps

World Bank (2018), "Nature-Based Solutions for Disaster Risk Management", in *Global Fund for Disaster Reduction and Recovery (GFDRR)*

World Road Association (PIARC) (2015), *PIARC's International Climate Change Adaptation Framework for Road Infrastructure*, Paris

World Road Association (PIARC) (2019), *Adaptation Methodologies and Strategies to Increase the Resilience of Roads to Climate Change: Case Study Approach*, Paris

World Road Association (PIARC) (2020a), *COVID-19: Initial Impacts and Responses to the Pandemic from Road and Transport Agencies Technical Report*, Paris

World Road Association (PIARC) (2020b), *COVID-19: Key Lessons for the Road and Transport Community*, Paris

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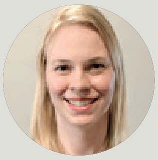

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