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Engineering challenges of intrafirm technology reuse

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Abstract

Companies derive additional value from technological investments by repeatedly applying them across different product lines in their portfolios. Technology reuse strategies have helped to increase efficiency in leveraging research and development investments, but the attempts to explain how to duplicate such results for technology reuse at the engineering level are missing. While there are synergetic effects to the reuse of technologies, there are also transaction costs that limit the benefits in practice. This paper presents a model, along with three examples, of technology reuse to help account for these transaction costs and mitigate the fallacy of perceiving technologies as reusable “off-the-shelf” elements.

KEYWORDS

technology development, technology reuse, technology transfer

1 | INTRODUCTION

A natural way for companies to leverage their investments in research and development (R&D) is to reuse product architectures, components, manufacturing equipment, and technologies between different product lines, or from one generation of products to the next. The knowledge gained from one development project can then be reused to avoid repeating similar design tasks and help reducing both cost and development time, while at the same time improving the robustness of the solutions by building upon previous experience. Though the strategies connected to reuse of physical artifacts tend to be highly successful and generate higher profitability and prolonged lifecycles,¹ the same cannot be said about the reuse of technological knowledge within engineering firms since this has been measured to fail in 50% of the time.²

Possessing the capability to use a technology appropriately in the development and manufacture of a product can be highly valuable to companies. Hence, companies invest vast amounts of resources in developing new technologies and refining existing ones, expecting to get a return on their investments by selling more products or reaching higher profit margins.

Previous research has provided insights into how product development can be conducted in ways that help companies reuse product architectures, components, and design concepts across applications by means of “product platforms.”^{3,4} Another stream of research

has praised the potential benefits of systematically reusing technologies across applications rather than components, commonly referred to as “core competencies” or “technology platforms.”^{5–9} However, it has mainly been focusing on the business and strategy level and has not yet been reaching the engineering level to show how such strategies can be realized in practice.

Engineers intuitively exploit opportunities for reusing previous results when pursuing new development, but to do so systematically remains a challenge. Research in engineering design is in agreement with strategic management research showing that a formal, instead of ad hoc, approach to reuse of capabilities can provide additional leverage on investments in development (eg, Refs. 5, 10, and 11).

Activities on an engineering management level that are credited with supporting both design reuse in general and reuse of technologies in particular include: deciding when to invest in developing reusable assets, identifying which knowledge assets a company has available for reuse, classifying assets, creating organized libraries of reusable knowledge, and assessing the options that exist for reusing assets and their feasibility.^{10,12–14}

A “technology” can be defined as “the theoretical and practical knowledge, skills, and artefacts that can be used to develop products and services, as well as their production and delivery systems,”¹⁵ or more simply as “organized knowledge for practical purposes”;¹⁶ cited in Ref. 17. From these definitions, it can be concluded that the study of technology is closely related to the study of knowledge.

The ability to share knowledge between units in an organization is an important source of competitive advantage.^{18,19} Knowledge sharing aspects at the organizational level have several challenges and barriers that have been rigorously researched in the management literature.^{20,21} Technology transfer studies focus, however, on the multidimensional aspects of the transfer and the difficulty in both measuring and perceiving immediate or long-term effect of knowledge transfer.²² Technology transfer has inspired a host of research on technology transfers between various actors, for example, universities and industry, military and civil applications (“dual-use”), developed and developing countries, between companies, within alliances, between organizational units, and within organizational units.^{23–26} Lack of absorptive capacity and knowledge complexity are commonly pointed out as the main sources of such challenges^{27,28} and the problems seem to persist even when the transfer takes place within the same department of an organization.²⁹

The integration of technologies in products and production can be a great challenge in itself,^{30–33} and when companies reuse technologies for new applications, they face a number of additional challenges. Even minor changes in the requirements for a technology can prompt new development efforts that might be both costly and time-consuming due to the inherent uncertainties of technology development. Also, the distance in time between the first and subsequent technology application projects induces challenges to the transfer and management of the knowledge involved. If a team reuses their own technology in a new application, they will likely remember much of what they previously did. However, a great gap in time leads to the risk that individuals of a team overlook solutions and have trouble accessing and interpreting existing documentation. To reuse a technology previously developed and applied by other people is even more difficult. Some elements of the knowledge gained by a previous team might be impractical or even impossible to document and transfer. Residual knowledge elements, which can be transferred, will induce a transaction cost that increases with the gap between the source and recipient of the knowledge.

Hence, the case of technology reuse can be regarded as a combination of a technology recontextualization effort and a transfer of technological knowledge from a source organization or team to a recipient. Thus, in order to reduce the effects of challenges inherent in technology reuse, engineers need to use purposeful practices that support this special case of technology integration and knowledge transfer.

2 | RESEARCH APPROACH

This paper is based on exploratory research together with a case company over the course of approximately 5 years between 2010 and 2015 to identify the factors involved in technology reuse on the engineering level. The topic of interest studied called for a deeper understanding of the real-life context of engineers in order to explore what might be important factors that affect technology reuse. This problem favored the use of qualitative case study research, seeking to generate hypotheses rather than testing existing ones.^{34,35} The setup of the research project as a partnership with the case company also gave access to a detailed inquiry about the topic in a real setting, over a

long period. This access to data (through interviews, document studies, and participation at meetings and workshops) was the main rationale for selecting a single case design, that is, this was an opportunity to study a situation otherwise inaccessible to researchers. At the time, this partnership would have been difficult to replicate with other case companies, where this deep relationship was not established. This set-up, Yin³⁴ refers to as a “revelatory case.” The case company has been described as a company typical of the aero industry,³⁶ which also provides some rationale for regarding the case as “typical.”³⁵

Throughout the 5-year project, data were collected from the case company using semistructured interviews, document analysis, informal meetings, and internal seminars. The interviews, 24 in total by the main author, were conducted primarily with technology developers, production developers, technology managers, and product developers. The interviews mainly focused on how knowledge was stored and disseminated, how decisions for technology reuse were made, and the challenges that were experienced when transferring technological knowledge and reusing technologies in new applications. Analyses were based on the coding of statements in the interview transcripts and identification of patterns, as well as “thought experiments” using both results from the case studies and from previous research found in the literature. These results were used to help our understanding of the context of technology reuse at the case company, and the cases of technology reuse presented mainly stem from the reports of the main technology developers during three of the interviews.

Reviews of existing literature were conducted primarily from the academic fields of technology management, engineering design, and knowledge management, which helped positioning the empirical findings in a larger context and generalizing the observations. The model developed to explain technology reuse is the result of an incremental refinement of our understanding of technology reuse, based on both the empirical data we collected and the literature reviewed. Even though the findings regarding technology reuse are considered to be general and repetitive, the focus of this research has been on technologies relating to the design and manufacturing of physical components, in particular components for civil aviation, and may as such be biased toward this type of low series, high-cost, research-intensive physical components.

3 | TECHNOLOGY REUSE GAPS

Reuse of technology can be seen as a special type of technology integration, in which the target application has been preceded by other applications. In other words, the company has already been developing or otherwise acquiring the technology and has been accumulating valuable experience from prior implementations. Technology reuse faces many of the same challenges as regular technology integration, with a few additions. First, there might be a misalignment between the goals that guided the development of the technology in the initial case and the requirements of the new application. An additional technology development effort might then be required to enable the technology and close potential knowledge gaps. Second, the transfer of technology is likely to involve a greater temporal gap between the

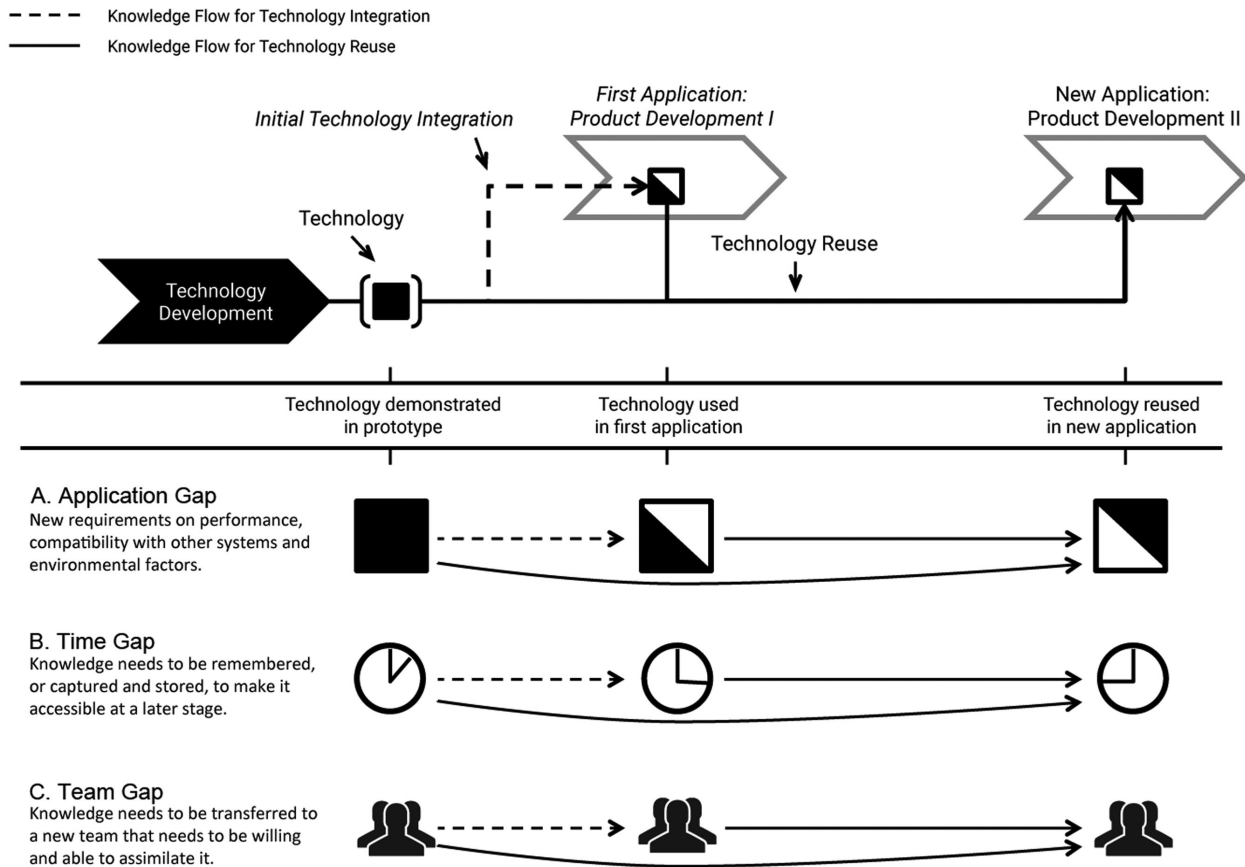


FIGURE 1 Model of technology reuse and the three types of distances that affect engineering level challenges

development and application projects than normally if the technology were reused in a later generation product. Third, the transfer might take place over a greater spatial or organizational distance if it is applied to a product managed by a different business unit. These types of gaps place additional requirements on the processes and methods used for preparing flexible technology options and for storing and transferring knowledge.

When discussing “dual-use” technologies,³⁷ that is, technologies reused from commercial applications to military applications or vice versa, Molas-Gallart²³ classify such reuse along two dimensions to define four types of reuse. The first dimension concerns whether an adaptation to the technology will be necessary or not, whereas the second dimension measures whether the same or a different unit will reuse the technology. We have adopted a similar classification of reuse types in order to discuss engineering challenges, but also add time as a third dimension. This helps to account for the potential fading of memory and availability of resources when a technology is reused at a later stage. The resulting model is presented in Figure 1, and is further explained in the following sections in reviewing existing literature. The figure shows how technologies are developed in technology development projects, and then transferred to product development projects to be integrated in a first product application. Later, the technologies can be reused during subsequent product development projects, facing three gaps in application context, time, and team when applying the knowledge.

3.1 | Application gap

Technologies do not work in isolation and need to be regarded as elements that only bring value when integrated in an application context,³² which could require synchronization with one or many other technologies and system components.^{38,39} Further, when technologies are integrated in applications, the domain-specific knowledge that technology experts possess needs to be combined with context-specific knowledge related to the application, which can be both novel and complex.³²

Thus, the uncertainty of technology reuse is affected by the degree of similarity between the environment in which it has already been proven and its intended future application. With novel requirements for the technology comes the need for an innovation effort to close knowledge gaps and make sure the technology and product system work smoothly together. It also means that the recipient is likely to face new problems, which imposes higher requirements on the recipient's internalization of the new knowledge to be able to commit to, recreate, and use it.⁴⁰

Normal transfer of technology between technology development and its first product application project is complicated for various reasons, and the effort required is often underestimated.³¹ In a study of 32 internal transfers of manufacturing technologies, Galbraith⁴¹ found that almost all the employees interviewed had underestimated how complicated the transfers would be and thus gave insufficient attention to planning and controlling them. When reusing technology,

there are probably lessons learned from previous implementation that can be useful to predict and prevent some of the complications in the new case. However, it may also be difficult to discern how new requirements from the new application context might affect the enabling of the technology and which previous results are in fact reusable. For example, in a case from the telecom industry, a new technology that introduced changes to the product's architecture required the energy supply unit and some of the mechanical components to be redesigned, with the consequences that the old simulation models could not account for the new technology.³³

An integral part of the process of knowledge reuse is to understand the contextual factors of the setting in which knowledge was created in order to be able to recontextualize it and make it useful in a new setting.⁴² In order to reapply existing knowledge, there is thus a need to be aware of the contingent factors upon which it relies, such as under what conditions the technology has been proven. Technology readiness levels (TRLs) are commonly used to measure the extent to which a technology has been proven in an environment resembling its final operating conditions in order to estimate and control the remaining risks during its development.^{43,44} However, this metric has been criticized for not adequately addressing the interrelations between technologies and their environments, which spurred the creation of supplementary metrics for integration and system readiness assessments by Sauser et al.³⁹ The dependence on environmental factors for technology maturity was also noted by Högman,³⁶ who found that the TRL for a technology dropped a few steps on the scale when its target application changed.

In some cases, the difference between the requirements of the new and the previous applications can be so extensive that there is almost no synergistic benefit left. This is exemplified by Molas-Gallart,²³ who mentions the attempt to reuse production processes for titanium from military to civilian applications, which was unsuitable due to the much higher production volumes required by the latter.

3.2 | Time gap

When introducing a time gap between the initial application of a technology and its reuse in a new application, a number of risks appear. First, the knowledge that was previously accurate and according to best practice might have changed, making part of the knowledge base obsolete and in need of being replaced or refined to function in a new setting.⁴⁵ Machines and equipment previously used may have been replaced, for instance requiring new tests and fine-tuning of the processes for applying a manufacturing technology. Software code may be incompatible with a new IT environment or written in a language no longer supported or used by the company. Also, development taken place outside the company may have brought new discoveries or best practices that might need to be integrated to make the application of the technology competitive.

Second, the availability of necessary knowledge is likely to diminish over time. This is something that is assumed in the study of knowledge management and organizational memory, but the effects of forgetting over time have not yet gained much attention in research.⁴⁶ Not only do people forget the knowledge they store in their own memory, but

codified knowledge may be also hard to find in legacy IT systems, provided that the reusers would even be aware that these records exist. Casey and Olivera⁴⁶ exemplify this occurrence with a case from NASA, where incident reports were found to be inadequately indexed and stored, which inhibits the long-term benefits of their lessons learned.

Third, many people who used to work on the development or application of the technology will probably have changed positions within the company, even left the company for retirement, or moved on to work for another company. Such "turnover" is commonly quoted as a cause of "organizational forgetting."⁴⁷⁻⁴⁹ Accessing both their tacit knowledge and their knowledge of where relevant documents may be found impractical, if at all possible. de Holan and Phillips⁴⁷ cite a case reported by Anand et al.,⁵⁰ whereby an engineer at an aerospace company had been appointed in-house expert in a new technology but was then reassigned to his original role after some changes in management. After additional changes, they realized that the technology was in fact critical to them, but failed to remember that an expert already was available within the company and went on to appoint yet another person to the role. Whereas the loss of an individual in a team does not necessarily threaten the knowledge base of the company, there is also the reverse situation where a missing piece of knowledge may disrupt the effectiveness of the collective knowledge necessary to use a certain capability.⁴⁷

3.3 | Team gap

Technologies that are new to the world most certainly bring uncertainty, but technologies that are new to the firm can display the same characteristics regardless of the existence of prior knowledge in the scientific community.⁵¹ If a technology is reused by another team than that developing or applying it previously, much knowledge will have to be transferred to ensure a successful result. The new team might be within the same department, perhaps also including some people from previous implementation, or it might be a different business unit at the same site or a site in a different geographical location. Knowledge management literature presents a host of challenges pertinent to the transfer of knowledge applicable to the case of technology reuse by different teams.⁵²

The preconditions for a recipient of technology transfer to learn a new capability are primarily based on two factors: the characteristics of the knowledge and the learning capacity of the recipient team. "Causal ambiguity" is a characteristic of knowledge that is commonly cited as one of the significant causes of unsuccessful knowledge transfer.^{18,40,53} Causal ambiguity occurs when it is difficult to identify, express, or transfer the knowledge elements necessary for applying a technology.^{53,54} Some literature narrowly defines it as the possibility to discern the knowledge elements,⁵³ whereas others define it as a wider concept of transferability, including tacitness, complexity, prior experience of the recipient, cultural distance, etc.⁵⁴ Based on their study, Cohen and Levinthal²⁷ suggest that innovations embodied in equipment rather than dispersed knowledge will diffuse more easily to others. Other knowledge characteristics that have been shown to affect the speed of knowledge transfer are "teachability" and "codifiability."⁵⁵

In relation to the recipient aspect, Cohen and Levinthal²⁷ define “absorptive capacity” as the ability of an organization to assimilate new knowledge from external sources. It is defined to include related prior knowledge, usually through proprietary R&D, as well as internal and external communication patterns and incentives for learning. With existing knowledge in a related domain, new knowledge can be readily integrated through shared language, less new knowledge to absorb, and additional prior experience to which new ideas can be related and memorized. The amount of relevant prior knowledge of a firm in a technological domain greatly influences its ability to learn, especially from codified knowledge.⁵⁴ If the distance between the knowledge bases of two transferring parties is extensive, there will be additional learning steps for the recipient.⁴⁰

Szulanski⁵³ found that the intimacy and ease of communication between the source and recipient to strongly influence the success of transferring best practices across organizational units. There are, however, obstacles to attaining such a relationship. Since it may lose ownership or its position as an important expert in the area, the source unit may not be fully willing to share its knowledge.⁵⁴ It could also be due to a lack of interest in allocating resources to supporting someone else, which does not have a direct benefit to the source itself.⁴² Cultural differences have been shown to present challenges to collaboration between firms, requiring more time for communication and the synchronization of design routines and managerial approaches.⁵⁴

Prior experience of collaboration between the transferring parties can be expected to lower the cultural distance, as well as contributing to increased trust and familiarity with each other's expertise, thereby facilitating knowledge transfer.⁵⁴ Stock and Tatikonda⁵⁶ did not find support in their study for the hypothesis that prior experience of technology transfer generally influenced transfer success, but discussed the possibility that its effect may be less direct than indirect.

Technology transfer across organizational units requires a deep commitment from the source, which may not always be the case since it is typically not part of its main mission.²³ Stock and Tatikonda⁵⁶ showed that the criticality of a technology transfer project influences its chances of success. Without proper motivation, the recipient may directly or indirectly sabotage the transfer through passive behavior or a rejection of outside knowledge as in the case of the “not-invented-here syndrome.”⁵⁷

4 | DIFFERENT TYPES OF TECHNOLOGY REUSE

All three gaps—application, time, and team—are not equally relevant to every case of technology reuse. Instead, each case has its profile that may experience challenges in one or more of the dimensions. By considering each gap as a binary variable, that is, either there is a noteworthy gap or not, eight cases of technology reuse can be created through the possible combinations of the three distances (Figure 2). In the illustrative cases, all gaps have been identified through qualitative interviews as outlined in the Methodology section, this means that gaps have been identified on the basis of the perception of the engineers participating in the evaluation and interview studies. Depending

on which case a company faces in a certain situation, different challenges at the engineering level can be expected, which are presented below.

4.1 | Type 1: Repeat application

In the first case of technology reuse, there are no distances in any of the dimensions. The technology is applied to a similar application by the same team as a direct continuation of their previous work. To classify a new application as similar to previous applications can often be done only in retrospect, as even small differences in requirements may become major challenges as seen in one of the cases presented in a later section. However, this case can be seen as business as usual for the development teams and as it would not require any specific interventions in order to be successful it may therefore not even be noticed as a distinct “case” of technology reuse.

4.2 | Type 2: Direct technology extension

In the second case of technology reuse, a team is working on a new application for the technology shortly after the previous application by the same team. They may also have been the same team that initially developed the technology or otherwise acquired the necessary skills for the company to be able to apply it. With relevant knowledge still at the top of their minds, there is little risk that important considerations, tacit or explicit, would be overlooked. Previous equipment and documentation is likely to be close at hand and prepared for testing the technology under new conditions. Relations with other experts or departments previously involved are active and the team knows whom to ask when input from internal and external stakeholders is required. However, the technology needs to be adapted to a new application, and the main task at hand is to test the applications under the new circumstances.

4.3 | Type 3: Delayed repeat application

In the third case of technology reuse, a team that previously applied the technology is working on a similar application, at a later stage. The team has both tacit and explicit knowledge of the workings of the technology in this type of application based on previous experience, but team members have erased much of the memory of it. Documentation will probably be possible to locate, as long as the systems for storing such documentation has not changed. The rationale behind design decisions is often poorly captured in documents, which might present a problem if there are wishes for updating something about the technology before the new application. As time passes and even if the application appears to be the same, there is a greater risk that other elements of the technology's environment in the meantime changes. For example, the production facilities that are used may have changed, and new product standards and legal requirements might have been put into place that require some alterations to the technology in its new application.

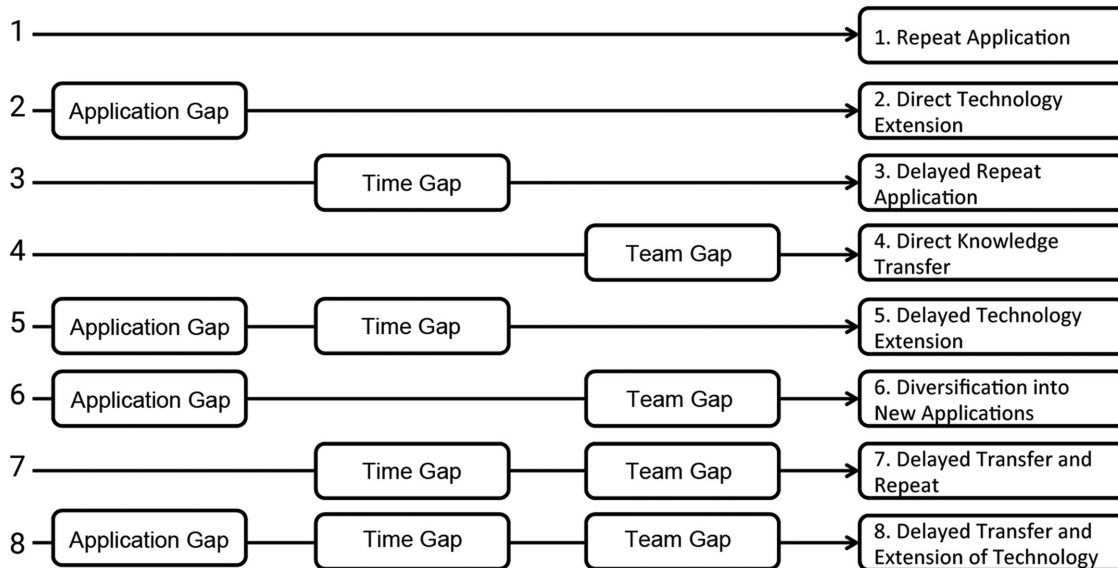


FIGURE 2 Eight types of cases of technology reuse

4.4 | Type 4: Direct knowledge transfer

In the fourth case of technology reuse, the new application is identical or very similar to previous applications and there is no significant time lag, but a different team has been assigned to work on its implementation. A typical case would be the transfer of technology from a site that has successfully used the technology to a different site that develops similar products, within the same corporation. Since there is no time difference between applications, the source team will likely still be available to help transfer their knowledge to the recipient team. However, there are numerous caveats to the transfer of advanced technological knowledge, especially if there is much tacit content that needs to be conveyed, which is evident from the existing literature on technology transfers. It is recommended that members of the source team work closely together with the recipient team in order to transfer tacit knowledge and build trust in the technology. Since the application in this case is identical, there is little technical risk involved. However, the transfer to a different site may present unexpected problems due to environmental circumstances. An example could be Cummings and Teng,⁵⁸ where the transfer of a new manufacturing technology required changes not only to the production facility, but also to the routines used by the production personnel in order to maintain a dust-free environment.

4.5 | Type 5: Delayed technology extension

The fifth case of technology reuse is a combination of cases 2 and 3, whereby a team that previously used a technology will adapt it to a new application after a significant amount of time has passed. Thus, the team will not only face challenges related to the novel requirements of the new application context, but will also need to recollect the important contingency factors under which the technology previously functioned. Interpreting the important changes from previous applications can be more challenging when the knowledge is no longer fresh

in mind and the equipment and test procedures previously used may have changed or may require additional time to get up to speed.

4.6 | Type 6: Diversification into new applications

The sixth case of technology reuse combines the challenges of cases 2 and 4, by distancing itself in both application and team, but with no delay in time from previous applications. A typical case would be a company that has developed a new technology within one business unit that it wishes to leverage on another product line managed by a different business unit. Although the case is tempting in terms of offering same leverage, it may be treacherous. Besides the knowledge transfer problems discussed about in case 4, the recipient team will also need to extend the technology to enable it for the new applications, which brings technological uncertainty. This will require the recipients to acquire deeper knowledge about the technology in order to be able to solve the new problems arising from the novel application and to be able to discern the knowledge that need to be recontextualized from previous findings.

4.7 | Type 7: Delayed transfer and repeat

This seventh case of technology reuse combines the basic cases 3 and 4, that is, a different team would reuse the technology for a similar application at a later time. Since the requirements would be more or less the same, the lessons from previous applications would be useful, but in this case the success of knowledge reuse hinges on the availability of that knowledge. The team of people previously involved also possesses necessary tacit knowledge that may have dispersed across or even left the organization. If the application of the technology would be straight-forward, with little or no need for tacit knowledge or adaptation, well-prepared documentation would likely be sufficient for the recipient team to successfully reuse the technology as long as team members are knowledgeable in the domain at large.

4.8 | Type 8: Delayed transfer and extension of technology

The eighth and most difficult case of technology reuse combines all three distances, where a different team reuses the technology in a different application at a later stage. Not only would there be challenges to the identification of existing knowledge in terms of documents and personnel, but there would also be a need for extensive knowledge assimilation by the new team in order to continue the development and adaptation of the technology to the new application.

5 | ILLUSTRATIVE CASES: AEROSPACE SUPPLIER

The case company develops and manufactures components and sub-systems for aircraft engines, with the majority of its operations at the headquarters in Sweden. It operates across three different business areas: space, military, and commercial aircraft. The business areas were managed quite independently until a reorganization in early 2000 when they became integrated. Its products are characterized by advanced technology and low volumes, and the current strategy has been to focus on developing strong capabilities within a number of key technological areas by working with multiple engine makers as risk-and-revenue sharing partners.

While the specialized competency can be leveraged across various products to different customers or partners, the reuse of the detailed designs is complicated by a number of factors.⁵⁹ One such factor is that designs developed in alliances may have elements of property rights belonging to partners, which must not be reused in products developed with other partners. In order to design components that would have been reusable in other products, trade-offs must be introduced with regard to their design and performance which in the end are impossible to meet. Instead, when a team of industrial researchers analyzed the potential for reusing components using a product platform approach, they found that most of the assets shared between products consisted of technological knowledge.⁶⁰ The following three cases relate to the transfer of manufacturing technologies. Manufacturing technologies were seen as both a core competence, where the company had built experience and knowledge over several decades, and also typical for technologies that were considered transferable.

5.1 | Case 1: Automatic deburring

Automatic deburring uses robots to deburr metal components after milling and turning operations. Automatic deburring was developed at the case company around the year 2000 for the purpose of reducing injuries sustained from the manual deburring process. It turned out to be an effective way of also reducing the time and cost of production while at the same time augmenting the quality of the operation compared to the manual process. The development team consisted of a couple of production developers responsible for introducing automatic deburring process on a product at the site where they worked.

Two years later, another site within the company situated in a different country showed an interest in adopting the technology to one

of their products after having heard of its success from the original developers in their small “community of practice.” The new product was very similar to the product at the first site and after a short visit to the site, the original developers deemed the case feasible. A team at the recipient site started to adopt the technology in collaboration with the source team and especially focused on purchasing the necessary equipment and training the new operators.

A second technology reuse case was started 5 years later, where yet another site, this time on a different continent, after hearing about the technology. However, their products had much rougher burrs, which required new development efforts to identify edges of the product that would be possible to deburr automatically and the edges that would still require manual work. Once again, the original team traveled to the site and worked jointly with the recipient team to purchase the equipment and install the automatic deburring process. The case is summarized in Table 1.

5.2 | Case 2: Laser welding

Laser welding was first developed at the case company around 1995 as a way of experimenting with the new method. In 1997, there was a breakthrough that led the company to use it for space application prototypes. Shortly thereafter, the lead technology developer was transferred to the business unit for civil aircraft engine components to reuse the technology for a new application. A team was formed to develop an experimental production cell for enabling the technology in the new application, spending several years to reach the required process stability and quality levels.

A new case of technology reuse surfaced a few years later, when the company decided to use laser welding for a different product in their portfolio that is exposed to significantly higher temperatures and for that purpose also uses a different material. The same team worked on enabling the technology in the new application, but it turned out to be an unexpectedly great challenge from a technology perspective. The team had been continuously working on adjusting and refining the technology for the previous application, so there was in effect no time lag. The case in relation to the technology reuse gaps is summarized in Table 2.

5.3 | Case 3: Surface treatment

The case company developed a technique by which one of the engine components that is prone to wear during use could be repaired by surface treatment, as an alternative to having to replace it with expensive new parts. The technology was first used for a part of approximately 120 mm in length, depth, and width and then reused on a similar component that was about a third the size in each direction. The same team was working on developing the repair for the new application, and although new tools needed to be developed, it was fairly straightforward.

Later, a similar component of a size smaller than the large component but larger than the small component was targeted for the same type of repair procedure. Based on the previous experience with both larger and smaller components, the case was expected to be an easy

TABLE 1 Summary of cases 1a and 1b in relation to the model

	Reuse case 1a	Reuse case 1b
Corresponding technology reuse type	Type 4: Direct knowledge transfer	Type 6: Diversification into new applications
Application gap	Minor	Medium
Team gap	Different site, similar competence, support from original team	Different site, similar competence, support from original team
Time gap	2 years, source team still actively using technology	5 years, source team still actively using technology
Challenges experienced	Knowledge transfer	Technology development and knowledge transfer
Result	Successful, no significant problems	Successful, no significant problems

TABLE 2 Summary of cases 2a and 2b in relation to the model

	Reuse case 2a	Reuse case 2b
Corresponding technology reuse type	Type 6: Diversification into new applications	Type 2: Direct technology extension
Application gap	Major	Major
Team gap	Same lead developer, new team	Same team
Time gap	Direct continuation	Direct continuation
Challenges experienced	Technology development	Technology development
Result	Successful, no unexpected problems but continuous technical matters being solved during development	Successful, but unexpectedly great technical challenges causing delays and cost overruns during development

TABLE 3 Summary of cases 3a and 3b in relation to the model

	Reuse case 3a	Reuse case 3b
Corresponding technology reuse type	Type 3: Delayed repeat application	Type 7: Delayed transfer and development of technology (but relatively small distances)
Application gap	Major at face value, minor in reality	Minor at face value, major in reality
Team gap	Same team	Different core team, but same collaborators and suppliers
Time gap	1 year	3 years
Challenges experienced	Incremental technology development	Technology development
Result	Successful, no unexpected problems	Technically successful in the end, but unexpectedly great technical challenges causing delays and cost overruns during development

task and the project was assigned to a new small team on a short schedule. However, since it was not possible with the existing tools to direct the tool with a 90° angle toward the surface where the material was to be applied, the new component had a geometry that presented access problems for the surface treatment. None of the stakeholders involved had foreseen the problems, and the expectation of being able to quickly adapt the technology continued to generate new problems that had to be solved throughout the year-long project. The project manager commented that if they had better predicted any potential problems, the project could have used a more exploratory phase in the beginning to avoid much of the rework without the trial-and-error mode of development. This case in technology reuse has been summarized in Table 3.

6 | DISCUSSION

This article discusses the results relating to three main perspectives: reuse-cases studied, implications for a technology reuse strategy and, finally, the engineering and managerial perspectives.

6.1 | Implications for technology reuse-cases

Inherent in the notion of technology reuse, as the term is used in this paper, is a need to recontextualize the technology to its new application. It would otherwise be possible to categorize it as component or process reuse, which might be supported in ways that are outside the scope of this research. TRLs⁴³ have become widely used to support the assessment of the level of maturity of a technology for its designated application environment. However, TRL assessments work best for measuring progress and, comparing a single technology to a previous state, as opposed to an absolute state of readiness. Speaking of technologies as mature and possessing high TRLs is generally a fallacy that disguises the contingencies from the environment in which the technology has been proven.

The three cases presented in this paper illustrate how the reuse of technology can be a straightforward process or an unexpected challenge, even for the same technology. The distance in terms of application, team, and time, in combination with the intricate characteristics of the technology, dictates the outcome.

The distance between application contexts was mainly faced in cases 1b, 2a, 2b, 3a, and 3b. Whereas cases 1b, 2a, and 3b were

prepared for the technical challenges inherent in their reuse, cases 2b and 3b underestimated them with extensive consequences for time and cost of development.

The case company had correctly acknowledged the team distance and the need to actively support the recipient team in cases 1a and 1b in order to transfer knowledge and ensure correct application of the technology. Case 3b was handed to a new developer and faced unexpected problems; however, the experienced stakeholders supporting the new developer had also not been able to anticipate the problem. It is possible that some of the problems faced later in the project might have been mitigated by the tacit knowledge held by the original development team had they been involved.

Even though there were time gaps in many of the cases between the applications, all of them were supported by ongoing development by established technology experts. Hence, no significant challenges were found that could be derived from difficulties of locating and accessing previous knowledge. There might have been effects stemming from having to recall design decisions from a long time ago, but the interviews conducted did not reveal any such barriers.

Another barrier inherent in the reuse of technological knowledge has to do with the generally applied dimension of knowledge. In late phases of technology development, there is a need for adapting it to the specific requirements of the application intended. The knowledge generated during this phase is less generic and reusable in other contexts, which may be difficult to discern when reviewing documentation for reusable elements of previous work conducted.

6.2 | Implications considering technology reuse strategies

The case company had not at the time of the study introduced any formal knowledge strategies featuring technologies as foundational elements. However, the case company had decided to introduce such strategies, which also led to the formation of this research project. Current knowledge sharing at the case company could be characterized as having primarily a personalization strategy, supported by a decentralized IT infrastructure for codified knowledge with partly ad hoc content. A notable exception was that the company had a central repository of design practices under development. The idea has been to introduce a technology reuse strategy, entitled the “Technology Platform,” consisting of knowledge elements to be reused across product lines similar to components in a product platform.

At the case company, there were examples of functional teams or interest groups that centered around a technological capability, as well as experts appointed as “method owners” for technologies, especially those involving an engineering or manufacturing method. To gain technological knowledge, knowledge seekers could identify this functional unit or group of employees who would, hopefully, be able to answer any questions or refer to other sources for answers. However, directories of existing groups were nonexistent or inaccessible. The groups often stored codified knowledge in reports, specifications, and manuals in shared folders on their Intranet. The content of these folders differed between groups, but there was some standardization stemming from the requirements of certain documentation specified

for the technology development process. Hence, for technologies that had been developed recently in dedicated projects, these documents could be found.

The future technology reuse strategy may build upon the idea that each technology would have one or more appointed experts assuming the roles as “knowledge owners,” to decide on the best strategy to empower other employees with the knowledge in their domain. The goal would be to achieve the best possible leverage on any time and money spent on preparing and sharing knowledge for reuse, which is especially important when the resources and intrinsic motivating factors are scarce, as they tend to be for that type of activity.

In relation to existing literature, this practice would fit into several of the reuse frameworks from engineering management research. It can be seen as a refinement of the classification phase during the process for improving reuse of technological assets proposed by Antelme et al.,¹³ and as a method related to both the “design for reuse” process in Duffy et al.¹⁰ and the decision on what products to develop for reuse in the proposed reuse strategy by Davis.¹²

An early version of such a method has been developed to support the development of individual “Technology Communication Plans.” It asks technology experts to identify potential knowledge reusers, how many they are, and what type of knowledge they might need. Guidelines are then supplied to the experts for helping them decide how to effectively satisfy these needs. For instance, depending on the type of knowledge, different mechanisms for transferring such knowledge through manuals, newsletters, or face-to-face consultation with experts could be suitable. Further, if there are many potential reusers and the knowledge is primarily explicit, it might be worthwhile to make an investment in recontextualizing and applying such knowledge in a guideline or even create an expert system to execute tasks automatically. If the knowledge is not needed frequently, then by-products from normal work or modes of getting in contact with experts to pose a question might be sufficient.

There are three main reasons for suggesting individual plans to make knowledge about technologies accessible. First, it is desirable to introduce a general strategy that is applied to all technologies to ensure optimization of the whole inventory of technological knowledge. Second, each technology is unique and has specific knowledge elements that are critical or useful for reusers to address correctly, the criticality of each knowledge building block is best identified by the experts themselves. Third, knowledge management initiatives often fail because of a lack of motivation or resources, which means that every activity needs to have clear purpose and they need to be chosen wisely to achieve their intended purpose with minimum effort. In order to make smart choices on how to share knowledge, technical experts need to have the skills for doing so, which could be ensured with support from knowledge codification guidelines, or with direct training or support from knowledge experts.

6.3 | Engineering and managerial implications

Effective technology reuse enables organizations to systematically leverage their technologies across different applications and they have previously been studied mainly from the business strategy and

management perspectives. This research has attempted to make a contribution by studying implications of knowledge transfer at the engineering level, with a particular focus on existing challenges for the effective reuse of technological knowledge in new applications.

Organizational culture was not explicitly studied as a dimension of the empirical part of this research, but it is clear from the literature that it plays an important role in knowledge transfer. It has been stated as one of the most important factors for successfully transferring knowledge (Davenport & Prusak, 1998) and for succeeding in introducing knowledge repositories, especially for collaborative repositories such as Wikis (Standing & Kiniti, 2011). Based on our interviews and discussions, the case company seems to find itself in an early stage of the transformation into a culture of knowledge sharing. The general impression from the interviews conducted was that there were no signs of active resistance such as knowledge hoarding or unwillingness of sharing knowledge when asked for it. However, there was low transparency as well as lack of incentives, internal and external, for making an effort to make new knowledge readily accessible. Since the mindset of prioritizing future reuse needs to be infused along with the methods, this presents a challenge for the adoption of new methods for knowledge capture and sharing.

7 | CONCLUSION

The activity of technology reuse deserves more attention as a challenge at the engineering level than has previously been devoted to this object. Companies adopting strategies to systematically reuse technologies to leverage their investments in R&D, as well as expectations and purposeful planning of supportive activities are crucial. This paper has attempted to clarify the factors involved when experiencing different barriers and complications to effective technology reuse. In particular, this paper has presented a model of technology reuse that featured three potential gaps between previous and new applications that need to be bridged: between the technology application contexts, between the teams that apply it, and in terms of the time before the technology is reused. The extent to which these gaps experienced in a particular case has implications for how the reuse process needs to address new technology development and the transfer of knowledge from the source unit to the recipient team acting as reuser.

In the model presented, for simplification, the measures for the gaps were defined as a binary variable, there was either a gap or not in each dimension. However, as seen in the technology reuse case presented, the variables operate on a continuum, and it may not be clear from the outset how these variables should be assigned. An application that seems similar may feature a small difference that has great effects on the technical feasibility and vice versa. However, recognition of the presented gaps allows for a better discussion and assessment of what technology developers have to deal with and what might be the challenges involved. With a better understanding of a planned case of technology reuse, correct measures can be put in place to mitigate the potential difficulties and plan for the uncertainties involved.

As a future research topic, an assessment methodology considering the technology reuse potential has been evaluated as a means to

mitigate experienced gaps. The initial experiments regarding this assessment have been tested on technology development teams in an early stage of the technology transfer process, at the case company. The result of this prescriptive research has been published in Ref. 61 outlining the foundations of the TEchnology Reuse Assessment (TERA). One major benefit of the assessment tool is that it enables gaps to be measurable and comparable on a continuum scale, which would be useful when addressing real-life trade-offs regarding the technology transfer.

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