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Smart Forest Fire Management in the Republic of Korea: Creating a Data-Driven and User-Oriented Wildfire Prediction and Monitoring System

Korea Program FOR Operational Knowledge

기획재정부 Ministry of Economy and Finance

PROJECT DATA

IMPLEMENTING AGENCIES:
Korea Forest Service

DEVELOPMENT CHALLENGE:
Reduction and Mitigation of Wildfire Risk; Prevention of Loss of Life and Property

DELIVERY CHALLENGES:
Data Availability; Communication; and Skilled Human Resources

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Environment and Natural Resources

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Division of Forest Fire Prevention and Control, Korea Forest Service; Division of ICT Management and Statistics, Korea Forest Service; Division of Forest Disaster Management, National Institute of Forest Science

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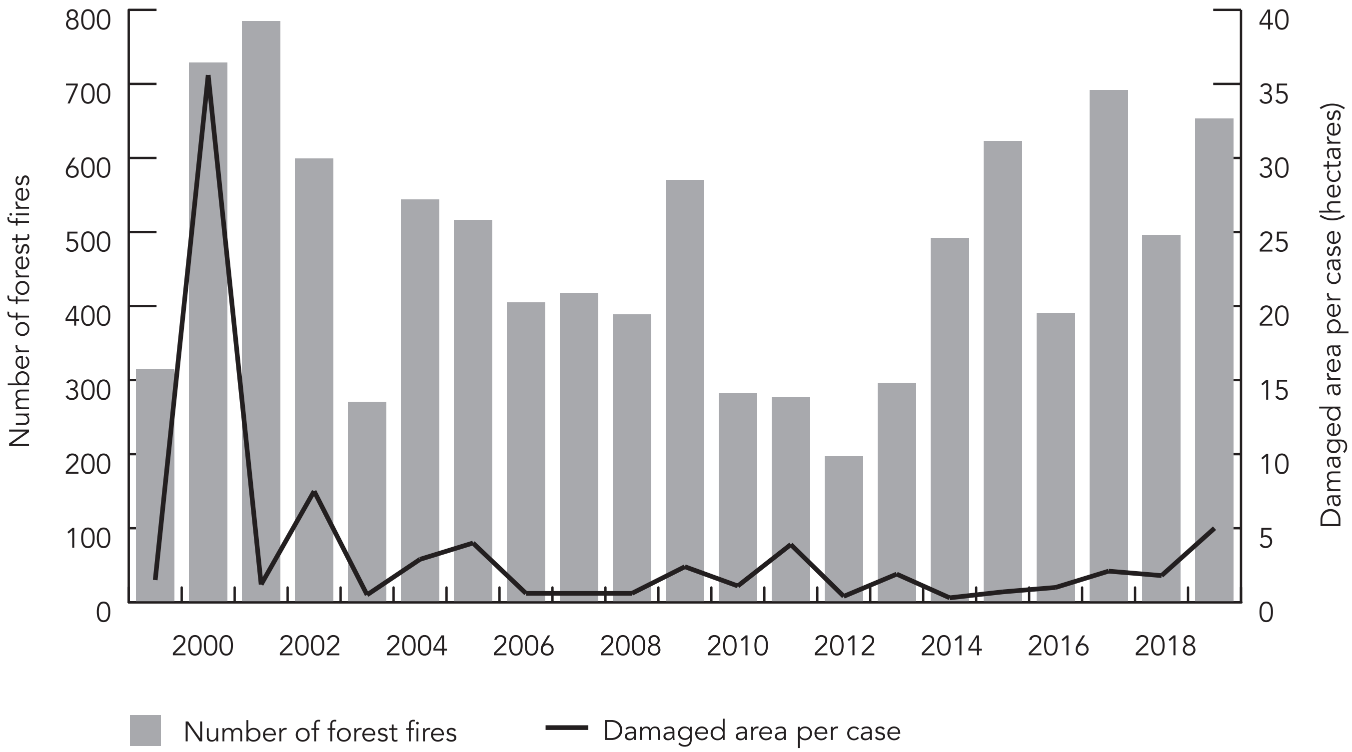
Executive Summary

Public outcry over a series of forest fires and a ferry disaster in the 2010s prompted the government of the Republic of Korea to make public safety a top priority. From 2013 to 2017, the Korea Forest Service, the national forestry agency, developed a data-driven forest fire prediction and monitoring system to support interagency cooperation and facilitate rapid response and fire suppression. The system drew from a wide range of data to provide consistent and reliable information on the estimated risk and status of a forest fire to the public on a real-time basis. The system also supports informed decision-making by forest service officers.

Despite the challenges of coordinating among agencies and ensuring data accuracy, the forest service made a series of systematic changes. The development of the new system benefited from crowdsourced feedback from broad-based experts and users through multiple channels, such as citizen surveys, training sessions, and a help desk that served as a channel for technical support and user experience. The forest service developed a smartphone application based on surveys and interviews with end users. The application allowed anyone to report the exact location of a forest fire, share photos and videos of it, and track its spread. The government's strong commitment to better crisis response facilitated interagency cooperation and resulted in the establishment of an interagency fire operations center in 2018. Ultimately, by cross-checking data

This case study was prepared by Ahram Han based on initial work by Christine Hyunjeong Joo and interviews conducted in the Republic of Korea. This research was supported by the Korea Program for Operational Knowledge, a partnership between the Ministry of Economy and Finance of the Republic of Korea and the World Bank Group. The author appreciates the guidance and assistance provided by colleagues in the World Bank's Environment, Natural Resources, and Blue Economy Global Practice. In particular, Maurice Andres Rawlins and Eunji Shin provided thoughtful feedback on various drafts and aspects of the case study.

FIGURE 1. TREND OF FOREST FIRE CASES AND DAMAGES IN THE REPUBLIC OF KOREA, 1999–2018



Source: Data from *Korea Forest Service Yearly Statistics, 2000–19.*

accuracy and incorporating user demands and lessons learned, the forest service made the fire prevention and monitoring system easier to use and more effective at wildfire mitigation.

Introduction

The most destructive wildfire ever recorded in the Republic of Korea, the East Coast Fires of 2000, started with a spark from burning trash in the far northeast of the country. Fueled by gale-force winds and dry underbrush, the overnight fire quickly exploded through forests and rural villages. Hours later, another wildfire near the northern border raged through the demilitarized zone and raced south, forcing thousands of residents to flee. Over the next eight days, a series of destructive fires near four populated coastal cities cut a swath of devastation across Korea's east coast. The fires claimed two lives, forced tens of thousands to evacuate, halted the operations of a nuclear power plant and a cement factory, and scorched 23,794 hectares of land (KFS n.d.).

Korea has long faced frequent wildfires. Since the Forest Rehabilitation Plan of the 1970s,[1] more than 60 percent of Korean land has been forested, half of that covered by highly ignitable conifers such as pine trees.[2] However, the disastrous East Coast Fires left damage at an unprecedented scale, comparable to the total area of wildfire damage over the previous two decades, which drew public attention to the Korean government's failure to control wildfires (figure 1).

Recognizing that fire prevention policies and practices, rather than fire suppression, would save both lives and money, the Korean government invested in strengthening

1 For more information about the Forest Rehabilitation Plan, refer to the 2017 GDI case study, "How Introducing a Tree Monitoring System Improved Forest Rehabilitation in Korea (1973–1987)," available at: http://www.globaldeliveryinitiative.org/library/case-studies/how-introducing-tree-monitoring-system-improved-forest-rehabilitation-korea.

2 Conifers are vulnerable to wildfires and landslides because they are highly flammable and their roots grow outward at shallow depths. Most of Korea's annual average precipitation is concentrated in the summer, exacerbating flood and fire risks. Coniferous trees are abundant in Korea because many were planted under the Forest Rehabilitation Plan (because they settle well in barren land and grow quickly), and their roots provide a habitat for valuable pine mushrooms, a culturally and financially important income source in the Gangwon area (Ministry of the Interior and Safety 2019; UNDP 2019).

forest fire management. With an increased budget, the Korea Forest Service, the government agency in charge of forest management nationwide, laid the institutional and legal foundations for coordinating and improving forest resource management under its leadership.

Following another disastrous forest fire in Yangyang in April 2005, the forest service established an integrated incident command guideline to facilitate clear response, acquire and mobilize resources, and coordinate interagency action led by the National Security Council. The service also published a manual that established emergency management protocols to effectively coordinate central and local government responses. Other major institutional changes included new divisions dedicated to forest fire control and training within the forest service and related offices, expansion of the forest fire research division in the National Institute of Forest Science, and organization of a forest fire suppression team. The forest service also invested in fire detection and suppression equipment, including helicopters and surveillance cameras.

The forest service's use of information technology dovetailed with broad efforts across the Korean government to lay the groundwork for e-government by introducing digital infrastructure, bringing government services online, and digitizing national databases.[3] For example, the government began to digitize the land registry to construct a national geospatial database based on digitized topographic maps.[4]

The National Institute of Forest Science developed a spatial database, which used relevant historical data to make predictive models of forest fires. Using this model and other studies, the institute developed and launched a forest fire danger rating system in 2005 to assess and quantify the possibility of extreme fire behavior. Researchers and administrators had hoped that the system would improve the implementation of fire prevention, detection, preparedness, and fire response plans. However, limitations and inconsistencies of the data used by the system constrained the system's accuracy in predicting forest fires.

The system used GEOMania, a company that supplied the GPS (Global Positioning System) trackers used by forest fire field agents, and developed a system for authorized government officials to manually mark the updated locations of fires on an online map. Government experts adopted a three-stage, color-coded fire danger rating system to present the degree of risk in public warnings issued online. In 2009, the forest service reclassified the risk levels according to the risk index and developed a text messaging system to share fire information by mobile phone.[5]

Despite the forest service's efforts, the forest fire management system faded in urgency between 2005 and 2012, when no notable fires occurred. In March 2013, however, a fatal wildfire spread to residential areas in the southeastern city of Pohang. The timing coincided with the introduction of a new e-government plan by recently elected president Geun-hye Park.[6] To mitigate the risk of wildfire and prevent the loss of life and property, the Korean government aimed to build an advanced, integrated forest fire management system. With interest renewed by the fire and by the new focus on data-driven government, the forest service introduced a plan to develop a smart forest fire prediction and monitoring system in 2013. Between 2014 and 2017, the forest service implemented this system as part of an integrated forest disaster management system that unified data and management systems related to forest fires, landslides, and forest pests.[7] See the appendix for a timeline.

Delivery Challenges

Several challenges emerged during the project's implementation, including acquisition of reliable baseline data as well as coordination across divisions within the forest service and efficient communication between system designers and intended users.

3 For more information about the Korean government's e-government plan, refer to the 2019 GDI case study, "The On-nara System for Task and Document Management: Scaling Up Back-Office e-Government across the Korean Government," available at: http://www.globaldeliveryinitiative.org/library/case-studies/nara-system-task-and-document-management-scaling-back-office-e-government.

4 For more information about the Korean government's integrated geospatial database, refer to the 2020 GDI case study, "Integrating Geospatial Information: How the Republic of Korea Overcame Institutional Obstacles to Improve Data Management, 1998–2016," available at: http://www.globaldeliveryinitiative.org/library/case-studies/integrating-geospatial-information-how-republic-korea-overcame-institutional-0.

5 In 2004, the National Security Council enacted a guideline for national crisis management and published manuals to respond to national crises such as natural disasters or terrorist attacks. The council designed a four-level, color-coded early warning system (blue, yellow, orange, and red) and stipulated that each ministry should respond accordingly. The Korea Forest Service applied the system by designing public warnings using the four-level fire danger rating system to express the degree of risk on a 100-scale index: blue (risk index up to 50); yellow (risk index 51 or higher); orange (risk index 66 or higher); and red (risk index 86 or higher). The forest service has issued a specific instruction manual to follow at each level.

6 Interview by Christine Joo with Gyutae Lee on July 16, 2020.

7 The integrated forest disaster management system, known as the 2013 Information Strategic Planning Project, was codeveloped with the National Information Society Agency.

Data Availability

Rapid and effective emergency response and monitoring depend largely on the availability of reliable data and service statistics. However, the existing system was too outdated by 2013 to handle high-resolution maps and was incompatible with a new shared database the Korean government had started using to replace an existing database for processing big data (KFS 2018a). The system could not handle a broad user base because it was developed as a stand-alone application. The entire program ran on a single licensed computer with different users accessing the same files on the network. Furthermore, the forest service was unable to address system errors and updates because the contractor for technical support, GEOMania, had gone out of business.

Most importantly, the forecast system and the fire location marking system were imprecise and did not provide meaningful information to support rapid emergency response. On-site field officers could not access the system remotely and instead tended to collect information and notes by hand. The forest fire prevention and control division would manually draw maps that were based on information relayed by phone and then scan those maps to share with other government agencies. This manual process lengthened response times and made it hard to revise maps when new data arrived or to collect current, consistent, and coherent statistical data sets.

To support informed decision-making in case of a forest fire, the forest service also needed to integrate and harmonize data from multiple sources, including climatic data, emergency call reports, and locations of nearby facilities such as freshwater reserves, transmission towers, highly combustible buildings, and precious cultural resources.

Communication and Skilled Human Resources

Efficient planning and implementation of sustainable fire management required a dedicated and knowledgeable team. The work required coordination between the division of the forest service dedicated to the management of forest disasters and the division dedicated to data and system management. To implement a new forest fire prediction and monitoring system in connection with information communications and technology (ICT), the forest service assigned system development to the ICT management and statistics division. Although frequent interactions and knowledge-sharing between departmental experts were critical, the system development team faced challenges in getting other departments on board because of preexisting rivalries between divisions.

In particular, the officials in the forest fire prevention and control division had doubts about the ICT division's field-specific expertise to develop and review fire policies. The forest fire prevention and control division had been disappointed by previous attempts by the ICT division to upgrade the system, leading to lingering distrust between the divisions.

The support of the forest fire team that had been formed within the ICT division was critical because forest fire team members would be the main users responsible for the administration and operation of the new forest fire prediction and monitoring systems. However, forest fire team members disputed the necessity of the new system because they reported only a few inconveniences with the existing system and anticipated more inconveniences with the replacement system. Without knowing exactly what the new system would look like or how useful an integrated data management system would be in predicting and managing forest disasters, and without preexisting models or international best practices, it was difficult for forest fire team members to convince and engage other officials.

When the system was initially implemented in 2014, many users, especially in local offices on the front line for small- and medium-scale forest fires, had difficulty navigating the system even after multiple training sessions and the dissemination of various learning materials such as videos, online resources, and manuals. Because many older and more established employees had limited digital literacy, they were more accustomed to delivering printed materials in person, which could be slow and inefficient.

Tracing the Implementation Process

The smart forest fire prediction and monitoring system was part of the forest service's master plan, an integrated forest disaster management system to improve the accuracy and efficiency of forest fire management. The forest service implemented the new system step by step by setting clear short-term goals at each of four phases from 2014 to 2017.

Linking Internal and External Information Systems

In 2013, the forest service secured funds from the Ministry of Security and Public Administration, which governs internal affairs, to launch the master plan. Securing the budget went smoothly because the central government supported the plan as one of the national e-government projects backed by strong political will from the administration. The forest service also secured a special project budget for analyzing ministry data to develop a forest fire prediction and monitoring system.

After securing funds, the forest service assigned the ICT division to lead system development. There were three forest disaster management bureau prevention and control divisions, in charge of forest fires, landslides, and forest pests, respectively. Although the newly planned integrated system required all divisions to work together closely, many officials, especially in the forest fire prevention and control division, preferred their existing forest fire forecast system over the new system.

The existing system, in use for more than 10 years, had critical pitfalls that hindered rapid response. Not only was it poorly designed to read accurate locations from aerial photographs, but also the data collection method relied on inconsistent manual processes. Field officers transmitted information orally over the phone to officials in the situation room, who then manually marked locations on a map, which they scanned to share with other government agencies.

Despite the issues with the existing system, the officials in the forest fire prevention and control division had low expectations for the new system under development, because they lacked comparable models and doubted the ICT division's understanding of fire suppression. In the experience of officials in the forest fire prevention and control division, changes made by the ICT division had made their work more confusing rather than more convenient and efficient.

The ICT division team members developing the new system felt that they had to create a user-friendly, technically superior system to induce support from their colleagues in other divisions.[8] In the early stage, the development team strategically focused on developing the underlying infrastructure, believing that colleagues' concerns would ease once users found the system useful and convenient.[9]

The ICT division team began by collecting national geospatial data of forest and conservation areas that were scattered across multiple divisions, along with additional data sets from other agencies that could assist decision-making in the event of forest disasters. The service drew on data such as cultural heritage protection areas from the cultural heritage administration, climatic data from the meteorological administration, and aerial images from the Ministry of Land, Infrastructure, and Transport.

After combining the data sets into one database, the team created thematic maps that could be analyzed by different themes, such as the composition of tree types, climate, and cultural properties. Whereas the existing system had only one type of fire risk map, the team created multiple maps subdivided for better fire situation analysis: a forest fire risk map, a large-scale forest fire risk map, a vulnerability map, and a high-risk-area map containing public facilities (such as schools and hospitals) and fire hazards (such as gas stations and factories). The team also enhanced the resolution of geospatial data by 25 times by refining the scale of maps showing the extent and distribution of various tree types (Byun 2018). With the inclusion of climatic information—namely, the temperature lapse rate caused by wind strength and altitude—in the forest fire prediction and monitoring system, the improvement of visual data accuracy increased the wildfire forecast accuracy rate by more than 10 percent: from 74 percent in 2014, to 83 percent in 2015, to 87 percent in 2016 (Byun 2018; KFS 2018b).

Increasing Convenience for Users

The team made a particular effort to improve user experience. To minimize potential confusion, the team applied the button images from the existing system to the new one. The team also based system development on functions frequently used in the field to supplement functions that had not been upgraded after GEOMania went out of business. The team also conducted multiple training sessions for 212 officers who would be using the system in 2015 (KFS 2018a).

The database provided statistical data, which reduced the time to prepare statistical data reports from an hour to a minute. It also reduced the time required to process

8 Interview by Christine Joo with Seungtae Hong on June 22, 2020.

9 Author interview with Sangwoo Byun on January 7, 2021.

climate data from three hours to 50 minutes using a high-speed data-processing and analysis tool (Byun 2018).

Although fires had been traditionally reported in Korea by a 119 emergency call system, the absence of a method to share call records delayed report delivery. The team linked the new system with the 119 call system to automatically retrieve call records managed by the internal affairs ministry, as demanded by the forest fire prevention and control division. This feature helped to shorten the initial response time from 20 minutes to 5 minutes (KFS 2018b).

To facilitate open sharing, communication, and collaboration across the forest service, the project team, working from May 2013 to January 2015, developed a smart dashboard to display key information from diverse sources on a single screen without overwhelming the end users with too much data. The dashboard displays essential information for disaster response such as climate conditions and public facilities in a visually intuitive way. Immediate information pooling and big data analysis facilitate rapid response. The user-friendly interface helps smooth cooperation, alleviating user doubts about the new system as officials see their ideas and feedback incorporated.

"The introduction of the smart forest fire prediction and monitoring system has changed the way of information delivery and communication from one-way reporting to a crowdsourced sharing method," reported Se-mi Kim, a forest service staff member (KFS 2018a).

Increasing Intergovernmental Cooperation in Response to a National Disaster

In April 2014, a shocking ferry disaster prompted greater cooperation and focus on emergency response among officials at all levels of government. The sinking of the Sewol ferry, which took 304 lives—including those of roughly 250 high school students—sent a shock wave across the country for years, leading to criminal charges, a presidential impeachment, and new public interest in and political will for disaster prevention and control.[10] As the Korean government set high-technology public safety as a top priority, official cooperation increased across divisions and agencies (KFS 2018a).

The forest service began expanding forest fire management services to local governments to make the safety net tighter. Because of a reduction in personnel and resources, many local governments suffered from limited capacity to effectively prepare for and mitigate forest fires.[11] The forest service reorganized forest management planning areas into 79 districts to make sharing locations of fires easier and more precise. The forest service piloted the forest fire prediction and monitoring system in 2015 and extended its services to local governments in 2016. The forest service also signed a memorandum of understanding with the land ministry to share and use geospatial information, including satellite maps to increase visual data accuracy.

A cooperative effort of various experts, including researchers, contractors, and members of development and project teams, backed up the system. The National Institute of Forest Science provided many suggestions, based on current research, for improving forecasts and early detection of wildfires. Institute researchers shared a hotline with colleagues at the forest service and worked closely to exchange feedback. They were also in frequent contact with local offices, system management contractors (Seesun IT), and other researchers in the field. "I contact the forest service officers more often than I call my wife during weekdays," joked Dr. Chungeun Kwon, a research fellow at the National Institute.[12] Representatives of the local governments, forestry agencies, and independent research institutes also gathered their feedback on the system at formal meetings at least once per year.

The ICT division and forest fire prediction and control division also provided training for local governments at five regional offices in the country. The forest service held about seven education and training programs from 2015 to 2020, including annual group education seminars and semiannual professional trainings for the GPS and geospatial information managers beginning in 2017 (KFS 2018a).

10 Interview by Christine Joo with Jaehee Shin on June 22, 2020. For another Korean public reform prompted by the Sewol disaster, refer to the GDI case study, "Innovating Inter-Agency Collaboration for a Smart Emergency Response System: Daejeon Smart City Operation Center, 2010–2017," available at: http://www.globaldeliveryinitiative.org/library/case-studies/innovating-inter-agency-collaboration-smart-emergency-response-system-daejeon.

11 After decentralization reforms in 1995, the central government mainly managed forest fire projects and budgets, while local-level forest fire administrators had authority and autonomy to implement and manage forest fire prevention and suppression practices in the field. From 1998 to 2004, many local governments restructured, downsized, and merged forest management divisions, as they became more interested in forest land use rather than fire management (Yoo 2008). For instance, Gangwon Province on the northeast coast of Korea, where both the 1996 and 2000 forest fires occurred, had reduced the number of forest officers by a quarter from 400 to 292 people in 1998.

12 Interview by Christine Joo with Chungeun Kwon on June 17, 2020.

Increasing System Accessibility

The Korean government's drive for e-government raised information security concerns and led to the introduction of stronger information security procedures and a separation of networks into internal and external systems throughout government. Authorized users could access secure resources only from an internal network connected to a device disconnected from the internet and other external networks. Though the policy enhanced security, public officials lost accessibility outside of the office. Field officers could no longer access data on-site. The reinforced security level also hindered the flow of information to citizens. The media and the National Assembly called for making government services available to citizens across multiple platforms while consolidating related applications.

Beginning in 2016, the development team focused on improving accessibility and reducing emergency response time. The development team began by working on a web-based portal accessible from anywhere and a mobile application to provide real-time updates on developing situations. The team also expanded access to provide secure connectivity to other government agencies via the Government Virtual Private Network.

In 2016, the ICT division also added a situation map to the forest fire prediction and monitoring system, which was essential during any emergency, showing conditions in real time for situational assessment.

"There was a significant improvement to the forest fire prediction and monitoring system," said Sujung Ahn, a researcher at the National Institute of Forest Science. "The existing system only ran on a personal computer, but it now runs on any device connected to the internet, allowing users to draw situation maps without intranet connection in the field and post real-time updates at the same time. The GPS coordinates find the accurate location of a fire."[13]

In April 2017, the forest service launched a GPS-enabled mobile application called Smart Forest Disaster Management that allowed field forestry officers and members of the public to easily report forest fires. This application shared real-time location information of reported fires, which enabled faster emergency response and decision-making. Previously, there were two separate applications for detection reports and damage reports, as well as separate applications created by the disaster prevention and control division for reporting forest fires, landslides, and forest damage. By combining those individual applications in a single app, the forest service reduced total administrative costs by 75 percent.

At the same time, the development team aimed to ensure that all potential users of the system—government officers as well as members of the public—could easily access real-time information about forest fires without going through the internal government network. At the beginning stage of the mobile application development, the development team formed a system design team of 11 service design experts, application development experts, and everyday citizens, setting priorities that were based on expert opinion and online voting results. The team conducted surveys and user interviews to reveal hidden user concerns. For example, many citizens were willing to report forest fires but were unfamiliar with channels to report them and unwilling to install extra applications for unlikely events. Notably, the survey found that most citizens did not want compensation for reporting forest fires and perceived contributing to problem solving as its own reward.

Incorporating this feedback, the team made the application more useful by adding a simple report button on the main screen and provided hiking information and risk forecasts of nearby forest disasters. The app allowed users who made reports to track the reports, monitor progress, learn about the government's response, and view guidelines for residents (KFS 2017, 2018a).

For authorized officials from any government agency, real-time monitoring became immediately available without turning on a computer. The application displayed the location of more than 12,000 field agents hired to patrol and detect signs of forest fires during the high-risk season through GPS tracking.

Incorporating Lessons Learned

By 2017, the smart forest fire prediction and monitoring system integrated various functions synergistically. As soon as a potential forest fire case was reported through a 119 call, the system would immediately pick it up. Local forest management office staff and firefighters could open the smart forest disaster mobile application to check the exact location of the reported incident before dispatching personnel to the field. This check took less than a minute, an improvement from the previous process of cross-checking the approximate address on a map with other

13 Interview by Christine Joo with Sujung Ahn on June 22, 2020.

information on the approximate location of the incident, which took more than 10 minutes. The forest service could then deploy response teams or helicopters for initial fire suppression.

In the situation room, officials could visualize every process in real time, locate emergency routes, and view color-coded properties and other information on a situation map and dashboard. A quick grasp of the situation made the information sharing faster between the situation room and dispatched officers.

Related organizations received fire reports through text messages to assist with the emergency response. For example, electric utilities could check the status of transmission towers, and rural community organizations could check nearby freshwater reserves.

The forest fire database system ensured widespread availability of fire data at various levels of detail to researchers and the public. Their feedback promoted continued system improvements and informed policies and responses. All government actors, from local emergency response agencies to the central government, have relied on this real-time data to make data-driven decisions when forest fires occur. By disclosing the fire control process, the new system has also quickly provided consistent and reliable information throughout the government agencies. "In the past, responding to various contacts who were curious about the situation was another job that distracted from the fire response work, but the new system enabled those contacts to check directly so that it cut unnecessary calls," Se-mi Kim said (KFS 2018a). The forest service's fire location database has included the location of the ignition point, ignition timing, extinguishment date, damaged area, property loss, cause of fire, meteorological factors of the affected site, and other parameters available over the past decade.

Some ideas did not work as planned. For example, satellite images turned out to be less useful for fire detection than expected. Stationary satellites, which view the same portion of the Earth's surface to produce images of a specific area, produced images with inadequate spatial resolution, whereas orbital satellites that produced high-resolution images could not stay focused on a designated area.[14] Although helpful, the 119 call connection created other challenges. The 119 system received many false reports that wasted time and resources because the protocol required the dispatch of field officers for a firsthand check. Also, the web-based service experienced frequent slowdowns when loading data, especially for individuals using an older web browser.

When the new system was fully in operation in spring 2016, it experienced accessibility issues, and the forest service had to go back to using the old system (KFS 2018a). When forest service officers tried to reopen the new system in the fall, they found it was missing a core function of the old system, an automatic text notification to the person in charge once a forest fire was reported by a device. It turned out that neither the forest service nor the contractor had sufficiently reviewed which core functions were to be included, a problem that arose from the separation of work between the forest fire division and the ICT division from the beginning of the development process.

To tackle the frequent slowdowns of the system, the ICT division continued to improve an algorithm to retrieve information from the database. In addition, the ICT division also invested in physical resources such as obtaining more equipment for web services to increase accessibility capacity.

The ICT division collected feedback from users and addressed technical issues and systemic errors to improve user-friendliness and convenience. Although the situation map was a useful and valuable resource, only a few people were able to draw the maps—even fewer in the case of local governments. There was a bulletin board for questions and answers in the integrated forest disaster management system, but officials did not actively post questions. The ICT division operated a help desk for IT support for officials from 2016 onward. At the help desk, an officer who could directly assist the caller answered the phone. The help desk also worked as a channel to exchange opinions, because the client seeking help could tell the help desk officer how he or she felt about using the system. The forest fire prevention and control division regularly provided wildfire response plans to system users and held annual meetings to receive complaints and collect opinions.

Outcomes

Since 2016, the forest service has kept a history of forest data by matching aerial photographs from the past with exact locations and by updating forest type maps for

14 Author interview with Sangwoo Byun on January 7, 2021.

sustainable management. The forest service expects that such sustained management of data will help researchers grasp changes to the forest caused by climate change and human development, and their analysis will increase the accuracy of wildfire forecasts. Given the integrated data, the forest service plans to cross-reference forest fire data to analyze other types of disasters, such as landslides and forest pests.

By collecting reports of forest fires through various channels, including satellite image analysis, high-resolution closed-circuit television cameras, heat-sensing drones, 119 calls, and mobile app reports, the forest service reduced the time required for forest fire detection from 30 minutes to under 5 minutes by 2018.

The number of users accessing the integrated fire disaster management system increased steadily from 2,182 website visits per month in 2015 to 3,735 in 2016, and 9,396 in 2017. In 2017, the Korean government granted the smart forest fire prediction and monitoring system an E-Government Award for the governmentwide best practice of use of ICT to make an administrative improvement, in which participants included government agencies, private firms, and research institutes. Since 2018, the forest service has shared knowledge of the integrated forest disaster management system with countries in Latin America and Asia.

The smart forest fire prediction and monitoring system played a key role in containing a massive forest fire that broke out in April 2019 on the east coast, thus helping to prevent a repeat of the catastrophic East Coast Fires of 2000 or the Yangyang Fire of 2005, which occurred on the same day of the year under similar conditions. Although the Yangyang Fire of 2005 caused great damage and took 32 hours to extinguish, the 2019 fire on the east coast was extinguished within 13 hours. A rapid, coordinated governmentwide response that was based on real-time information actively shared through the integrated fire disaster management system made this success possible (Ministry of the Interior and Safety 2019).

One institution that proved critical to rapid response in the 2019 fire was the East Coastal Forest Fire Center in Gangwon Province, an interagency fire operations center established by the forest service, the meteorological administration, and six local governments in 2018. The center, based in the eastern coastal area where large-scale forest fires have most frequently occurred, worked closely with other government agencies, such as the fire department, police, forest management service, and national park service. Channeling all the related information from different sources into one center facilitated information sharing. "Each agency dispatches officers to the center . . . [which] naturally induces interagency communication and cooperation," said Sujung Ahn, who was dispatched to the center from the National Institute of Forest Science.[15] In the case of a large-scale wildfire, even the executive office of the president dispatched personnel.

Lessons Learned

The development of Korea's smart forest fire prediction and monitoring system achieved promising results despite setbacks. The Korean experience holds lessons for reform implementation worldwide, although forest fire management systems may differ because of contextual variations in capacity and resources, government structures and norms, and forest fire management policies.

Setting a Clear Priority Helped Agencies Adopt a Data-Driven Culture and Gain Buy-in from Leaders and Staff

Korean government leaders sent a clear message throughout government agencies about governmentwide commitment to prioritize public safety by advancing crisis response systems, especially after the 2014 Sewol ferry disaster. Linking public consensus to a national goal helped to increase awareness and create a cooperative atmosphere among public officials. The central government incentivized interagency cooperation by rewarding effective data use at an annual information technology competition and factoring it into performance evaluations and promotions.

Such incentives, along with formal and informal training, encouraged the forest service and local officials to build the skills and expertise to analyze and act on data to ultimately strengthen their fire management capacity.

Iterative, User-Oriented Processes Encouraged Innovation and Problem Solving

The forest fire prediction and monitoring system evolved incrementally in multiple phases. System development

15 Interview by Christine Joo with Sujung Ahn on June 22, 2020.

relied on intensive tests and trials to gather feedback, monitor outcomes to improve user experience, and encourage adoption. For the system to perform well, end users had to be involved in the development process to gain a sense of ownership and familiarity. In turn, end users needed training and a system designed with their needs in mind. Developers incorporated the demands of main users and integrated lessons learned to address emergent concerns. By doing so, the developers assuaged long-rooted doubts and made the system convenient for users. The forest service also launched a help desk service to support users whenever they encountered a technical problem, provided guidance to navigate the system, and collected user feedback to improve the system. Regular system evaluations with defined performance metrics allowed developers to evaluate operational capabilities, efficiency, and effectiveness.

Incorporating Both Experts' Input and Crowdsourced User Feedback Improved System Design

The forest fire management system depended on contributions from a wide range of experts in technology, science, and government policy to harmonize and integrate relevant data from diverse sources. The forest service could not have developed a useful system without the National Institute of Forest Science, which provided research support to improve the accuracy and efficiency of the predictive model. Fire operations data and feedback from local offices helped the institute develop meaningful performance metrics and test and hone models.

The system development team carried out training sessions and workshops for officials from the forest service, related organizations, and local governments, allowing participants to share knowledge and identify barriers and potential improvements. Crucially, the final system relied on observations from local users, including professionals and everyday users, to collect, update, confirm, and share data. This crowdsourced system proved more resilient and useful than the original system, which was more hierarchical and government directed.

A Commitment to Maintaining Accurate and Reliable Data Supported Informed Decision-Making and Operational Response

For effective forest fire responses, it was crucial to secure accurate and reliable data early on and continuously cross-check the accuracy of the forest fire prediction and monitoring system. Keeping a history of forest data and observing changes helped to increase prediction accuracy. Because the informed decision-making and operational response depended largely on rapid integration and harmonization of data from various sources, it was critical to define the rules and protocols for data sharing, create a standardized data format, and use compatible systems. Establishing a plan for system maintenance and improvement and assigning a data expert to ensure continued data flow also proved helpful. The forest service updated its database annually with the findings of regular field surveys.

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Appendix: Project Timeline

Year	Key event
1996	Forest fire prevention training division is established under the Forest Training Institute.
1999	Korea Forest Service establishes forest fire prevention division under the Forest Policy Bureau.
2000	The East Coast Forest Fires spread for nine days and damage 23,794 hectares of forestland.
2004	Korea Forest Research Institute develops the Korea Forest Fire Danger Rating System. Forest fire prevention and control division is established under the newly created Forest Protection Bureau.
2005	The Yangyang Forest Fire destroys a national landmark, Naksan-sa temple.
2006	Forest Fire Action Center is established on the east coast.
2010	Forest Protection Act is enacted. Korea Forest Service develops the Forest Fire Situation Control System to locate forest fires and develop appropriate countermeasures based on analysis of the surrounding environment. During the fire prevention period, field officers are hired to report forest fires throughout the country on GPS-enabled portable devices.
2011	Helicopter-based geospatial data system is developed.
2012	Forest fire field video-sharing system is piloted.
2013	Korea Forest Service, with the National Information Society Agency, develops the 2013 Information Strategic Planning Project, a master plan to increase technology and data use in the forest disaster management system.
2014	Korea Forest Service launches the first phase of the Integrated Forest Disaster Management System (FDMS) Development Project.
2015	Second phase of the Integrated FDMS Development Project is implemented.
2016	Third phase of the Integrated FDMS Development Project is implemented.
2017	Fourth phase of the Integrated FDMS Development Project is implemented. Smart forest fire monitoring system wins the 2017 E-Government Award.
2018	The Integrated FDMS is recognized as an excellent case of geographic information system (GIS) application at the 2018 GIS Software Technology Conference. Korea Forest Service begins partnering with countries in Latin America for knowledge sharing and dissemination of the Integrated FDMS. East Coastal Forest Fire Center of Gangwon Province is established.