Planning Resilient Infrastructure Systems

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Preface

During the winter of 1992–1993, we hacked and blasted 76 km of two-lane road through the Dinaric Alps into the interior of Bosnia–Herzegovina. An expedient-military road, *Route Triangle* carried essential humanitarian relief during the Bosnian War. With each season that followed, the road was gradually enhanced, only to be abandoned following the 1995 Dayton Peace Accords. The experience and example of *Route Triangle* spurred in me a lifelong interest in infrastructure. I was particularly interested in how infrastructure use and value could change so completely. I also wanted to understand how a successful project could fail its intended beneficiaries.

Over three decades, I have had the distinct privilege of working in many countries, variously as client, consultant and contractor, with some of the most capable engineers, architects, financiers and planners. More recently, I had the opportunity to investigate how my observations and experiences compared with academic teachings and to conduct research. For me, infrastructure is, quite simply, fascinating. Water infrastructure has had a more profound and lasting effect on public health than any number of physicians. These infrastructure systems have allowed us to advance civilisation, densify cities and project trade. Improvements in communications and energy infrastructure systems have advanced economies around the world. Yet, it is often misunderstood and misapplied despite all that infrastructure is and enables us to do.

Hindsight is, as they say, 20/20. After navigating the complexities of planning and implementing a new infrastructure scheme, someone will identify the real and perceived failings in the delivered works. I have conducted audits of infrastructure schemes on behalf of underwriters, financiers and owners, and risk profiled development strategies. There would seem to be two consistent issues. The first is the lack of a common conceptual understanding of infrastructure and how it works in the broader socioeconomic environment. The second is an apparent lack of evidence or use of a common reference to inform planning and discussions.

The lack of a common conceptual understanding affects everything from the approach to planning, assessment of benefit and commonality of purpose, and our understanding of through-life value and how to finance it. None of the particular tools that we use is wrong, per se, but they may not be the most appropriate to the situation. By any definition, infrastructure is a system that draws together structures, protocols for use and environmental dynamics to enable a capability or function. This system affects other systems and is supported by and influenced by yet other systems. The whole is thoroughly interconnected. We cannot fully understand one system in isolation, much less a multiplicity of individual or component systems.

Similarly, when something exists to enable an activity or capability, its value is defined by the degree of activity it enables. We can spend millions on a utility infrastructure system, but it has no value if no one uses it. Valuing infrastructure by the service it enables can present a challenge for infrastructure financing. Investment models that use real property cost or market value at the time of investment cannot capture the value of the infrastructure's use throughout its life.

Institutional investment in infrastructure as an asset class is still establishing itself. Many investment decision support models still use real property asset class valuation. Such models require assumptions, generalisations and estimates based on experience to inform the decision. These models are not designed for infrastructure investment decision-making. Therefore, the investor must use subjective assessment that is calibrated by experience, rather than an objective judgement based on available evidence. This evidence in context is the basis for the common reference. Institutional investors still wrestle with this, specifically how to inform the decision to invest. We often default to familiar models, defining the question by what we know we can answer. Consequently, we base our decision on a projection of value at the time of the investment.

Through-life investment decision-making involves real change. Climate, technological and societal changes all directly influence socioeconomic behaviours and so the use of the infrastructure. These changes in use represent changes in value and risks. The material disclosures in the annual directors' reports for public corporations generally focus on corporate and compliance-type risks around these investments rather than the actual risks to continued operation and hence value change. In the absence of empirical data collected for the latter, the former relies more on estimate and subjective assessment. This issue extends beyond financial measures and speaks to the heart of corporate resilience. We can have the best corporate risk management and resilience package, but there is no business if we cease operating. The two are inseparable.

Similarly, infrastructure risk management and resilience are about both performance and contingent capability. We can align key risk indicators with our key performance indicators to present a real understanding of threats and opportunities to our infrastructure's value. The performance and capability of infrastructure will depend on how it is perceived and the broader community's sense of ownership. Infrastructure is one of the critical connectors between a corporation or municipality and the community. It is environmental, social and corporate governance in its very essence. Little wonder that it is or enables most of the 17 Sustainable Development Goals (SDGs).

The apparent lack of evidence used in planning and design is becoming a common refrain. Emphasised in the (UK) 2013 Armitage Review and in the 2016 National Infrastructure Commission report, *Connected Future*, the use of evidence allows us to establish a common reference. This common reference is a pure expression of fact, empirically based, associating an action with a series of consequences and an outcome. These connections are knowable and, in most regions, can be established using little more than satellite data and

open-source references. Informed discussion informs perspective, collaborative problem identification and solving, and judgement-based decision-making.

In the absence of any (empirical) common reference, we necessarily rely on individual perceptions of the situation and deficiencies informed by our professional experience and bias. We are hardwired to infer an understanding of requirements from familiar fragments of patterns, which we then reinforce using curated corroborating evidence. This inevitably leads to optimism bias and failures in beneficial outcomes and cost management. If we can control the patterning of perceived deficiencies by better informing ourselves of what is, we can better define the actual problems. We must avoid defining the problem by the solution or tools we have to hand.

The willingness to study a situation and derive the problem requires a professional humility and patience that may be lacking, particularly when a time imperative drives the agenda. For example, following conflict or natural disaster, the reconstruction effort is frequently driven by an assumption of what pre-existed the catastrophe and how it worked, with a vision of what the solution should be based on what is familiar to the reconstruction engineers, planners and donors. Often, there is an apparent mismatch between what was intended and the delivered benefit to the local community in postconflict reconstruction. The better use of evidence can fundamentally change practice and, I believe, reduce needless confrontation and expense.

When professional practitioners draw on a common concept of infrastructure and situational evidence, they can devise and deliver infrastructure systems that maintain value through life, benefiting all stakeholders. To me, this is the most explicit articulation of engineering in society. Engineering practice in infrastructure is inseparable from value, financing and the socioeconomic and natural environment that it functions within. Infrastructure

is complex but needn't be complicated;
it is dynamic but inanimate.

With this book, I hope to inform a more cohesive, joined-up understanding of infrastructure from a first-principles perspective. Consequently, this is not jurisdictional or sector-specific. Though I am an engineer, writing predominantly for engineers, I do not feel that our language use always promotes understanding across all stakeholders. Why, for example, would we use different risk terminology from the finance and underwriting industries? That is not to say that technical definitions, codes and standards are necessarily wrong. We must understand these differences in interpretation and intelligently adjust if we are to speak with different audiences.

The emphasis of this book is understanding. I have endeavoured to keep it mercifully short, hoping that I may keep your interest through to the conclusion. I also hope to stimulate your further reading and exploration of the various topics covered. The concepts and practices are accessible. Where I have not been able to identify a commonly agreed theory or practice, I offer my perspective based on my research and experience. I annotate each instance where I do this, most notably around unifying purpose and beneficial capability. I use examples to illustrate points rather than whole case studies. I've avoided case studies because it is rare for the combination of conditions that led to the successful application of a particular practice in one location to replicate in another. Each situation (operation, location and context) is unique, even within the same city.

I begin by introducing infrastructure, exploring why it is essential and where the issues are and presenting my argument. I focus heavily on the theory of infrastructure. This theory leads to an exploration of value and the use of risk as both a tool and a language. I explore sustainability, resilience and protection in infrastructure systems before drawing all of these strands together to present infrastructure planning in theory. I balance

this with a planning-in-practice perspective, exploring the noise and disconnects that can change the planned infrastructure's path and outcome. I conclude by exploring what the future holds for the infrastructure world.

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About the author

Alexander H Hay PhD CEng PEng FICE RSES is a civil engineer specialising in infrastructure systems risk. He is a graduate of the University of Edinburgh and the University of Toronto, where he is an adjunct professor. He has 35 years of international experience in infrastructure development and fortifications in regions as diverse as the High Arctic, Europe, North Africa, the Middle East and Central Asia. Commissioned into the (British) Royal Engineers in 1989, he released in 2013 to pursue a career in industry. He is the founding principal of Southern Harbour Ltd, an independent infrastructure risk advisory service operating globally, advising on the through-life risk profiles of sustainable economic development strategies, and infrastructure reconfiguration and development. His research interest at the University of Toronto's Centre for Resilience of Critical Infrastructure is postconflict and postdisaster community rehabilitation and the role of infrastructure in regional socioeconomic transition to a low carbon dioxide emissions world. He joined the ICE knowledge panel on capacity building from 2007 to 2009 and has remained keenly interested in professional formation and development since, particularly in how to develop the competencies that the next generation of professional engineers will need to deal with the world they inherit.

About the collaborators

Yannick C Beaudoin MA PhD is a senior economist and Director General for Ontario and Northern Canada with the David Suzuki Foundation. Previously, he was Chief Scientist with UNEP/GRID-Arendal in Norway. He brings an ‘economics for transition’ lens to the Foundation, aimed at helping to enable a socially thriving and ecologically sustainable Canada. He applies art of change and participatory social processes to a variety of themes that include: adaptation to uncertain climate futures; embedding of local, traditional and indigenous knowledge in policy-, decision- and choice-making; and promoting a transition to a sustainable relationship between society and Nature. From his decade with the United Nations to his return to Canada in 2018, he has been facilitating conversations around the world, highlighting various solution pathways towards a well-being centric, #beyondGDP economic system.

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Board of Canada, his team informed the shift in approach from critical infrastructure protection to critical infrastructure resilience, and published several cross-border reports. He was a strategic advisor to the Defence Research and Development Canada's Centre for Security Science for 4 years to integrate the first responder community in science and technology programmes. He is a sought-after consultant, facilitator and coach, working with established and upcoming leaders in both public and private sectors.

List of abbreviations

AI	Artificial intelligence
AOI	Area of influence
AOO	Area of operations
BFCA	Builders for Climate Action
BLM	Black Lives Matter
BOMA	Building Owners and Managers Association
BRE	Building Research Establishment
CAF	Corporacion Andina de Fomento
CAPEX	Capital expenditure
CC	Carrying capacity
CDBB	Centre for Digital Built Britain
COP	Common operating picture
CP	Calculation plan
CPNI	Centre for the Protection of the National Infrastructure
CPTED	Crime Prevention Through Environmental Design
CRA	Canadian Revenue Agency
CRCI	Centre for Resilience of Critical Infrastructure
CSR	Corporate social responsibility
DCS	Distributed control system
DHS	Department of Homeland Security
ERM	Enterprise-wide risk management
ERSA	European Regional Science Association
ESDA	Exploratory spatial data analysis
ESG	Environment, social and governance
FMEA	Failure modes effects analysis
FMECA	Failure modes effects and criticality analysis
GDPR	General Data Protection Regulation
GPIF	Government Pension Investment Fund
GRMI	Global Risk Management Institute
GSD	Ground sample distance
HTT	Hazard travel time
IAO	Indicators of anticipated outcome
ICE	Institution of Civil Engineers
ICS	Industrial control systems
ICT	Information and communications technology
IDP	Infrastructure development plan
IMF	International Monetary Fund
ISO	International Standards Organization

LCA	Life-cycle analysis
LCI	Life-cycle inventory
LEED	Leadership in Energy and Environmental Design
LoP	Level of protection
LRA	Location risk assessment
MAR	Maximum acceptable risk
MDG	Millennium Development Goals
MOC	Minimum operating capability
MRTC	Maximum realisable threat capability
MSC	Minimum sustainable capability
NOAA	National Oceanic and Atmospheric Administration
OECD	Organization for Economic Cooperation and Development
OPEX	Operation and maintenance expenses
OSPA	Oxford Scenario Planning Approach
PP	Planning point
PRI	Principles for Responsible Investment
PTSD	Post-traumatic stress disorder
RAMP	Risk Analysis and Management for Projects
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
RIMS	Risk and Insurance Management Society
ROI	Return on investment
SAID	Systems approach to infrastructure delivery
SARS	Severe acute respiratory syndrome
SCADA	Supervisory control and data acquisition
SDG	Sustainable Development Goals
SPV	Special purpose vehicle
TCFD	Task Force on Climate-related Financial Disclosures
TRA	Threat & risk assessment
TUNA	Turbulence, uncertainty, novelty and ambiguity
UN	United Nations
UNDRR	UN Office for Disaster Risk Reduction
UNEP	UN Environment Programme
UNISDR	UN International Strategy for Disaster Reduction
UPS	Uninterruptable power supply
VaR	Value at risk

VBIED	Vehicle-borne improvised explosive device
VSOS	Vitae system of systems
WCED	World Commission on Environment and Development
WCR	Whole cost of risk
WEF	World Economic Forum
WHO	World Health Organization
WRI	World Resources Institute