Leveraging Research for Knowledge Continuity: A Case in Infrastructure Management

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Abstract: Ensuring long-term knowledge continuity is a key challenge for organizations managing the long-cycle maintenance of complex infrastructure. This paper explores how agency-led research programs can support dynamic knowledge continuity within the Dutch Directorate-General for Public Works and Water Management (Rijkswaterstaat, RWS), particularly in relation to its storm surge barriers. The long-cycle maintenance of the storm surge barriers faces long redesign cycles which result in a challenging human capital development environment with regards to specialist knowledge domains. Current knowledge of complex barrier systems is of a distributed nature following several decades of intensive outsourcing. At present the agency is investing in research programs aimed to strengthen its knowledge in strategic areas. This article aims to add to the limited literature of leveraging research efforts for long term knowledge continuity in a distributed knowledge environment. The research was conducted using questionnaires and semi-structured interviews. Fourteen respondents comprise of active researchers, research supervisors, and research managers. Researchers acquire high levels of proficiency in critical engineering knowledge domains. This equates to the development of valuable human capital that flows from the program when researchers complete their projects. Researchers were found to be highly motivated to stay on and locally implement their findings or contribute to their domain of engineering knowledge. Results include nine ways in which the research programs contribute to long-term knowledge continuity, of which human capital development is the most important. The study further reveals that while research programs effectively cultivate deep technical expertise, their potential is underutilized due to limited follow-up employment opportunities and a lack of strategic alignment with staffing and insourcing. We argue that research-developed talent should be strategically integrated into local technical teams to strengthen RWS's internal capabilities, foster standardization, and ensure preparedness for long-cycle maintenance and redesign challenges. Our findings inform both theoretical perspectives on dynamic knowledge management and practical strategies for asset-intensive public organizations.

Keywords: Knowledge continuity, Critical infrastructure, Research programs, Strategic insourcing, Human capital, Talent development, Rotating traineeship, Long-cycle maintenance

1. Introduction

Achieving knowledge continuity across generations of engineers is essential to the asset management of critical infrastructure. Achieving this for unique, complex, and ageing infrastructure with high demands for reliability and availability has proven to be challenging. This has been previously investigated in the context of the Dutch storm surge barriers (Kharoubi *et al.*, 2024; Walraven, Vrolijk and Kothuis, 2022; Ponsioen *et al.,* 2023). The core of the knowledge management challenge is that the long-term management of assets is not a very suitable environment for developing lead-designer level technical knowledge because many critical tasks are too infrequent to facilitate reliable 'learning on the job' (Kamps *et al.*, 2024a). Absence of authentic learning opportunities can be a major challenge to development of specific knowledge, even if sufficient time and other learning resources are available (Beane, 2019). Challenges to knowledge continuity are regularly exacerbated by attrition through retirement happening in waves, as reported from research at a different public agency (Delany and O'Donnell, 2005). Waves of attrition and limits to knowledge development outside the highly dynamic phase of design and construction cannot be completely avoided. Therefore strengthening institutional pathways for

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developing technical talent with barrier-domain knowledge is needed for knowledge continuity at the agency (Kamps *et al.*, 2024a).

Infrastructure is affected by trends like population growth, technological development, climate change, energy transition and environmental protection (Nezami *et al.*, 2022). Avoiding obsolescence of infrastructure in a changing environment requires continual redesigns demanding deep engineering knowledge. Research as a knowledge-using, creating, and sharing activity can support rebuilding knowledge in time for long-cycle maintenance challenges. Research activity can be planned outside the timeframes of redesign and updating of technical systems when knowledge is most needed (Kamps *et al.*, 2024a). This article will investigate the research question "How can agency-led research programs be leveraged to achieve dynamic knowledge continuity in the management of critical complex infrastructure?". The research was situated at and centred around the knowledge continuity challenges of the Dutch storm surge barriers. The study used a trial round of semi-structured interviews, followed by the main round where quantitative survey questions were added. Due to the small sample size, all quantitative responses were also extensively discussed during the interviews.

This first section explores literature and practice with regards to the relationships between knowledge continuity, research programs, distributed knowledge and knowledge process outsourcing. The second section describes the method employed for the research, while the third section elicits its results. The fourth section discusses the findings from both a theoretical and practical perspective, while the fifth section concludes the research with theoretical and practical recommendations, as well as limitations and potential for follow-up research.

1.1 Static Goals in a Dynamic World

The Dutch Directorate General of Public Works and Water Management, Rijkswaterstaat (RWS), manages many critical and complex infrastructures. The six storm surge barriers are among its most complex and unique assets, and in 2018, a knowledge strategy was published specifically for these barriers. The knowledge strategy includes a provision for continuity of distributed knowledge, which states that engineering knowledge is sufficiently assured when held by two or more reliable partners (organizations with which RWS regularly works). If it is not, it must be held by two or more engineers employed by RWS. This straightforward knowledge continuity policy reveals an underlying assumption that 'sufficient' engineering knowledge is a constant or steady state that needs to be managed. The knowledge strategy provides the tools for determining knowledge risk for key domains of barrier knowledge.

Rijkswaterstaat has a long and rich history of managing knowledge risk. The earliest RWS document on managing knowledge risks dates back to 1983 (Mazure, 1983), several years before knowledge management emerged as a distinct scientific discipline. Mazure's report addresses the risk of losing hydraulic engineering knowledge at the end of the Delta program, which built the modern Dutch flood defences and provided employment for many engineers. Mazure's method is relatively simple and revolves around counting the number of 'heads' of hydraulic engineers across various departments of RWS. Knowledge risk management has since evolved, and current practice at RWS agrees well with the task-centred approach described by Boyles (2009) for the nuclear industry. A task-centred approach is also used for the professional standards adopted and published by the International Atomic Energy Agency (IAEA) (2017). In this approach, the organizational knowledge base is scanned for the risk of losing key knowledge carriers, while also assessing the impact on the ability to complete key tasks. When the method's goals are met, critical knowledge remains continuously available.

Prescribing in policy a continuous availability of engineering knowledge for all critical tasks does not take into account that some engineering tasks have very long cycles, as fifteen to thirty years between updates of systems is typical (Vader *et al.,* 2023). Currently, in line with the steady-state assumption, policy does not account for what employed engineers knowledgeable in critical domains should do with this knowledge during periods of discontinuity in use. Knowledge of infrequent tasks however tends to fluctuate in time, following the intensity of knowledge use (Walker, 2018). This paper, therefore, questions whether a steady-state knowledge continuity model is most suitable for infrequent tasks and instead proposes a policy of directed knowledge build-ups, leveraging agency-led research.

Conventional knowledge risk management minimizes the risk of losing key knowledge. If it is known in advance when knowledge will be needed however, this risk does not need to be considered for any point in time, but only for the time when the focal task is set to commence. Taking this perspective, some knowledge attrition can be viewed as acceptable, so long as it is rebuilt in time for the focal task. Conceptualizing knowledge continuity in a different way than avoiding all loss of knowledge offers clear advantages. Conventional management of knowledge risks aligns the timing of mitigating efforts with the time of the expected loss of knowledge, i.e., the retirement of a highly valued expert. Assigning an apprentice to a soon-to-retire expert has been found in both the literature and internally at RWS to not always to be successful, as there may be no relevant tasks to enable the apprentice to absorb the tacit knowledge of the expert during the apprenticeship (Kamps *et al.*, 2024a; Leonard, Swap and Barton, (2015); Mazzucato and Collington, (2024)). Managing engineering knowledge for expected tasks aligns the timing of efforts to improve task readiness with challenging tasks to come. This does not replace the need for knowledge risk assessments and associated mitigation efforts; it does, however, provide a more useful basis for deploying non-core activities aimed at reactivating dormant knowledge, such as research and (digital) twinning (Kamps *et al.*, 2024a). Long-cycle engineering challenges are reasonably predictable in terms of time, as RWS has detailed plans containing all expected upgrades and system replacements for the next thirty years. The term 'dynamic knowledge continuity' is introduced here to describe a policy of seeking to continuate critical knowledge over time, but accept significant variability. During, or preferably even leading up to periods of high demand, a concentrated effort of human resource development will then be necessary to compensate for the periods of low demand and associated attrition.

1.2 Managing Local Assets with Distributed Knowledge

In the present time, RWS outsources most of its design and engineering work. Outsourcing such knowledge processes causes reliance on distributed rather than internal knowledge (Edvardsson and Durst, 2014). A specialized firm often has superior knowledge continuity and opportunities for learning in its field (Mudambi and Tallman, 2010). Internal knowledge retention also carries cost, and a firm's internal retention capacity is limited, which is why Lichtenthaler (2008) advocates for an integrated strategy comprising both internal and external knowledge. Mudambi and Tallman (2010) note that managing external knowledge processes and distributed knowledge requires having overlapping knowledge in-house, and the more in-house knowledge is available, the better it is for management of external processes. Hartman, Ogden and Hazen (2017) advocate avoiding knowledge attrition by partially insourcing tasks for which knowledge retention is considered necessary. This is also supported by Anderson and Parker (2002), who focus on component-integration and show a significant amount of insourcing is necessary to support the local learning that results in intimate component knowledge and integrated system knowledge.

An asset management organization that must ensure the reliability and availability of complex and unique infrastructure has knowledge continuity vulnerabilities similar to a firm acting as a systems-integrator. It must avoid vendor lock-in, and the resulting dependency and loss of negotiating power as well as prevent gradual loss of local knowledge. At RWS these are not just theoretical risks either, as some of the research programs investigated for this study were, among other reasons, started to reduce undesirable dependency and lock-in. If complex tasks are completely outsourced for some time, knowledge is also very challenging to bring back (Agndal and Nordin, 2009; Mazzucato and Collington, 2024).

Summarizing, an organization like RWS should retain critical engineering abilities necessary to effectively work with their partners and, learn and develop knowledge, but also seek to benefit from specialist provider's abilities to stay up-to-date on innovation. As a 'first among peers' of Dutch public asset managers such as provinces, municipalities and water boards, RWS is well-positioned to develop and lead knowledge development for the asset management of complex public assets. This would be in line with the recommendation by Mazzucato (2024) for public agencies to assume such a role.

1.3 Research Driving Human Capital Development for Knowledge Continuity

Well-chosen avenues of research give researchers time and reason to read through documentation that has been untouched for a long time and bring its content to life, providing valuable opportunities for learning about critical but sparsely-used domains of knowledge (Kamps *et al.,* 2024a). Knowledge management also teaches us that we all know and learn more than we can tell. The advances in a researcher's (tacit) knowledge will far surpass that which is captured in written research reports (Nonaka and Takeuchi, 1995; Grant, 2007). The developing technical talent through research builds valuable human capital. Conventional academic models of value creation through research emphasize primarily the products of research and their application, whereas value creation through human capital development receives less recognition as a key aim of research. Williams (2020) provides an overview of thirty-six measures of scientific impact, only one of which is about human capital development (number of PhDs awarded). Some authors do recognize human capital as a key output of research programs. Guimarães and Humann (1995) for example give a detailed account of a major research program initiated by the Brazilian government in the 1960s with the main aim of developing human capital. More notably Bozeman, Dietz, and Gaughan (2001) propose a value model that includes human capital aspects, but consider the property difficult to measure. They also point to the 'social capital' development during research, which develops a potentially highly valuable network of individuals with related knowledge in the asset management of critical infrastructure. In asset management, continuity of personified, tacit and connected knowledge is independently valuable, because only by having knowledgeable technical staff at hand can the agency be ready for the challenges presented by the long-term maintenance of its critical infrastructure. RWS itself does mention human capital development as a research program goal, but does not provide any further provisions or elaboration on the topic.

While doing research, absorbing critical but long-dormant details of a complex asset's engineering helps researchers find answers to the questions they work on and increase their knowledge, but that in itself does little for knowledge continuity. Knowledge continuity is served mostly when the personified knowledge gained remains available for the organization, yet the research periods for Masters, EngD and PhD projects of six months to four years are not enough to significantly contribute to retention and continuity of tacit knowledge. This makes prolonged post-research involvement essential in the face of a century-long service life of key infrastructure. A human resource strategy that aligns with knowledge development and transfer goals is highly recommended by the literature, but often not achieved in the practice of state owned companies (Phaladi, 2023). This supports the case for further research in integration of research, knowledge management and human resource management in public agencies. This argument is also strengthened by the expectation of AI replacing entry-level white collar jobs first (Dillender and Forsythe, 2022), potentially reducing developmental paths by learning on the job in the near future. Using non-primary tasks like research assignments to develop new talent may soon gain even more importance.

2. Method

The first step in this research was developing a case for the contribution of research to knowledge continuity based on the literature and agency policy documents in relevant domains. RWS has attracted a diverse pool of researchers to work on their research needs at the storm surge barriers, supervised by academics from several universities. While preparing the study there was an opportunity to observe a key meeting discussing the future of the I-storm platform. The I-storm platform facilitates international knowledge-exchange between storm surge barrier managing agencies and various partner organization. It currently also facilitates multiple international research collaborations. To see some of the ongoing research at the agency in action two full-day sessions of focus group research conducted by another researcher were observed.

Next, a round of four semi-structured trial interviews was conducted. These interviews were held with one PhD researcher, one postdoctoral researcher, one research supervisor, and one senior research manager. These trial interviews were used to test the interview questions and get a better feel of the topic and the most pressing concerns relating to knowledge development at the agency. To get the best preparation for the main data collection, a thematic analysis (Braun and Clarke, 2021) was conducted on the interview transcripts. The narratives were coded using the initially included, largely literature-derived benefits as codebook. Groundedness and supportiveness of quotes were used to evaluate each benefit. This analysis revealed that the research programs do indeed develop engineering talent, but subsequent talent retention is suboptimal. This motivated deepening the research on talent retention, and to achieve this a more structured interview format including multiple-selection and scale questions was adopted.

Bozeman, Dietz and Gaughan (2001) point to the contributions research activity in organizations makes to human capital development. They concede, however, that measuring the value of this human capital contribution is challenging and must at least in part rely on interviews and questionnaires. They caution against relying solely on simple quantitative metrics such as salary development to assess the human capital value created. Following the recommendations of Bozeman, Dietz and Gaughan (2001), interviews were used to detail the contributions of agency research to knowledge and talent development. In addition, scale questions were used to provide measure for key outcomes.

For the main round of data collection, all the current researchers, research supervisors and research managers working for the Dutch storm surge barriers were invited. All managers and supervisors accepted the invitation. Among active researchers there were a few declines, mostly of researchers in the final stages of their project. Ultimately there were fourteen participants. The participant group consisted of six research managers and supervisors, three PhD candidates, one employed postdoctoral researcher, one Engineering Doctorate (EngD) researcher, two Masters of Science (MSc.) students and one Bachelor of Science (BSc.) student.

The research community of the Dutch storm surge barriers offers a valuable study opportunity of an intrinsic case (Creswell and Poth, 2018). Knowledge continuity challenges affect virtually all complex ageing assets within the RWS portfolio of assets, but the storm surge barriers are recognized as their most challenging case. They combine the most unique technical solutions with the highest demands for proving adherence to high reliability standards at all time (Kharoubi *et al.,* 2024; Mooyaart *et al.*, 2023). Because of the importance and visibility of the storm surge barriers, their knowledge requirements receive a relatively high degree of attention. It is therefore that the research programs of the storm surge barriers make a valuable intrinsic case for study as successes in assuring technical knowledge in this challenging case may provide lessons which can be applied to other less prestigious yet also complex public assets later.

Participants primarily contributed in-depth interviews ranging from just over an hour to two and half hours. A quantitative survey was added to the interviews to be able to visualize the spread of their opinions. This gives a reliable record of how they view their contribution to knowledge continuity of the storm surge barrier community, what more they would like to do and what impediments they experience. The questions can be found in Appendix A. Participants were asked to explain the reasoning behind their choices while completing the form, so that their responses could be reliably interpreted. The form started with a discussion of a simple flow-diagram of research process and benefits, followed by a self-assessment of the knowledge gained during the research period, using six scales. Also the supervising managers, employed by RWS, where asked to assess the knowledge level of their researchers with this form for comparison. This was followed by a multiple-selection question asking participants where they would like and expected to work after completion of their research, and one about the best follow-up to their research. More open questions were discussed at the end of the interviews.

Quantitative self-assessment of knowledge can yield unreliable results (Tracey *et al.*, 1997). To improve quality, results from the trial round were used to develop a semantic scale with five described levels. Participants used the five descriptions to compare their perceived individual knowledge to. This way, the five levels were used to provide 'anchors' on a twelve-point scale. This approach had some unintended effects. In the trial round, knowledge was described by participants in terms of 'able to talk on equal terms to the best experts available'. This approach appears to have been effective for individuals who view knowledge in such terms, but in the main round, it was discovered that people have different ways of assessing their knowledge compared to others. Some participants assess their knowledge mostly based on the length of time they have worked on a topic compared to others. Other participants assess their relative knowledgeability based on whether the agency itself employs experts in their field, and yet others indeed explain their self-ranking based on whether they can discuss their topic 'as equals' with experts in their domain. Discovering these different ways of viewing their own knowledge shows the value of having a discussion with each participant over their answers to the scale questions, and the interpretation of the results.

To validate research findings, the combined results were shared with all participants for review. The responses were analysed and have led to minor revisions. Additionally, results were also discussed with two knowledge managers from the Port of Rotterdam to receive an outside perspective from another asset management organization with critical infrastructure with long life cycles and consequently, long knowledge use gaps between major works.

The research was conducted within the Asset Management Research Group at RWS. The majority of interviews were conducted on-site. Interviews were divided over four RWS offices, located in the Dutch cities of Rijswijk, Eindhoven, Capelle, and Utrecht. Participants are, for the most part, clustered in four research topics: Formal verification (part of the international Stormsafe consortium), Synthesis-Based Engineering (also part of Stormsafe), Asset Management, and Digital Twins. The digital twins group is now mostly out of the research phase and functions as an expert group within RWS, which builds and advises on digital twins, and also advises on related research.

3. Results: Leveraging Research for Dynamic Knowledge Continuity

New research groups have been initiated for various reasons. Some were initiated because of repeated dissatisfaction with asset management project results. This applies to the groups concerned with developing better ways to re-develop and verify asset control software. Others were initiated because technological advancements were perceived to create new opportunities for asset management; the Digital Twins group is a notable example of this. Yet other research has started to develop knowledge to improve readiness for future challenges, such as changing storm seasons and associated maintenance windows. Existing local technical knowledge, partially centred around existing research groups, is essential for determining whether there are technological opportunities to structurally improve asset management project outcomes through research.

3.1 Research Contributions to Knowledge Continuity

From the responses of participants, we identified nine benefits of performing research for the knowledge continuity at the agency (Table 1). These benefits cover as well tacit, explicit, social and embedded knowledge.

Research will contribute valuable explicit knowledge for future challenges (benefit 1). By choosing real asset management challenges as domains for research, the researchers involved will get to intimately know the challenges, technical systems, and procedures. Some researchers will be hired to stay on after completing their research. Knowledge of challenges and systems will give researchers a significant head start to be able to contribute to solving these challenges professionally (benefit 2). Not every researcher makes a great fit for long-term employment within the government. Traits participants associate with a successful career at RWS are valuing the 'greater good' of society over money, thinking long term, and being 'a connector' who enjoys working with professionals from contracted firms and other departments. The agency can still benefit from research-acquired skills even if researchers are not hired, if they remain involved with the topic while working for a different employer such as a knowledge institute, engineering firm, or IT company. There are several examples of senior external consultants who started their involvement with the storm surge barriers through a barrier-related research assignment.

Research benefits three to nine are important but secondary. Although discussed with enthusiasm, no participant thought these secondary benefits on their own, were likely to significantly impact knowledge continuity. They create value, but are predominantly seen as a collateral benefit. They are each described in Table 1. The next sections will explore the current state and challenges with regard to the talent pool emerging from the research programs.

Table 1: Benefits of research for knowledge continuity

Benefits		Discussion
1.	Solutions to barrier engineering long-cycle maintenance challenges	Some research outcomes were very successful and immediately implemented, others required further development, and one case showed a seemingly promising idea unfortunately did not work. All cases give direction to future improvement efforts on the barriers.
2.	Talent pool with highly specific domain knowledge	Researchers working on unique knowledge domains, such as the one-off-a-kind drive units of the Maeslant Barrier finish their research period with knowledge only very few other people possess. This knowledge is internally classified as at-risk, mostly from retirements of older knowledge carriers. Through the research program a new generation of engineers becomes available for the long-cycle maintenance of the barriers.
3.	Finding errors in existing systems	Software oriented research has found previously unnoticed weaknesses in existing software, even though that was not the research goal. Improvements in software and its documentation are valuable to knowledge continuity.
4.	Highlighting missing system information	One researcher found system information to be incomplete. This will now be addressed before the actual redesign is commissioned. Research filling the gaps in system information can prevent delays.
5.	Learning by others	Focus group research and interview research provide a learning opportunity for their participants. Several participants noted that giving interviews about their work and experience in specific topics was a reflective experience. Focus group research brings people in the organization together to discuss meaningful challenges.
6.	Codification of existing practice	A researcher in the organization domain reported that through the research, the actual practice in the agency was documented in much more detail than in policy documents. Thus, a degree of codification of tacit practice was achieved.
7.	Tool development	Research has created several valuable digital tools. Digital twins especially have a multitude of uses such as (control) scenario research, testing of software modifications, improving the systems' documentation and educational purposes.
8.	Connecting organizations	Sponsoring research connects RWS with several universities and knowledge institutes. This provides access to the latest developments about how best to deal with barrier system obsolescence challenges. Research groups also bring together people from different barrier managing organizations and countries. These connections and collaborations provide benefits beyond

Benefits		Discussion
		direct research results. They also benefit continuity as the network becomes more robust and valuable external experts can be more easily located.
9.	Adapting to discipline developments for long-cycle maintenance needs	Sponsoring research, either directly or through larger consortia, provides opportunity to assure that research directions align with the long-term needs of the storm surge barriers and or other critical assets. Steering the direction of research may yield much more long-term benefits than the direct research results. All the research currently sponsored is directly linked to known challenges in the long-cycle management of critical assets.

3.2 Knowledge Self-assessment

The analysis of the trial interviews revealed that human talent development was perceived as the most important knowledge continuity benefit of the research program. The extent to which the research period matured researchers into knowledge carriers valuable to the long-cycle maintenance of the storm surge barriers was measured with a questionnaire. Participants scored a knowledge assessment form, and afterwards discussed why they had given particular scores, providing insight into the given scores. Researchers scored the form for themselves, whereas research managers scored it for the researchers they had recently worked with.

Six categories of knowledge were investigated, ranging from specialist domain to integral knowledge of the barriers' engineering, and covering both knowledge of the barriers as they are now to knowing what revisions to make to improve their future-readiness. McElroy (2010) stresses the importance of incorporating both storing and sharing existing knowledge as well as organizational proficiency in developing knowledge needed for new challenges in any comprehensive knowledge management program. At the storm surge barriers, the most challenging cases of knowledge use are maintenance projects at the barrier which also encompass (partial) design revisions necessary to keep the barrier aligned with changing demands and conditions (Kamps *et al., 2024a*). Because of the importance of being able to not only understand current designs but also adapt them to changing conditions we asked participants to rate both (existing) domain knowledge and ability to revise it. Major projects require knowledge at the system-specialist level as well as at the systems-integrator level (Whyte and Davies, 2021). To see whether there might be major differences with regards to the development of specialist versus integrative knowledge we mapped this on a three point scale. Mapping both current domain vs revision ability and specialist to integrative knowledge lead to the six categories used. Below are the six categories as they were described on the form.

SD	Specialist domain barrier knowledge (research topic)
ID	Intermediate domain barrier knowledge (discipline associated with the research topic)
WD	Integral (wide) domain knowledge of the barrier as a whole, detailed interactions between barrier systems
SR	Specialist domain revision strategy
IR	Intermediate domain revision strategy
WR	Full barrier(wide) revision strategy

The participants were divided into four groups, as shown in Figure 1. The groups are labelled as:

- R-Phd: researchers doing their PhD and assessing their own knowledge level (n=5)
- M-PhD: managers (domain experts) from the RWS organisation, co-supervising the PhD researchers and assessing the knowledge level of their PhD's (n=5)
- R-M: master students working on their graduation research and assessing their own knowledge level (n=3)
- M-M: managers (domain experts) from the RWS-organization co-supervising the master thesis students, and assessing the knowledge level of their master thesis students (n=2)

These numbers do not exactly match the number of participants in the study. Some managers filled out for two rather than one recent student and two participants did not answer this question.

The scale that was filled out by participants, ran from 0 to 12, and had the following descriptions attached to the scale on how one would describe the knowledge level of oneself and other researchers in terms of knowledge development relative to incumbent engineers:

0. Just saw the barrier for the first time
3. Junior system specialist, 1-2 years at the barrier
6. Senior system specialist, 3-8 years at the barrier
9. Recognized system expert, 8+ years involved with the system, leading role in construction or major revision
12. Full knowledge, can do any task or answer any reasonable question

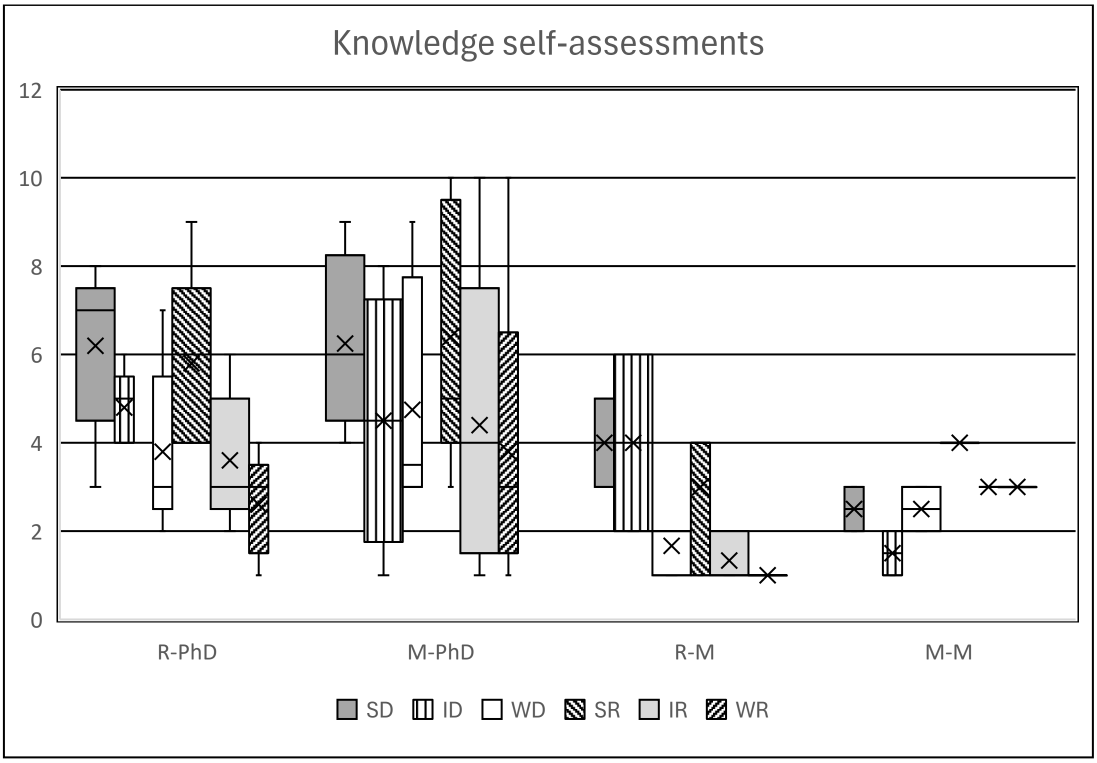

Figure 1: Box plots of knowledge (self)-assessment of researchers and research managers

Results in Figure 1 show that the mean values between researchers and supervising managers are similar; however, the scores given by managers show higher variation. The high variability in responses can generally be attributed to participants choosing different ways to score the scales. One manager and one researcher explained the high scores they gave by explaining that within their domain, there are currently no others at the agency with more knowledge about the topic. Another manager gave high scores because the researchers they supervised were observed talking on equal terms with senior experts about the most complicated details of the system they worked on. One manager who gave low scores explained that PhD research faces stiff demands in terms of scientific rigor and specialization, leaving little room to learn about the broader engineering aspects of the barrier during the research period. Some researchers preferred not to rate their ability any higher than the number of years of experience mentioned at the corresponding point of the scale. They would explain 'at the end of my PhD, I will be four years in, and then counted two points up from the 'Junior specialist, 1-2 years at the barrier'. Multiple managers gave high scores for the 'revision strategy decision making' scales because they explained the (PhD) researchers that they supervise know the latest technological developments better than almost any RWS professional. When researchers and managers gave low rankings for revision strategy decision making, they explained this in terms of a lack of organizational knowledge about what will actually be feasible and work within the RWS context.

Reflecting on the approach for this question and its results, we notice that while we intended to measure professionally applicable knowledge, the answers are actually a compound of two concepts. We believed that because the storm surge barrier engineers are a small community, it would be practical for participants and the interviewing researcher to agree on who would be good examples in their domain for the junior, senior and expert levels used in the scoring system and then accurately score the question. A careful read of participants recorded explanation of their given scores however shows that the way we presented the question caused both managers and participating SSB researchers to include aspects of organizational socialization (Bauer and

Erdogan, 2011) in their answers. Perceived limits to the achieved organizational socialization explains most of the lower scores given. Taking this into account, it can be concluded that researchers are considered to have reached high levels of specialist domain knowledge within the research period, comparable to and sometimes exceeding incumbent engineers. Several managers also expressed they value input from researchers on barrier design revisions. In order to fully reach researcher's potential and apply their knowledge to the benefit of the organization, they may need to be able to give their input in a setting of existing technical know-how and support with regards to organizational socialization.

3.3 Post-research Scenarios for Employment

Researchers were asked where they would provide the most value to the long-cycle maintenance of the storm surge barriers post-research (Best), where they would like to work (Preference), and where they expect to work after research completion (Expectation). Managers filled out for one or two researchers they recently worked with. This results in the five categories shown in Figure 2:

- R-B: what researchers think is best for the barriers (where researchers think they should work after completion of their research)
- R-P: what researchers prefer (where researchers want to work after completion of their research)
- R-E: where researcher expect to work after completion of their research
- M-B: what supervising managers think is best for the barriers (where should the researchers work after completion of their research)
- M-E: where managers expect their researchers to work after completion of the research

The 'preference' question for the supervising managers was omitted as their perception of the researchers' preference is not relevant for the research objective of this study.

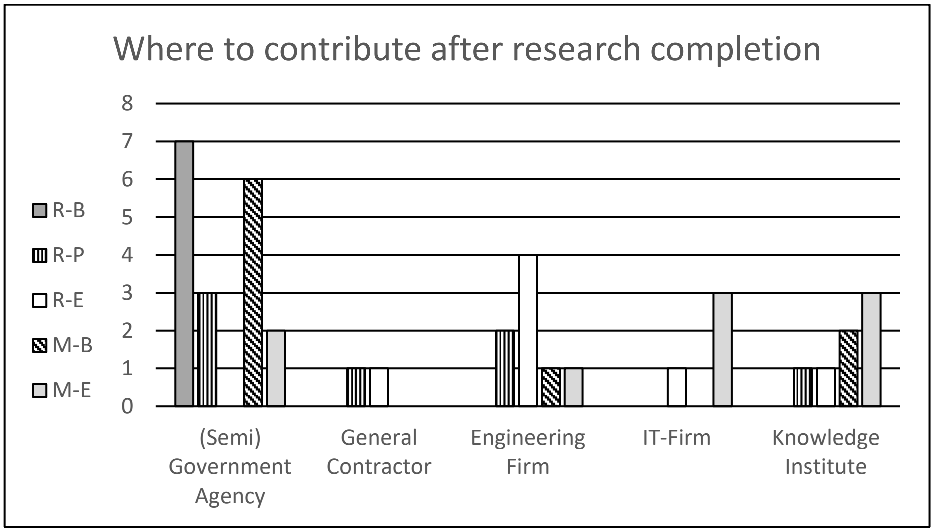

Figure 2: Post-research employment scenarios

All participating researchers scored being directly involved with locally implementing their research as the most valuable follow-up their research could have. The managers have a bit more nuanced view, and several explained the value of having consultants with knowledge of barrier systems at partner firms. Researchers who did not wish to work at the agency (made a different choice for R-P) provided the following reasons: the 'meeting culture', a lack of opportunities for technical work, and uncertainty about research-topic related employment opportunities. One former researcher who is now agency-employed enjoys being given a lot of responsibility and making high-impact decisions based on his expertise. Two managers gave separate accounts of researchers who started at the agency post-research but left soon because they were mostly handling unrelated urgent technical issues. Overall, the results indicate a strong desire to undertake more research-related technical work locally, which is also a recurring theme in the given narratives.

Being considered an innovative employer improves hiring success (Jones, 1996). The absence of substantial local implementation work appears to currently limit the attractiveness of the organization as an employer in domains that matter to the researchers at the agency. Researchers and managers explained that although conducting research-related work while employed outside of RWS is attractive, it is currently very difficult to find outside employment where they are confident that they will be able to continue working on their topic of choice.

Participating researchers explain that during the start of their professional career, they have a strong preference for doing technical projects themselves over managing design assignments contracted elsewhere. It is worth considering the career paths of those researchers that do not choose to progress into managerial or advisory roles but for whom no opportunity for further technical employment is desirable or feasible. Capacity building in partner organizations, which was suggested by several managers, can for example be achieved by initiating technology-centred rotating traineeships as an alternative to the current management and organization centred offering. This way researchers can experience working in their domain of choice at partners and suppliers and potentially find prolonged involvement. Research into this possibility is currently under way.

3.4 Next Steps for Research Outcomes

Participants were asked to indicate what should happen with their research topic after they were done, and they could award either three, two, or one point for an option and Figure 3 shows the number of points awarded. The first three options are indicated with an 'I'. These are options for direct Implementation of research outcomes, either by a local team, by another organization, or by developing policies or standards based on the research outcomes. The last three options are indicated with an 'R'. These are options for further Research, either at the agency, other organizations in the distributed knowledge network or by academia. Results show a clear preference for local research and implementation, which is shared by both researchers and managers. This is consistent with the R-B and M-B scores given in the previous section.

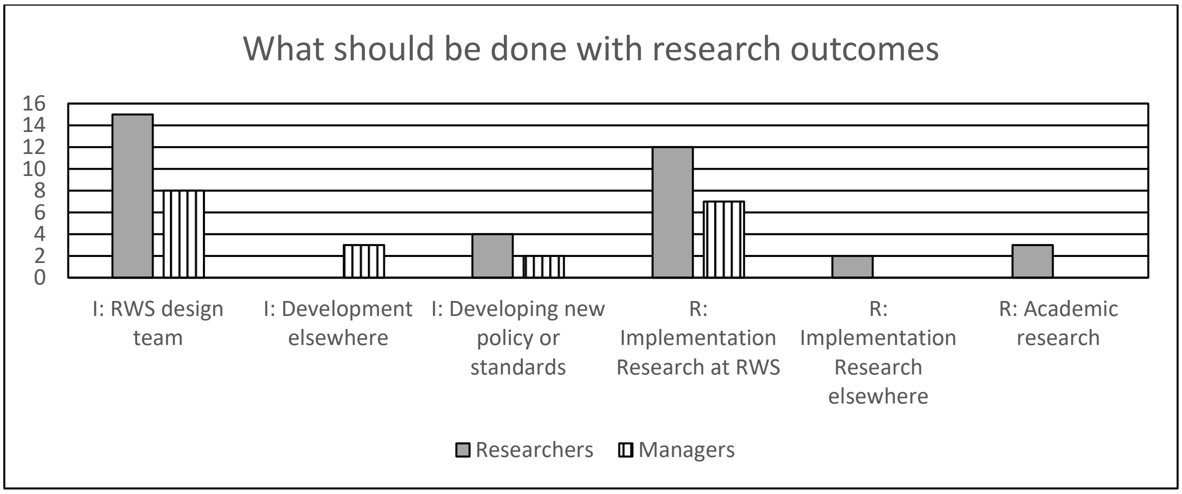

Figure 3: Preferences for further development of topic, points given

4. Discussion

4.1 Rebuilding Local Engineering Capacity for Long-term Continuity and Task Readiness

The most talented engineers want to be directly involved in building things, and often have a stronger attachment to their technical craft of choice than to their employer (Glen, 2003; James, 2002), which was also confirmed during the meetings with participants. Following the 2004 launch of the far-reaching outsourcing policy of 'market unless' (Brink, 2009; Rijkswaterstaat, 2004), RWS moved away from its technocratic roots and became oriented on network and asset management. As outsourcing maintenance and design work became the new standard, some engineering capabilities were lost, and RWS currently has limited in-house engineering and IT delivery capacity. Bringing back local expertise after it has been outsourced is a challenging and lengthy effort (Mazzucato and Collington, 2024). While limited opportunities to locally develop technical designs and solutions were a frequently heard observation among participants, all who have been with the agency for more than a few years report that the situation is improving. To further improve attractiveness to technical talent, RWS will need to invest in creating a more attractive work environment for them. To achieve this, the agency will need to insource technical development work, at least for a portion of the work in strategic domains, as described in Paragraph 1.2.

RWS currently has reliable suppliers of knowledge processes, such as engineering and IT, in several domains that it previously handled in-house. Historically, there have however been missed opportunities with regard to uniformity or standardization of work delivered, such as software built for comparable purposes by different partners being dissimilar in setup. Without strong and technically competent internal guidance and leading by example, vendors can adhere to their own standards and preferences, resulting in variability of technical systems beyond what is desirable for knowledge continuity and long term asset sustainment. Improving uniformity in solutions is currently addressed through the agency innovation policy. The policy framework is called IUP, or Innovation, Uniformity, and Production, conceptualized as three subsequent steps in the innovation process. Given the importance of achieving technological uniformity across systems and components within the portfolio of assets (Kamps *et al.*, 2024b), there is a strong case for uniformity as the central theme in innovation policy. The innovation policy is relatively recent, and a renewed focus on uniformity can be expected to benefit future knowledge continuity and asset management, especially when coupled with a focus on standardizing system data (Nezami *et al*., 2022). Research programs typically precede or reside in the 'I' phase of the IUP protocol. In the present set of fifteen policy documents on the RWS network about IUP, there is no explicit mention of using innovation efforts to develop human capital. This signals the agency does not (yet) view its innovation program as an opportunity to attract or retain technical talent alongside the important push for uniformity of systems.

Once local expertise is rebuilt, this will be reflected in more favourable knowledge continuity base, resulting in a reduced need for investment in the knowledge domains that have improved through research and/or partial insourcing. Due to the temporary nature of peaks in knowledge demand driven by technological and environmental changes, future investments will likely be necessary in different domains or disciplines than those currently receiving investment. Participants estimate that work on updating and replacing the control systems across the entire RWS portfolio may take approximately 15 to 20 years, during which there will be sufficient work to support a dedicated asset control system development group locally. This will support both innovation goals (uniformity), knowledge management goals (continuity), research quality (supervision and direction), and research-work transition (clear starting point for new hires).

4.2 Dynamic Knowledge Continuity Graphed Over Time

We learn by doing, and knowledge which is not being used will eventually not be readily available in people's heads. This implies a potentially quantifiable relationship between supply and demand of knowledge. At the storm surge barriers domain-specific technical knowledge will be in high demand during the design phase. During regular maintenance and operation it will be much lower, but will rise again during system upgrades or redesigns that need to address technological or environmental developments. To construct a graph of knowledge demand over time, we selected the general shape of the Paulson curve (Paulson, 1976), because it is an empirical distribution of design effort over time. Redesign efforts are typically no less difficult than initial design, but the total amount of work is (ideally) less (Anquetil *et al*., 2007). The redesign knowledge demand peak is plotted for a quarter of the time of the initial design and is placed at a point in the future, visualizing a long-cycle redesign effort.

Assuming that knowledge supply will follow demand but some knowledge will be lost per unit of time, we can calculate an associated supply-curve. This has been done in Figure 4. The supply curve is derived from the demand curve by the following formula:

$$S_i = \Delta t \cdot D_i + (1 - A)D_{i-1}$$

Symbol	**Meaning**
S:	Knowledge supply
D:	Knowledge demand
Δt:	Timestep
A:	Rate of attrition

The rate of attrition A was set to 0.2, roughly corresponding with a five-year average career at the agency. This is pessimistic compared with overall career lengths, but a reasonable estimate for the more recently hired engineers. Plotting over time, the supply curves of Figure 4 are found. To the right of the graph, it can be observed that due to the shorter timeframe of the redesign, a larger gap between knowledge demand and supply is exhibited compared to the initial design. Having to make difficult redesign decisions with limited remaining knowledge can lead to suboptimal outcomes (Kamps *et al.*, 2024a). Having a research program in the same knowledge domain preceding the redesign period can help to rebuild critical knowledge just-in-time for a challenging effort. This reduces the demand-supply gap (dashed lines).

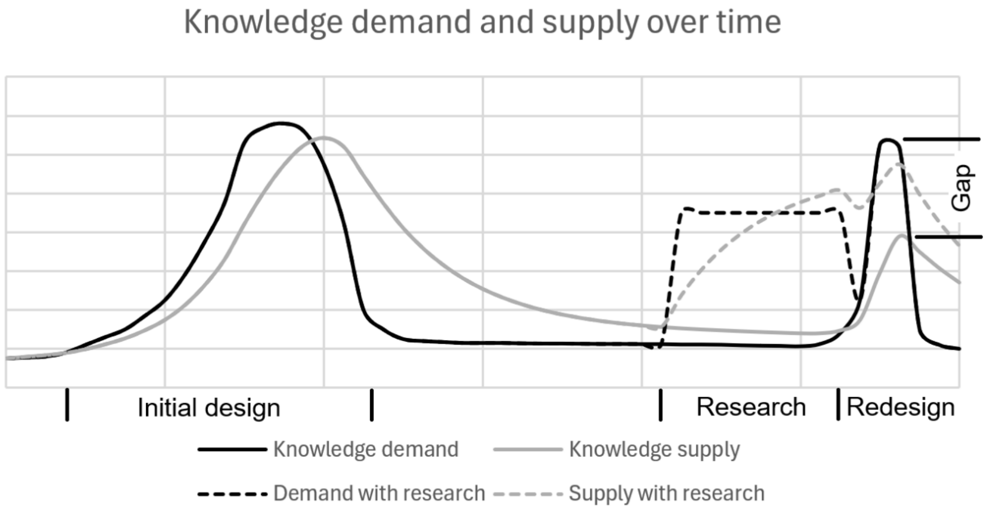

Figure 4: Knowledge demand and supply between initial design and redesign

For actual research programs to have the assumed effects, the research must be practice and implementation-oriented. This was stressed several times by senior research managers and supervisors participating in the study. It is also essential to achieve continuity of individuals associated with a task. Part of the knowledge development during the research phase will inevitably be tacit knowledge gained by the researchers. Even though research-developed knowledge is externalized in the report, as people will know much more than they wrote down or can tell (Nonaka and Takeuchi, 1995), most of the knowledge gained will be lost if only the report is passed on. By allowing researchers to continue through the uniformity and production phases of innovation, research benefits can be maximized. The total contribution of research can be increased even further by taking the potential benefits of research listed in Table 1 into active consideration during the planning phase.

4.3 Leveraging Research for Dynamic Knowledge Continuity: Decision Making

Since the 1990s RWS as a whole is oriented towards network management and is procurement oriented with regards to most engineering rather than considering itself a technical specialist (Vinke, 2013; Brink, 2009; Rijkswaterstaat, 2004). Most engineering knowledge being distributed with partner organizations leaves knowledge continuity of unique systems vulnerable (Kamps *et al.*, 2024a). To rebuild strategic expertise internally and develop a higher degree of internal knowledge for the storm surge barriers than is customary for the rest of the asset portfolio, a decision making framework is necessary. Figure 5 shows a decision-making process which involves considerations of knowledge, innovation, research and staffing, and reduces each decision to a yes/no junction. It was developed using the discussions of the flow-diagram image shown as conversation-starter in the main round and can be found in Appendix A. Here for example one manager explained that organizational needs are important drivers of research, but enthusiasm about new opportunities like digital twins and AI are important too for gaining the necessary momentum in getting new research approved. Another manager explained that RWS should not strive to do all research relevant to it internally, and collaborations and making contributions to research elsewhere can be much more cost-effective. A third manager explained that the bar for deciding to start an internal execution group is rather high and this is only decided on when there are no real alternatives but the task is still very important. These and other insights were collected in a visual format resulting in Figure 5, because they add an important dimension to the realizability of capturing human capital flowing out of the research program. Visualisation has been shown to improve understanding and decision-making in complex managerial contexts by making relationships explicit, and swim-lane diagrams in particular are recognised tools for clarifying responsibilities (Jeyaraj and Sauter, 2014). Although the diagram does not do justice to the full range of considerations involved, it was validated with participating research managers. They confirmed it captures the basic structure of how knowledge- and innovation management goals of continuity and uniformity can guide investment in research and expertise.

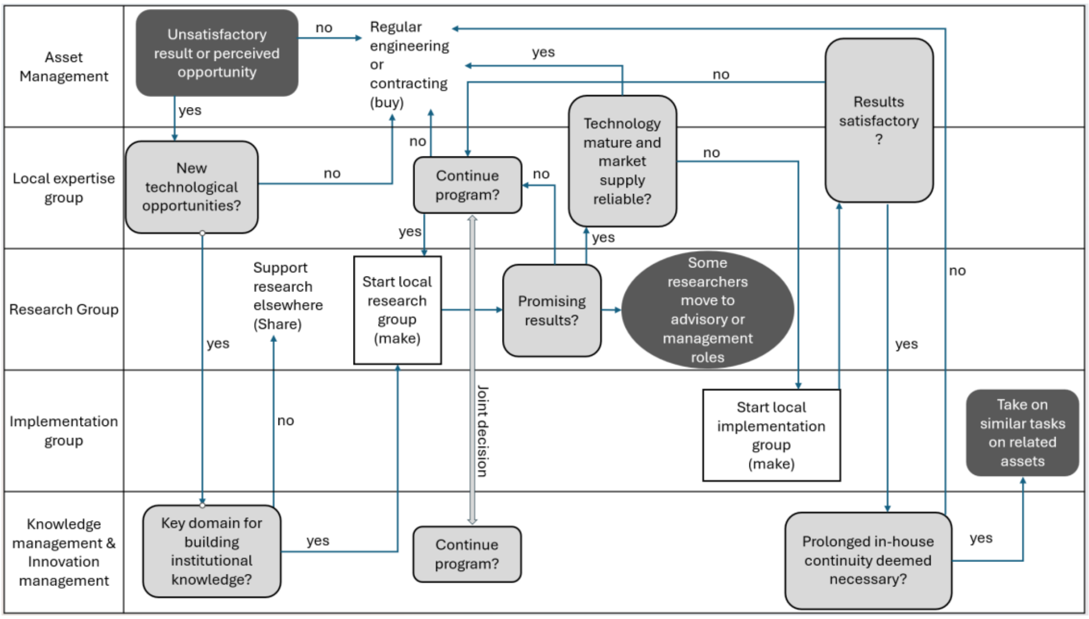

Figure 5: Swim Lane Diagram of applying research programs for knowledge continuity

5. Conclusion

5.1 Contributions to Theory

Knowledge continuity management was re-conceptualized from a steady-state organizational management function to one that triggers knowledge (re)development in time for the demands of asset management. Figure 4 shows that for redeveloping unique infrastructure, the gap between knowledge supply and demand during redesign decisions will tend to be more pronounced than for initial design. A well-developed research program can alter this dynamic and support the necessary knowledge buildup for redesign ahead of time.

It was shown that researchers develop valuable knowledge during their research period (Figure 1) and are highly motivated to locally implement their research results (Figures 2 and 3). Human capital was identified as the most important value created by the research function in an asset management agency, and several conditions for fully benefiting from developed human capital were identified. The effects on knowledge supply for future challenges were conceptually mapped in Figure 4.

Knowledge management and innovation management goals of continuity and uniformity can both be advanced by forming strategic expertise groups of former researchers and insource work for key knowledge domains. The strategic management decisions for starting research groups and local implementation were developed into a swim lane diagram (Figure 5). This demonstrates how research and innovation considerations at an asset management agency can be leveraged as a decision tool to integrate research management, innovation management and knowledge management.

5.2 Recommendations for Practice

The advent of substantial, well-connected and organized research groups positions RWS at the forefront of several key areas, where RWS should aspire to lead in knowledge development, implementation, and standardization. Continuing these programs will enable the agency to continue to develop its core competence as manager of complex and critical infrastructure networks. To reap the full benefits of these new successes, the agency also needs to strategically invest in local implementation capabilities associated with the most important avenues of research. These local expertise groups with practical implementation experience will provide a valuable starting point and support for young professionals who stay on after their research.

Opening and promoting post-research job opportunities that provide the most value to the agency should become a priority. Ideally, potential post-research professional opportunities should start to be developed as early as the planning stage of research, both within and outside the organization. One way to facilitate continued involvement with knowledge domains within which expertise was developed during the research period would be for the agency to provide a traineeship which rotates over RWS and partner organizations working with the same technology. This is expected to be more attractive to technical talent than the current internal and organization-centred model.

5.3 Limitations and Recommendations for Future Work

This study was conducted as a case study within a small research community focused on Dutch storm surge barriers, which limits the generalisability of the findings. Future research could broaden the scope to include larger populations responsible for managing complex but more common long-lived infrastructure, such as locks, tunnels, movable bridges or military systems. Key findings in this population are rapid technical knowledge development and high motivation coupled with limited organizational socialization, and high attrition of human capital due to limited follow up opportunities after research. Studying related groups may reveal whether these opportunities and challenges with leveraging research programs to improve knowledge continuity observed reflect wider patterns in the management of long-lived complex assets. Further work is also needed to determine how career pathways can be supported in ways that most benefit the continuity of knowledge in the wider distributed-knowledge system when long-term employment within the relevant public agency is limited. In addition, future research could focus on quantifying and modelling the relationship between supply and demand of domain-specific knowledge and notable events in asset management through systematic data collection. These steps would enable more robust validation of the conceptual model and support the development of an evidence-based and integrated management of knowledge continuity, innovation, strategic staffing and research programming.

Ethical statement: All interviews were conducted on the basis of informed consent obtained prior to participation. Written consent was secured after discussing the scope of the study and potential identification risks with participants. Participation was voluntary, and participants could decline to answer any question or withdraw from the study at any time. All participant contributions were anonymized, and all participants were provided with the full manuscript for review.

Use of AI and AI-Assisted Technologies: Generative AI tools (OpenAI's ChatGPT and Microsoft Copilot) were used during manuscript preparation to support literature exploration, language refinement, and proofreading. All sources identified with the assistance of AI were read and evaluated by the lead author prior to inclusion, and all AI-generated suggestions were reviewed, edited, and applied at the authors' discretion. The authors take full responsibility for the content of the publication, including the interpretation of sources and the conclusions drawn.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix A: Research Benefit Questionnaire

Table A1: Added benefits questionnaire

Topic	Questions
Introduction	**What research are you currently doing, supervising or managing?**
Activation of critical domain knowledge	Does your research involve working with any vulnerable knowledge (knowledge associated with a sustainment-critical domain that few people have a deep understanding of)
	Does your research involve studying documents, code or artifacts from critical infrastructure that you believe may have been untouched or rarely used for 10 years or more? Please explain?
	Did you interview people or were taught by people about their achievements designing or modifying critical infrastructure or its support systems from 10 or more years ago? Please explain?
Connecting organizations	What organizations are involved?
	Whom are the key people involved around the research (no names necessary, role, job description, knowledge discipline and organization. E.g. supervisors, participants)
	Has the research led to meaningful conversation, or do you even know of a follow up meeting between participants outside the research?
The researcher as future expert	Do you think you will be involved with this task yourself?
	What factors are important in determining this?
	Is it also as you would like to have it? Do you feel in control here?
	Do you agree with the statement 'I could make the contribution I want to make'
	Do you think anyone else associated with the research has a moderate or higher probability to be involved with such task themselves? If so, what is their role?

Topic	Questions
Introduction	**What research are you currently doing, supervising or managing?**
Learning by others	Do any of your research activities offer meaningful learning experiences? Example focus group sessions with experts whose time is very limited, system tests, expert feedback on proposed domain-specific solutions? To what extent do such sessions also facilitate learners / juniors? Do you see any specific group of people well suited to benefit from such learning experience?
Tool development	Does your research generate data or tools separate from the primary report?
	Who has access to these after the research, and how are they stored?
	Will these reach their full benefit for sustainment of critical infrastructure? If not, what could be improved to increase that?
Codification of existing practice	Does your research generate descriptions of previously tacit practices?
	Who has access to these after the research and how are they stored?
	Will these reach their full benefit for sustainment of critical infrastructure? If not, what could be improved to increase that?
Improved integration of codified sources	Do you or are you supposed to quote only or primarily public sources in your research
	Do you or could you also use proprietary domain documentation, artifacts or code as sources?
	Are these quoted or listed with the same diligence as public (scientific) sources
	If they are, where or how is this documented?
	Do you see any potential to improve the impact of your work to connectedness and navigability of proprietary explicit domain documentation?
Discipline wide impact and leadership	How are the goals in this line of research agreed upon? Is any party clearly 'in the lead' with regards to the goals of the line of research?
	What party do you perceive as 'leading the field' or the discipline?
	Does the field move in a direction favourable to support of long term sustainment of critical infrastructure?
	Do you think publicly funded research makes or could make a meaningful contribution to the development of your field to facilitate long term sustainment and life cycle of critical infrastructure?
Application to upcoming sustainment challenges	Are you aware of your research being intended or designed to contribute to a specific future task or set of tasks?
	If not, can you imagine it contributing to any major sustainment effort (maintenance + updates, upgrades and redesigns)
	Was there any possibility / potential to better associate with an upcoming sustainment challenge of the storm surge barriers? Was this in any way considered as far as you are aware?
Closing questions	The nine categories of the potential added value that research can have on knowledge continuity for critical infrastructure. As a person involved in infrastructure sustainment related research, what is your first impression of the added value investigation?
	Is there something you would like to see included?

Table A2: Comments, sources and groundedness with each topic

Benefit in Initial questionnaire	Comments and sources	Grounded ness
Activation of dormant critical domain knowledge	This idea is mentioned in Kamps *et al.* (2024a). This happens often but is a contributing activity rather than a benefit. See also the paragraph about 'reconsidering what constitutes research benefits' further in this appendix.	g12, 10s
Connecting organizations	Interpersonal connections between individuals improve knowledge sharing between organizations (Reagans and McEvily). The supportive quote in the preliminary interviews however is about several former RWS researchers later doing valued work as external consultants.	g8, 1s

Benefit in Initial questionnaire	Comments and sources	Grounded ness
The researcher as future expert	Bozeman, Dietz and Gaughan (2001) explore human capital development as a key research benefit. This is the most widely recognized benefit with participants, and also the one participants expect the most from. This is why the subsequent main round included additional questions to investigate the topic further.	g20, 12s
Learning by others	We expected there may be significant learning effects by professionals contributing to the research, for example the supervisors. Learning effects in supervisors have been studied, for example by Halse (2011), but this focusses mostly on supervision skills rather than improvements in their content knowledge, which we were most interested in. While there are several quotes supporting learning by others, none of the supervisors reported major improvements in their own content knowledge.	g14, 7s
Tool development	Research resulting in a working digital twin of the Maeslant barrier had just been completed (Ponsioen *et al.,* 2023). This got us interested in tool development by the research program. Most examples found are digital twins built for different purposes. Internal research on control system twins started much earlier than operation-visualising and information-ordering twins, and they are now in professional use.	g4, 3s
Improved integration of codified sources	Large digital archives can present significant challenges to effective use (Hawkins, 2022). Documents interconnected by citations are more navigable as they enable seed-based search practices such as snowballing (Sjögårde and Ahlgren, 2024). This sparked interest in potential improvements in navigability of the archived by the increased research activity working with and citing RWS documents. The only quote supporting better navigability however is from digital twin research, where many documents can be linked to the digital twin which increases structure and connectedness of documentation. It is probably too early to notice any improvement through citation activity. This benefit was dropped as there was insufficient supporting evidence.	g9, 1s
Discipline wide impact and leadership	Mazzucato and Collington (2024) explicitly advocate for public agencies taking a leading role in developing the knowledge domains most essential to them. The benefits of advancing knowledge domains to best support the idiosyncratic needs of the storm surge barriers are well recognized, in particular in the domains of decoupling control software and hardware for the security and automation of the barriers	g17, 12s
Application to upcoming sustainment challenges	This was included because some research topics deal specifically with challenges posed by climate change. It is already well embedded in RWS research planning practice. The main concern raised is that in current practice, results often come in at a later date than when they are needed for asset management practice.	g10, 4s
Codification of existing practice	From preliminary interviews. A participating researcher in asset management explained that existing written policies, handbooks and guidelines did not fully cover the way asset management practitioners handle their tasks. Research resulted in improved professional descriptions of procedures.	
Finding errors in existing systems	From preliminary interviews. A participant from the control systems domain explained research aimed at modernizing control systems found errors in parts of the existing code. Much of the control code is for dealing with (combinations of) partial system failures that have never happened. Research for control system modernization has elicited previously unnoticed errors in these difficult to assess parts of the control code.	

Reconsidering what constitutes a research benefit

One of the most well-grounded initially included benefits, mentioned in Kamps *et al.* (2024a) is activation of dormant critical domain knowledge. Thematic analysis however revealed that the initial list included both beneficial outcomes, and activities leading up to them. While activation of dormant knowledge is intuitive, as evidenced by research managers explicitly asking for it when it no longer appeared during the main interview series. It is however an activity that leads to benefits, not a benefit in and of itself. The actual benefit is already included in 'Learning experiences by participants' and 'the researcher as future expert. The beneficial outcome is knowledge gained by participants, for example due to reflection on their work caused by in-depth interviews questioning it, or gained by the researchers and brought into the organization if and when they transition from a research- to a professional role. In the same way adapting to upcoming challenges is a key goal of the research program, but the solutions it finds is the benefit.

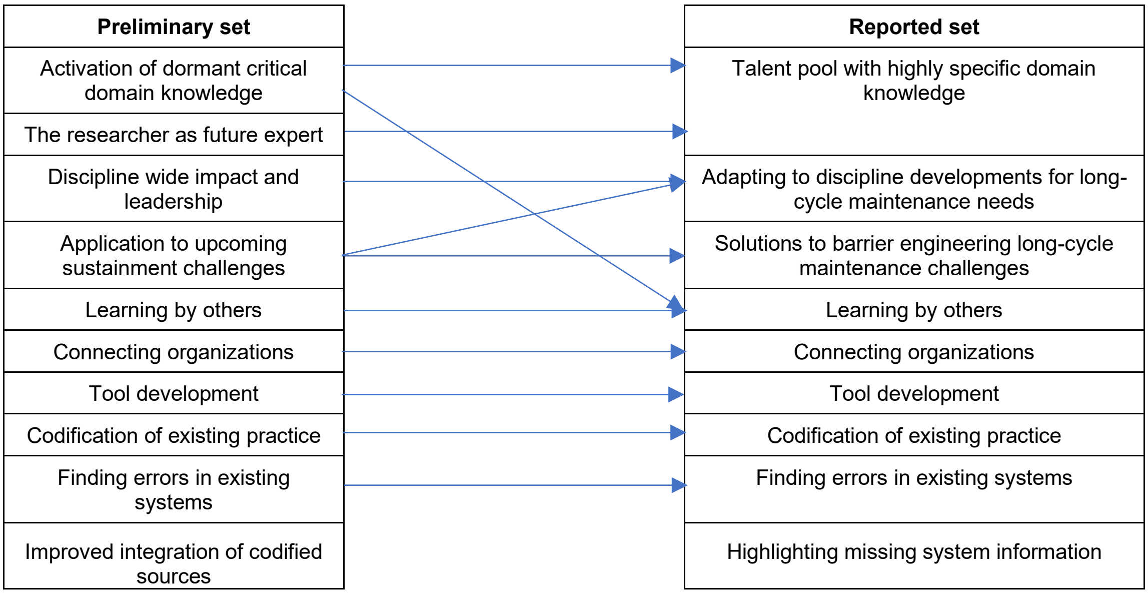
Other changes in the list

The main round of interviews resulted in surprisingly few new examples or insights not found in the preliminary round. The only really new benefit found was from the single participating Bachelor student. His research revealed serious limitations in the (technical) knowledge readily available to him for his research. This resulted in an effort to (professionally) gather and redevelop this knowledge to be able to further his topic. Because there were few new examples or benefits of the agency research programs, the thematic analysis was not repeated.

Mapping

The research benefits from the initial questionnaire are mapped onto the final set in Table 1 in the article. The order in the lists have been rearranged for uncluttered arrangement of the arrows.

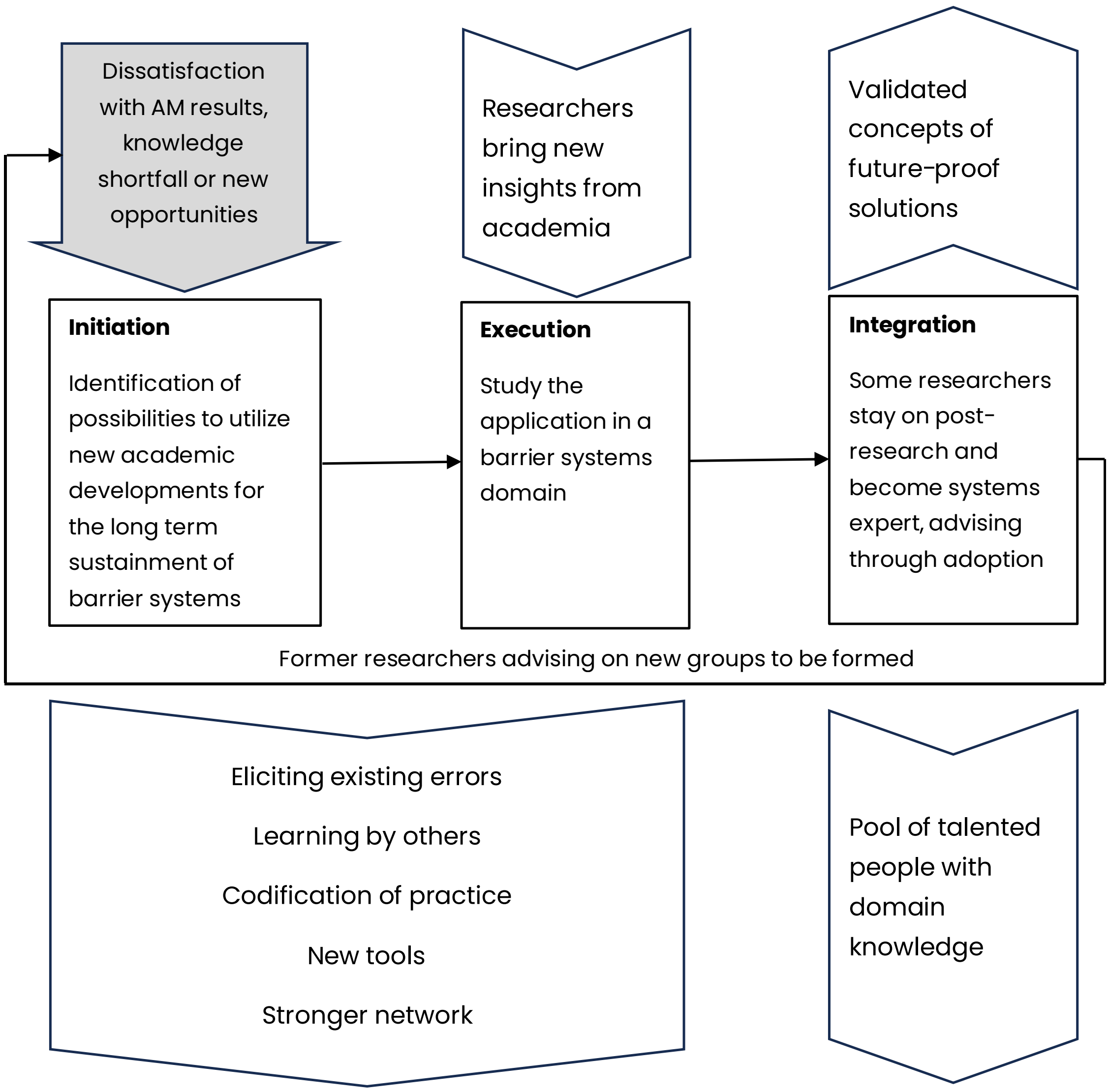
Table A3: Mapping of the research benefits in the questionnaires to the reported set



Main round added questions

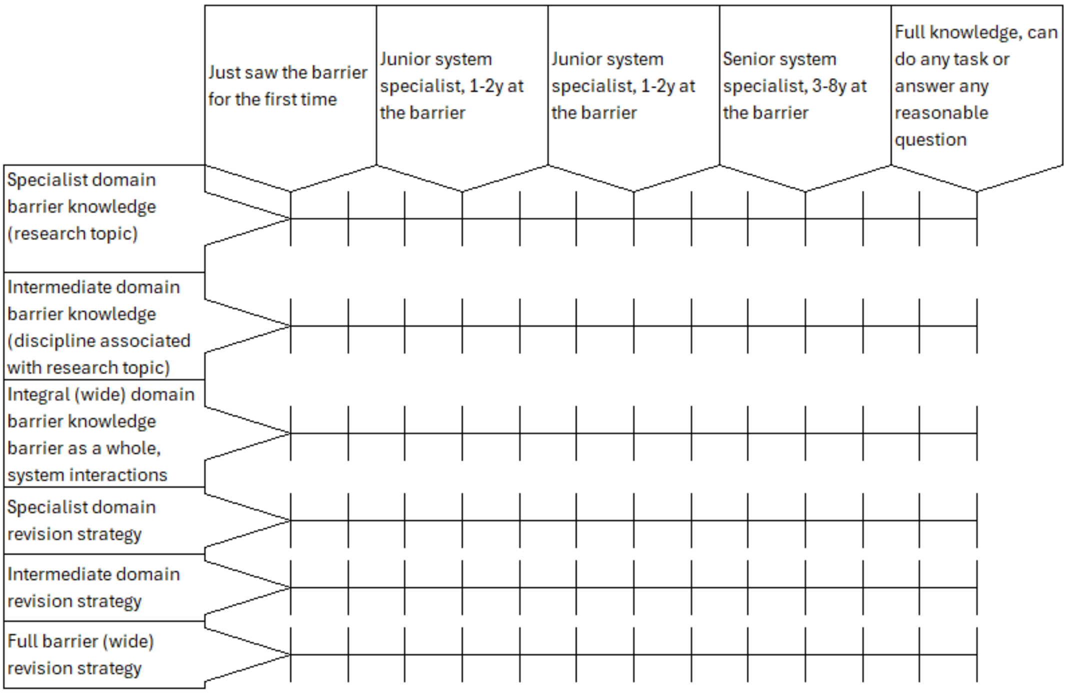
Q1: Flow-diagram of agency-research and its benefits

Participants were asked to comment on the flow diagram and the benefits to the agency during and after research (diagram adapted for size)



Q2: Research as future expert, current knowledge self-assessment

Participants were asked to estimate their knowledge in the given domains and indicate this on the form.



Q3: Researcher as future expert, post research employment

The bar below shows five post-research employment situations. Please write in the bar an E, a P and a B.

- Put the E where you expect to work
- Put the P where you would prefer to work
- Put the B where you think would be best for the barrier

(Semi) government agency	General contractor	Engineering firm	IT-firm	Knowledge institute

Q4: Implementation of research findings for knowledge continuity

Note: The 'organization' options were dropped from the graph in the report for readability and the number of points given to these options were low.

What is the best way to implement the findings / results of your research to benefit barrier reliability and maintainability.

Best immediate next step Pick and number 3 options. Write 1 for best option, down to 3. (Pick no more than one from the continuous bars)

More involved ←	Engineerting team at RWS, self-development & implementation of solution	Guided development elsewhere (involved guidance)	Development of new (design) guidelines / policies	Less involved →	(Implementation options)
	Local implementation oriented research	Implementation oriented research at other party	More academic research		(Research options)
	Increase workforce at....(department)	Start support team / expert team / community of practice	Improve process at RWS (which one)		(Organization)