



PARDEE RAND GRADUATE SCHOOL

- THE ARTS
- CHILD POLICY
- CIVIL JUSTICE
- EDUCATION
- ENERGY AND ENVIRONMENT
- HEALTH AND HEALTH CARE
- INTERNATIONAL AFFAIRS
- NATIONAL SECURITY
- POPULATION AND AGING
- PUBLIC SAFETY
- SCIENCE AND TECHNOLOGY
- SUBSTANCE ABUSE
- TERRORISM AND HOMELAND SECURITY
- TRANSPORTATION AND INFRASTRUCTURE
- WORKFORCE AND WORKPLACE

This PDF document was made available from www.rand.org as a public service of the RAND Corporation.

[Jump down to document](#) ▼

The RAND Corporation is a nonprofit research organization providing objective analysis and effective solutions that address the challenges facing the public and private sectors around the world.

Support RAND

[Browse Books & Publications](#)

[Make a charitable contribution](#)

For More Information

Visit RAND at www.rand.org

Explore [Pardee RAND Graduate School](#)

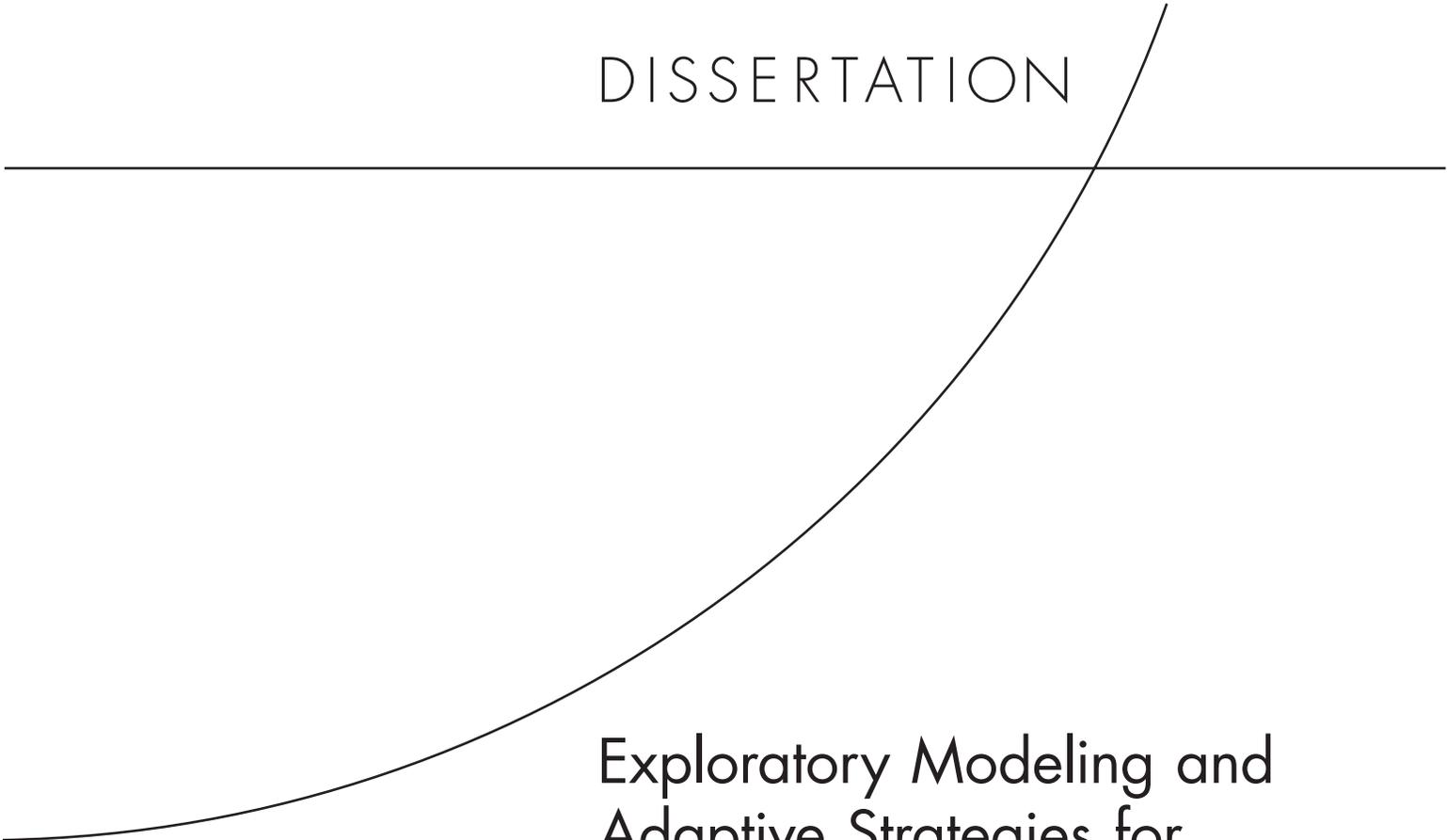
View [document details](#)

Limited Electronic Distribution Rights

This document and trademark(s) contained herein are protected by law as indicated in a notice appearing later in this work. This electronic representation of RAND intellectual property is provided for non-commercial use only. Permission is required from RAND to reproduce, or reuse in another form, any of our research documents for commercial use.

This product is part of the Pardee RAND Graduate School (PRGS) dissertation series. PRGS dissertations are produced by graduate fellows of the Pardee RAND Graduate School, the world's leading producer of Ph.D.'s in policy analysis. The dissertation has been supervised, reviewed, and approved by the graduate fellow's faculty committee.

DISSERTATION



Exploratory Modeling and
Adaptive Strategies for
Investment in Standard
Services to Facilitate
Public Service Networks

Sungho Lee

This document was submitted as a dissertation in December, 2005 in partial fulfillment of the requirements of the doctoral degree in public policy analysis at the Pardee RAND Graduate School. The faculty committee that supervised and approved the dissertation consisted of Steven W. Popper (Chair), Steven C. Bankes, and Paul K. Davis. Nalin Kulatilaka was the outside reader for the dissertation.



PARDEE RAND GRADUATE SCHOOL

The Pardee RAND Graduate School dissertation series reproduces dissertations that have been approved by the student's dissertation committee.

The RAND Corporation is a nonprofit research organization providing objective analysis and effective solutions that address the challenges facing the public and private sectors around the world. RAND's publications do not necessarily reflect the opinions of its research clients and sponsors.

RAND® is a registered trademark.

© Copyright 2006 RAND Corporation

All rights reserved. No part of this book may be reproduced in any form by any electronic or mechanical means (including photocopying, recording, or information storage and retrieval) without permission in writing from RAND.

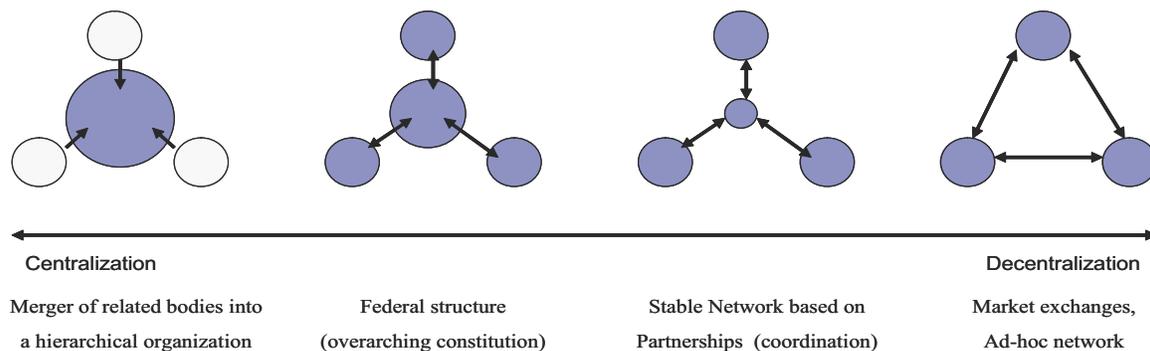
Published 2006 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
4570 Fifth Avenue, Suite 600, Pittsburgh, PA 15213
RAND URL: <http://www.rand.org/>
To order RAND documents or to obtain additional information, contact
Distribution Services: Telephone: (310) 451-7002;
Fax: (310) 451-6915; Email: order@rand.org

Executive Summary

Social and Technical Network for Public Services and Network-enablers

The dominant structural forms in all the governments have been stovepipe organizational units. As many contemporary policy challenges span multiple policy domains, there are growing needs for collaboration and coordination. Collaborations can be made in various forms. Interrelated bodies can be merged into single hierarchical organization which has clear, mutually exclusive areas of accountability and control (e.g. the creation of the Department of Homeland Security). On the other hand, public services can be delivered through decentralized market-based contracts. Between hierarchy and market, various forms of network and partnership exist (see Figure S-1). Collaborative networks of public organizations may improve aggregate productivity by enabling dispersed specialists to work together and view service recipients in a holistic way, and eliminating non-optimal duplication. A network model can be particularly effective with dynamically evolving environments and clearly defined goals while hierarchy can be more effective with stable environments and ambiguous goals.

Figure S-1. Forms of Collaborations (Modified from Schilling 2005)



Networks can be steered using a variety of incentives and sanctions, but cannot be totally controlled using a top-down command approach because a network is a set of self-organizing working relationships among autonomous agencies that have responsibility, authority and flexibility to accomplish their own missions. The focus should be on coordinating agencies with different goals and preferences and building trusting relationships. Information technology can help organizations collaborate by reducing transaction costs. However, information systems have been optimized previously for a specific application to form agency-centric vertically

integrated stovepipes, but not designed for the flexibility to perform multiple applications. Technology-enabled transformation from agency-centric public services into cross-agency networked public services will require investment in enhanced connectedness, integrated security, improving interoperability at mission activity and organizational levels as well as at information system level, and trust building. Standardization can improve technical, semantic, and organizational interoperability among broad range of agencies.

In sum, while interoperable information systems can facilitate intergovernmental collaborative networks, intergovernmental social network facilitates the standardizations and productive use of interoperable systems. Likewise, social and technical networks mutually reinforce each other and co-evolve. To effectively promote networked public services, these complex co-evolutions need to be strategically managed.

Enterprise Architecture and Investments in Shared Services and Standard Interfaces

To reduce the dilemma between empowering the central managers to assure the cross-agency interoperability and empowering the local managers to ensure the supply of information to responsibly accomplish their unique missions, it is necessary first to standardize basic supporting services and interfaces, and second to let individual agencies build specialized applications tailored to their own missions on top of these standard services. It should be noted that standardization does not require everyone to use the same services and infrastructure. Instead of standardizing the whole process, only those parts that are identified as involving important economies of scale or scope without undermining the qualities of services need to be standardized. Standards in the right parts of a system can enable much more flexibility and decentralization to customize other parts of the system to suit unique service needs.

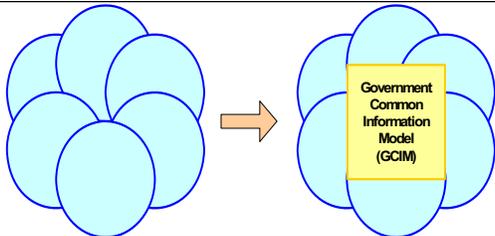
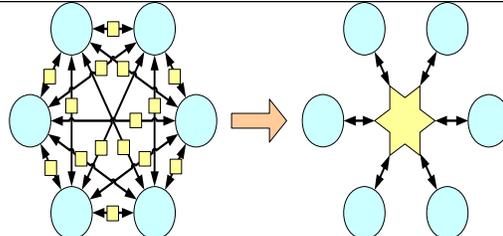
‘Enterprise architecture’ is a structural framework to identify the interdependencies among service missions and IT systems. Government-wide enterprise architecture such as the U.S. Federal Enterprise Architecture defines numerous cross-agency horizontal layers using the reference models for government businesses, service components, data, and technical infrastructures (see Figure S-2). This study will propose two types of standard services that are horizontally shared by multiple autonomous agencies (see Table S-1). Common basic supporting services can be consolidated as ‘shared services or infrastructure’ to minimize the non-optimal redundancies that add less values than costs. ‘Standard middleware or interfaces’

may improve the interoperability in a cost-effective manner and hence maximize synergies among diverse specialized systems. The U.S. Presidential e-Government initiatives are good examples of building standard services: the ‘Online Rule-making’ initiative provides about 160 federal agencies with a shared service that allows the public to view and comment on federal regulations, and the ‘Disaster Management’ initiative provides interoperability standards to enable information sharing among the nation’s emergency management communities.

Figure S-2. Transformation from Vertical Silos to Horizontal Layers

Agency	Defense	Homeland Security	Health	Mission (Business)	Services for Citizens, Mode of Delivery, Management of Government Resources	<i>Seamless process</i>
Application	Incompatible applications	Incompatible applications	Incompatible applications	Application (Service component)	Customer Services, Management Services, Process Automation, Digital Asset Services, Analytical Services, Back-office Services, Support Services	<i>Web-services</i>
Data	Paper, File, Picture, etc	Paper, File, Picture, etc	Paper, File, Picture, etc	Data	Digital Content: Data context, Data sharing, Data description	<i>Semantic standards</i>
Technology	Isolated infrastructure	Isolated infrastructure	Isolated infrastructure	Technology	Platform and infrastructure, Access and delivery, Component framework, Interface and integration	<i>Shared infrastructure</i>

Table S-1. Two Types of Standard Services

	Shared Services or Infrastructure	Standard Middleware or Interface
Objectives	Sharing common basic services and infrastructure by many users	Coupling diverse specialized applications in a cost-effective manner
Benefits	Cost saving (minimizing redundancies) while maintaining the quality of services	Value creation (maximizing synergies) while maintaining the cost of services
Focus	Supply-driven (indirectly supporting diverse specialized applications)	Demand-driven (dynamically creating the citizen-centered seamless services)
Diagram		
Examples	Online rule-making, e-Authentication, Federal asset sales, Integrated acquisition, Recruitment one-stop, HR integration, e-Training, e-Payroll, e-Travel, SAFECOM	Disaster management, One-stop business, Health informatics, Geospatial one-stop, Recreation one-stop, International trade, e-Loans, e-Grants

While many people recognize the value of inter-agency information sharing, little money and time has been spent for cross-agency initiatives to improve interoperability, mutual understanding and trust building. This study claims that by effectively designing and implementing investments in standard services to support or interconnect various specialized applications of participating organizations, organizations in a network can jointly achieve their common missions efficiently while retaining their own resources to pursue individually distinct missions (i.e. achieving economies of scale or scope while retaining autonomy and flexibility).

However, heterogeneity among users or among the nodes of a network makes it difficult to identify the appropriate scope and level of standard services. Heterogeneity also makes it difficult to choose among centralized, decentralized and hybrid approaches for implementing standard services. Not only complex social demands and technology changes, but also network effects, inter-agency collaborative capability and underlying social networks magnify the uncertainties arising from investments in standard services. Investment in standard services needs to be made anticipatorily, but once built and shared by many agencies, standard services are costly to change. Managers must understand the sources of uncertainty and define strategic hypotheses that causally link long-term outcomes and performance drivers.

This thesis argues that by designing and implementing adaptive strategies for incremental investments in standard services with the aids of exploratory modeling, diverse complementary systems of autonomous agencies can converge on networked public services in an evolutionary fashion, enhancing their long-term values and reducing the downfalls. Exploratory modeling (Lempert, Popper and Bankes 2003) will create a map of the path-dependent values and costs that are generated from flexible sequential investments under all plausible scenarios of exogenous uncertainties and endogenous relations, and help search for robustness – adequate effectiveness assured over the plausible scenario space – evaluated by diverse value systems.

Evaluating Investments in Shared Services and Standard Interface (Chapter 4)

Chapter 4 will identify a number of alternative strategies to invest in standard services and assess which strategy can maximize social welfare, by developing parametric exploratory models that explicitly incorporate heterogeneity among users or among the nodes of a network.

If the commonality is high and redundancies add little value, common service components can be consolidated into a standard service shared by many agencies. Inappropriate

redundancies disappear as individual agencies find it to their advantage to draw upon the more economical shared services. Since government agencies have different marginal willingness to pay for service level, this exercise simulates heterogeneous willingness to pay among agencies using probability distribution functions. Instead of a “one-size-fits-all” consolidation approach, one may develop modular services so that everyone uses the same basic modules and more demanding users use add-on modules layered on top of the basic modules. Assuming convex cost function of service level and no cost of reuse, economic analysis compares a one-size-fits-all approach, a competition approach, and a complementary modular approach in delivering common services, and proves that modularity markedly increases social welfare, by eliminating redundancies, improving service levels and expanding customer base.

There are alternatives to implement modularization. Agencies may individually outsource standard modular services (decentralized market-based approach). Since the basic and the add-on modules are complementary (as opposed to competing) services, the integrated developer or joint venture can maximize the joint profits by selling a higher quality basic module at a lower price than independent developers, and also improve consumer surplus and social welfare. The central authority may develop both basic and add-on modules, and provide them to all the government agencies at no cost (centralized hierarchical approach). The centralized public development theoretically maximizes the joint values of both modules and hence social welfare and consumer surplus. However, its effect is often questionable when standard services are based on emerging technologies or when demands of individual agencies are obscure and diversified. Hybrid approaches (e.g. mixed public and private development, public private partnership) also exist. The exploratory analysis finds that public private partnership (i.e. centralized procurement of de facto (market-based) standard modules developed by the integrated monopolist) is the most robust strategy against various scenarios. Mixed public and private development strategies turn out to be underperforming since they fail to coordinate complementarity between the basic and the add-on modules.

While most previous studies of network effects have examined the networks of homogeneous systems (e.g. the community of exchanging e-mail, faxes, and music files written in the same format), seamless public services often require interactions among technically and semantically heterogeneous yet complementary systems. N nodes of a network can create $N(N-$

1) links, and the Metcalfe's law claims increasing returns to scale by assuming that all the links are equally valuable. However, networking heterogeneous incompatible systems requires as many bilateral interfaces as interaction links. This study conceives a conceptual measure of disparity between systems using an abstract one-dimensional 'distance' parameter. The benefits and the costs of coupling incompatible systems are modeled as the functions of the distances of links, as opposed to the simple number of links.

Individual agencies may develop point-to-point tailored interface bilaterally, or a central authority may provide a government-wide standard interface, or a number of decentralized local standard interfaces can be developed as a hybrid approach. Standard middleware or interfaces may reduce the coupling costs, but broader participation in a standard tends to increase the heterogeneity among participating systems. If the Metcalfe's law holds, a universal 'supra-standard' interface may interconnect all the heterogeneous systems and maximize social welfare. If the complementary value of a system is assumed to decline with distance, appropriate coupling scopes for standard interfaces need to be identified. While a standard interface that interconnects a wide-ranging scope of heterogeneous systems may generate more network benefits than any single standard interface can, we are not constrained to make only one standard, but allowed to make multiple standards. Exploratory analysis indicates that either numerous standard interfaces that interconnect the modest scope of heterogeneous systems or customized bilateral interfaces can maximize net benefits from each unit of networked systems, and hence maximize social welfare gains from all the public information systems.

Agent-based Modeling of Evolving Network-centric Public Service (Chapter 5)

Building network-centric public services involves two steps: 1) identifying complementary systems across agencies and improving their interoperability, and 2) utilization of the interoperable systems to achieve missions effectively. While chapter 4 analytically searches for the static optimal solutions in controlled contexts, chapter 5 attempts to test the long-term dynamic effects of incremental investments in standard services jointly with inter-agency operation policies in more comprehensive contexts (i.e. by modeling heterogeneous interdependent relations among nodes that have heterogeneous service attributes and levels).

The modeling exercise designs an illustrative body of the federal government consisting of 20 agencies and corresponding 20 missions, and simulates the uncontrolled dynamics that

independent agencies in mission-centric networks may interactively create. That is, an agent-based model illustrates how autonomous agencies build and network complementary systems and operate them in a decentralized environment over time. This agent-based simulation exercise combines network economics to analyze system investment and social network analysis to analyze system utilization. This exercise assumes six social network drivers (similarity, reciprocity, centrality, mission priority, interdependent contribution of systems to missions, and transitivity) jointly determine inter-agency operational effectiveness. This study simulates two inter-agency operational mechanisms – operation dominantly driven by similarity and reciprocity (called ‘agency-centric’) and operation dominantly driven by contribution of systems to missions and transitivity (called ‘mission-centric’). Table S-2 summarizes the hypothetical causal-effects among key measures with their underlying uncertainties and policy levers.

Table S-2. Strategic Hypotheses of Key Measures, Policy Levers and Underlying Uncertainties

	Ultimate Outcomes	Intermediate Outputs	Indirect Drivers
Measures	Joint Mission capabilities	Interoperable capacities (information capital) Productivities (social capital)	Standard capacities Technology levels System utilization rates
Exogenous Uncertainty	Citizens’ priorities of mission capabilities	Interdependencies and disparities among systems	Technology advance, Social network density
Relationships		Production function, Cost function	Technology diffusion, System utilization function
Policy Levers		Budget allocation, IT investment portfolio	Standardization, Organizational incentives

Although this modeling exercise is based on the abstract assumptions in regards to production and cost functions and a number of speculative parameters about system-mission interdependencies and inter-agency distances, it illustrates that when autonomous agencies develop more mission-centric (rather than agency-centric) system portfolios, invest in standard systems modestly, and build more mission-centric (rather than agency-centric) relationships with other agencies, an encouraging evolutionary trajectory can be produced without any central commander.

Standard interfaces improve interoperability among a broad range of systems while point-to-point interfaces selectively couple only highly complementary systems. Building operational capabilities that activate a wide range of interoperable capacities also takes time. Hence, while small investments in standard systems increase interoperable capacities remarkably, but they increase mission capability rather moderately. Nonetheless, such untargeted interoperable capacities and mission-centric utilization of them may improve the robustness of mission capabilities faced with highly uncertain future states. Both the parametric and the probabilistic exploratory modeling (by varying the highly uncertain parameters for technology progress, interdependency, and inter-agency system utilization) confirm that modest investment in standard services jointly with mission-centric operation not only enhances the expected outcome but also reduces the variances of outcomes against highly uncertain future states. The approach of standard services and mission-centric operation is particularly effective when technology progresses faster than expected; inter-agency system utilization falls behind the expectation; and interdependencies among multiple missions and systems increase.

While these thought experiments are highly abstract, speculative and merely suggestive, the results are nonetheless interesting. They suggest that modest expansion of investment in standard services and building mission-centric inter-agency partnership may substantially improve the joint mission capability over the long run (even against challenging environments).

Case Study: Consolidation of Public Safety Wireless Networks

By means of a case study of investment in a consolidated wireless communication network for public safety missions, Chapter 6 demonstrates that adaptive investment strategies can enhance long-term values and mitigate risks. Enhanced connectedness is a critical building-block that enables public safety agencies to share information in real time across the central agencies, local governments and public institutes, and hence better respond to emergencies by rapidly mobilizing the complementary resources of other agencies. Communication network is also a platform for the interoperation among diverse information systems. However, the existing networks are far from supporting these goals because of the lack of interoperability across different agencies and the limited geographic coverage.

The Korean National Emergency Management Agency (NEMA) proposed an ambitious investment plan that commits itself to replace existing incompatible public safety wireless

networks of 46 agencies with a nation-wide consolidated network (with a budget request of KRW 360 billion (about US\$ 360 million) over three years). Tcha et al. (2004) conducted a preliminary feasibility study using a conventional cost-benefit analysis and approved the feasibility of this plan. However, the preliminary feasibility study suggested an inflexible single solution over a fixed consolidation scope despite substantial uncertainties. Although the preliminary feasibility study identified several uncertainty factors and emphasized the importance of risk management, it did not incorporate strategic uncertainties into decision models.

Key investment decisions should be made about the choice of a technical standard, an implementation method among many alternatives (including public-private partnership), and consolidation scope. A standard choice needs to be made by considering path dependent values (i.e. potential synergies with the existing networks), rather than by comparing the values of stand-alone systems. This study will examine the alternative of sharing the iDEN-based commercial network (public-private partnership) and the alternative of developing a TETRA-based government network. The heterogeneous potential participants are grouped into a few categories of users to help determine the scope of investments. This study defines three categories in terms of geographical areas rather than organizational boundaries: metropolitan terrestrial areas, nationwide terrestrial areas, and metropolitan underground areas. Exploratory analysis investigates uncertainties associated with network life span, inter-agency operational effectiveness, and public-private partnership. These uncertainties can be resolved over time and through actual implementation. An adaptive investment model starts in the highest pay-off area and then makes investment decisions about whether to expand (or redirect standard options) to lower pay-off areas, based on new information of the past implementation performances and the updated future prospect.

Because of synergies with (or reuse of) the existing networks and switching costs into new networks, investment decisions in the current stage are affected by the past investments. Exploratory modeling and real option analysis generate all the plausible paths of sequential investments over time and simulate their effects against a wide range of future states. The economic net present values for the society (as opposed to the accounting values for the governments) are estimated with 7.5 percent as a social discount rate across 75 scenarios

derived from combinations of five parameters of the inter-agency collaboration effectiveness, five parameters of the network life spans, and three parameters of public-private partnership effectiveness. The parametric exploratory modeling finds that the adaptive strategies substantially reduce the regrets, compared to pre-commitment strategies (see Figure S-3). Real option analysis finds that an adaptive investment starting with the public private partnership of sharing the iDEN-based network performs substantially better than the pre-committed investment in a TETRA-based network. That is, the exploratory analysis and the real option analysis identify that a choice of the iDEN-based network in the first stage will lead to the most robust long-term outcomes and design a roadmap about when to expand, switch, or abandon platforms over the investment life-cycle. It is because the experimenting with public private partnership in the first stage provides valuable information we currently lack about its effectiveness. This then yields better-decision making on the investment in nation-wide terrestrial and underground infrastructure. In sum, this case study demonstrates that well-designed adaptive strategy may mitigate the threats and capture the opportunity arising from the public-private partnership of providing a nation-wide consolidated network platform.

Figure S-3. Regrets of the Pre-committed Investment Plan and the Adaptive Investment Plan

TETRA precommitment		Improved Effectiveness of Inter-agency Collaborations				
iDEN	Life span	$\mu-2\sigma$	$\mu-1\sigma$	μ	$\mu+1\sigma$	$\mu+2\sigma$
50%	2010	-153,017	-108,415	-81,820	-80,690	-44,330
	2012	-157,318	-97,138	-89,138	-87,554	-79,496
	2014	-172,734	-101,236	-97,030	-95,053	-93,076
	2016	-168,653	-104,657	-102,341	-100,024	-81,218
	2018	-165,007	-109,539	-106,929	-104,318	-44,438
80%	2010	-153,017	-117,669	-107,844	-98,803	-54,653
	2012	-157,318	-129,994	-117,258	-105,222	-86,712
	2014	-172,734	-152,352	-136,318	-121,586	-106,854
	2016	-173,198	-154,280	-136,277	-119,212	-85,656
	2018	-177,005	-155,832	-136,131	-117,047	-46,343
110%	2010	-153,017	-148,667	-152,908	-157,368	-126,599
	2012	-167,502	-172,207	-178,225	-184,243	-183,787
	2014	-198,276	-203,576	-210,942	-218,308	-225,674
	2016	-207,487	-214,186	-222,719	-231,252	-223,294
	2018	-215,343	-223,257	-232,799	-242,341	-194,613

iDEN > Adaptive		Improved Effectiveness of Inter-agency Collaborations				
iDEN	Life span	$\mu-2\sigma$	$\mu-1\sigma$	μ	$\mu+1\sigma$	$\mu+2\sigma$
50%	2010	-23,245	-17,143	-18,016	-38,530	-38,530
	2012	-22,994	-8,928	-31,809	-39,754	-39,208
	2014	-22,777	0	-33,613	-40,814	-40,560
	2016	-22,589	-9,570	-41,731	-41,731	-40,845
	2018	-22,427	-19,888	-42,524	-42,392	-41,087
80%	2010	-18,203	0	0	0	0
	2012	-14,021	0	0	0	0
	2014	-4,068	0	0	0	0
	2016	0	0	0	0	0
	2018	0	0	0	0	-5,650
110%	2010	-7,566	0	0	0	0
	2012	0	0	0	0	0
	2014	0	0	0	0	0
	2016	0	0	0	0	0
	2018	0	0	0	0	0

(<-100,000€ <-50,000€ < 0) (Unit: KRW Million)