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TERA - An Assessment of Technology Reuse Feasibility

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Abstract

Instead of developing each new product from scratch, firms strive to reuse prior components and technologies in new applications in order to improve robustness, reduce cost and shorten time-to-market. Technologies come in the forms of methods, designs and processes, and are suitable for reuse since they are concepts for solving certain problems that multiple products have use for. However, reuse of technology where the application context is different requires adaptation of both the technology and the product system into which it is introduced. In practice, the magnitude and sources for this effect are often underestimated, which leads to unanticipated uncertainty in product development projects with consequences for robustness and efficiency in development. Based on available literature and needs identified within a case company, this paper proposes a method for identifying potential challenges of technology reuse that may otherwise be overlooked or only implicitly acknowledged. The method features a scorecard that guides a workshop to be attended by technology experts and managers where the prospect for successful technology reuse is assessed.

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Keywords: Technology development; technology transfer; knowledge transfer; technology assessment; technology reuse

1. Introduction

The ability to transfer knowledge between units in an organization is an important source of competitive advantage [1], [2], and has proved to be a complex process faced with many challenges. For technological knowledge specifically, it has inspired a host of research on technology transfers between various actors, e.g.

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universities and industry, military and civil applications ("dual-use"), developed and developing countries, between companies, within alliances, between organizational units and within organizational units [1], [3]-[5]. Lack of absorptive capacity and knowledge complexity are commonly pointed out as the main sources of such challenges [6], and the problems seem to persist even when the transfer takes place within the same department of an organization [7].

Strategies for reusing existing assets have become increasingly popular as companies strive to lower development cost and shorten time-to-market. The automotive industry was early with adopting product platforms, whereby the architecture and modules of product lines were reused between different product variants. Other companies have become known for reusing technological competencies and other generic building blocks [8], [9] and many multinational corporations have centralized R&D departments that supply new technologies to various business units.

There is strong agreement in research that any technology integration shall be preceded by a technology readiness assessment to ensure that the downstream product development project does not risk its objectives by taking on too much technical uncertainty [10]-[14]. Technologies do not work in isolation, and their implementations and performance are contingent on the surrounding product systems. The maturity of a technology can thus be judged only in the context of a specific application, as follows from the definitions of "Technology Readiness Levels" (TRL) developed by NASA [10] that are commonly used in the defense and aerospace industries. For instance, TRL 6 is defined as "System/subsystem model or prototype demonstration in a relevant environment (ground or space)" [10], where "relevant" can mean in terms of external requirements and interdependency with other technologies and systems.

Consequently, when reusing a technology in a new application, new uncertainties will surface about the technology's performance. These uncertainties are easily underestimated because of the fallacy to perceive a technology as a "proven capability" that can be used off-the-shelf. Further, reusing a technology for a new product typically means that a new team will work on its integration in the product system, that would need a deep understanding of the technology to overcome challenges of adaptation that will likely occur. Technology reuse can thus be regarded as a mechanism that occurs in two different contexts: (1) a technology recontextualization effort in the product context and (2) a transfer of technological knowledge from a source unit to a recipient unit in the organizational context. Mapped to the framework in [1] (Table 1), this paper is primarily concerned with "External Modification", which encompasses elements of both adaptation of technology and transfer to another unit. Since reuse of existing technological knowledge occurs naturally in all types of development, there are also cases in which technologies are reused only in part. This type of reuse is however not addressed in this paper, which instead focuses on cases where technologies are reused in a form that closely resembles their previous applications.

Table 1 A technology reuse case as described in this paper maps well with the term External Modification in the framework for dual-use technology transfers in [1].

Actors: \ Mode:	**No adaptation**	**Adaptation**
Transfer internal to a single unit	Internal Straight Transfer	Internal Modification
Transfer between two or more units	External Straight Transfer	**External Modification**

As technology can introduce significant uncertainties in product development and many times result in time and budget overruns [15], it is critical to assess the feasibility of the reuse case and identify actions required to achieve a successful knowledge transfer. Previous research has provided extensive insights into what constitutes typical obstacles and enablers for technology integration and transfer [5], such as 'knowledge stickiness' [16] and 'not-invented-here syndrome' [6], and some authors have integrated these in practical tools for use by companies to foresee and mitigate potential problems [3], [17]-[19]. However, no tools were found that integrate both technical- and transfer related factors to support technology reuse decisions on an operative level.

This paper proposes a TEchnology Reuse Assessment tool – TERA – based on findings from prior research, with the purpose to support firms in becoming proactive to avoid common pitfalls of technology reuse. It specifically addresses the case when a company possesses the capability to successfully apply a technology in a specific application and is considering reusing it in a similar way in a different application, e.g. a related but different product developed within another business unit. The assessment tool integrates elements of both technology development and transfer challenges, and adds a third dimension of business case in order to capture the rationale for the reuse case and contrast the reuse challenges with the benefits it is meant to provide.

2. Methodology

This research was initiated in a collaborative project with the industry partner GKN Aerospace. The company perceived a need for better support to evaluate potentially viable opportunities for technology reuse across subsidiaries and product areas, and the authors failed to find such support in literature.

On the other hand, a review of literature in technology management and knowledge transfer presented a host of enablers and challenges for successfully applying technology in different contexts. A set of papers were found that together summarize and synthesize much literature until around the year 2000 in the topic of interest [16], [17], [20]. These were used as a baseline together with the sources they cited, after which a search was performed for newer articles referencing to any of them.

The dimensions measured in the quantitative studies by [17], [20] were identified as possible dimensions for creating a self-assessment tool. Stock & Tatikonda [17] examine the effects of technology characteristic *uncertainty* on technology transfer success, while Cummings & Teng [20] focus on the organizational aspects of the transferring parties of knowledge transfer in R&D.

The first prototype of the assessment tool was a "long list" version featuring around 25 dimensions. Some of the dimensions overlapped and many of them were considered too complex to be used by practitioners. The set of dimensions was reworked in two stages, first to 11 dimensions of technical and transfer related challenges and then further down to six dimensions of Technical Readiness and Capability Transfer Readiness. The shift from measuring 'challenges' to 'readiness' reflects the authors' ambition to increase the cognitive ease of using the assessment by measuring with positive scales, meaning that a high rating on any of the dimensions is positive for the reuse case.

The TERA tool was developed through multiple iterations where feedback was provided by a technology expert and two technology managers at the industry partner GKN Aerospace. The first complete versions of the assessment were discussed during four interviews with technology experts at GKN Aerospace, from which a few adjustments were made to its design.

3. Review of dimensions affecting technology reuse

Based on analysis of literature, three complementary dimensions for technology reuse capability were identified: (1) Technical Readiness, (2) Capability Transfer Readiness, and (3) the Business Case (Figure 1). Successful transfer of technology requires careful attention to all three dimensions, as outlined below.

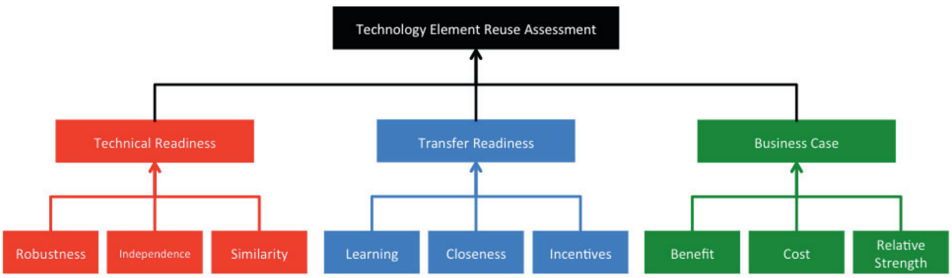

Figure 1 Dimensions of the TERA Framework

3.1. Technical Readiness

3.1.1. Robustness

While new technologies may provide technical advantages, firms face more uncertainty and higher risk of failure when applying them than with technologies for which they have prior experience [21]. Novelty for process technologies in particular showed to affect time-to-market more than did product technologies [22]. With experience, the potential problems and contingencies of a technology's behavior in various application environments become better known, which helps predict potential problems in future applications. 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 [23]. 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 [21].

Further, if the source unit has a history of successful cases, it is likely perceived as knowledgeable and reliable so that the recipient unit will trust them and refrain from challenging their advise and expertise [16].

3.1.2. Independence

The two factors *level of interdependence* and *number of parts* are often used to define complexity [5], [17], which is an important factor that influences the difficulty firms face when using and transferring technologies [5]. In the case of complex knowledge, also the people who possess the knowledge need to be taken into account [24].

When considering challenges for technology reuse, the number of parts can clearly have an influence. However, when assuming they have all been proven in a previous environment, it is only those that interact with or is affected by the rest of the system that will bring new uncertainties, which is why the level of independence is attributed more importance in this assessment.

A highly complex technology that is reused in a new application may have to be adapted to a multitude of new interfaces that affect its behavior, and vice versa. There are even cases in which it may not be possible to make technologies operate together, which greatly increases the efforts necessary to succeed with the reuse project since that technology needs to be replaced as well to accommodate the one being reused.

Further, the embeddedness of technology in various components increases the number of novel components that need to accompany its introduction in the new product system, which in turn may have dependencies to the system. In contrast, a technology that can be packaged as an independent module is characterized by a limited need to exchange material, energy, information or be spatially coordinated with other modules [25]. Hence, the consequences of recontextualization can be more easily predicted and controlled for in the case of independent or modular technologies.

3.1.3. Similarity

The uncertainty of technology is affected by similarity of the environment in which it has already been proven and its intended future application. With novel requirements for the technology comes 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, re-create and use it [20].

Technology Readiness Levels [10] were developed to gauge the remaining uncertainty in a technology before its application. They measure to what extent a technology has been tested in an environment that closely resembles its operative conditions. The transfer between applications creates a gap between the requirements from the original environment and the intended application environment, which has to be closed through additional testing and most likely adaptations to both the technology itself and, to the product system into which it is introduced. For example, in a case from the telecom industry, a new technology that introduced changes to the product's architecture required some of the mechanical components and the energy supply unit to be changed, and the old simulation models could not account for the new technology [26].

3.2. Capability Transfer Readiness

3.2.1. Learning

The preconditions for a recipient of technology transfer to learn a new capability, assuming adequate transfer mechanisms, are primarily based on two factors: the characteristics of the knowledge and the recipient's learning capacity.

Causal ambiguity is commonly cited as one of the significant causes of unsuccessful knowledge transfer [2], [16], [20]. Causal ambiguity occurs when it's difficult to identify, express and transfer the knowledge elements that are necessary for applying a technology [16], [27]. Some literature defines it narrowly as the possibility to discern the knowledge elements [16]. Others define it as a wider concept of transferability, including tacitness, complexity, prior experience of the recipient, cultural distance etc. [27]. In this article, these concepts are all included in the dimension Learning, except for cultural distance that is treated as a characteristic of Closeness of the relationship.

Teachability and codifiability have been shown to affect the speed of knowledge transfer [28], and [6] suggest based on their study that innovations embodied in equipment rather than dispersed knowledge will diffuse more easily to others.

Cohen & Levinthal [6] define absorptive capacity as an organization's ability to assimilate new knowledge from external sources. It is defined to include the organization's related prior knowledge, usually through proprietary R&D, as well as their internal and external communication patterns and incentives for learning. With existent knowledge in a related domain, new knowledge can be more readily integrated through shared language, less new knowledge to take in and more prior experience to which new ideas can be related and memorized. The amount of relevant prior knowledge a firm has in a technological domain greatly influences its ability to learn, especially from codified knowledge [27]. If the distance in knowledge bases of the two transferring parties is large, there will be more learning steps for the recipient [20].

3.2.2. Closeness

Szulanski [16] found that the intimacy and ease of communication between the source and recipient to have a strong influence on the success in transfer of best practices across organizational units. There are several obstacles to attaining such a relationship, however. The source unit may not be fully willing to share its knowledge, since it may lose ownership or its position as an important expert in the area [27]. It could also be due to a lack of interest in allocating resources to supporting someone else, which does not have a direct benefit for the source itself [23].

Cultural differences have been shown to present challenges to collaboration between firms, requiring more time for communication and synchronization of design routines and managerial approaches [27].

Prior experience of collaboration between the transferring parties can be expected to lower the cultural distance as well as contribute to increased trust and familiarity with each other's expertise, and thereby facilitate knowledge transfer [27]. Stock & Tatikonda [29] didn't find support in their study for the hypothesis that prior experience with technology transfer in general influenced transfer success, but they discussed the possibility that its effect is indirect rather than direct.

3.2.3. Incentives

Technology transfer across organizational units requires a deep commitment from the source, which may not always be the case since it's typically not part of their main mission [1]. Stock & Tatikonda [29] 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 rejection of outside knowledge as in the case of 'not-invented-here syndrome' [16].

3.3. Business Case

The three dimensions chosen for the business case evaluation are: Benefit, Cost, and Relative Strength of the technology. In order to serve as a tool for evaluating technology reuse options, it is inevitable to also include measures for the benefits that the reuse is expected to provide. As for most other R&D projects, the performance of a technology transfer project can be measured in three dimensions; the technical performance (of the transferred technology at the recipient), the cost of transfer and the time for completing the transfer [29]. Besides the viability of the technological option, decision makers also have to take into account the alternative technological solutions for the application, which is why a relative measure of strength has been included. Focusing too much on the predictable benefits of reuse might hamper investments in new, more promising technologies that face higher uncertainty [30].

3.3.1. Benefit

There may be a host of reasons to pursue a technological integration, e.g.: launch new innovative products, add functionality or increase the performance of a product system, meet new requirements posed by market demand or legal requirements, reducing manufacturing cost, or provide compatibility with other products and technologies. Schulz et al. [31] use four dimensions for evaluating the strength of a technology: superior performance, maturity, robustness and flexibility. Reused technologies have potential to contribute robustness and maturity due to the existence of prior experience and proof-of-concept in former applications, but that's contingent on the similarity between the prior and new contexts.

3.3.2. Cost

Even if a technology is reused, it will likely require investments in new equipment, training of developers and manufacturing staff, and additional technology development to synchronize with the new application. It may also incur additional recurrent costs for manufacturing and maintenance of the product system. Contingent on the challenges related to capability transfer, there may also be substantial transaction costs for rebuilding the necessary competences in the recipient unit [32].

3.3.3. Relative Strength

A reused technology is by definition not new and may be deeply rooted in the firm's routines, which means there is an increased risk that opportunities of new superior technologies are overlooked [30], [32], [33]. Hence, besides the immediate positive effects that the technology is intended to bring to the products, attention should be paid to how it compares to competing technologies that the firm could invest in. It might even be the case that the new product can perform satisfactory with a technological base already tested in that application, and that R&D budget should be spent elsewhere.

4. TERA – Proposed tool for technology reuse assessment

The tool TERA was designed to help companies address the most critical aspects when making decisions and planning for introducing technologies in new contexts of application. This section covers the requirements we set up to guide the development to make it useful in practice, as well as a description of the resulting Word template and assessment process that are necessary to complete the assessment.

4.1. Requirements on the Tool

4.1.1. Involve stakeholders

Insights for making the reuse decision and planning for technology integration can come from several sources. Managers can contribute a strategic and economic perspective regarding the value of the technology and its related costs, while subject matter experts know best the possibilities and limitations of the technology. In order to understand what changes from an existing application to a new, experts from both sides of the transfer need to be involved. This also helps to generate commitment from both sides to participate actively in the transfer and trust the plans for technology integration. Hence, a mix of managers and experts from both the source and recipient organizations should be involved and queried for input to the preparation for technology reuse.

4.1.2. Encourage discussions

Stakeholders have different knowledge and interest in a technology and will naturally perceive a case for technology reuse differently. In order to make the team wiser than its individual members, it's important that they can share their ideas and reason about how the case is affected by various factors. If the tool supports an open and thorough discussion amongst the team members, the mutual understanding will increase and the reuse preparation will likely be better.

4.1.3. Support comprehensiveness of analysis

Technology experts can surely identify many influencing factors for the transfer immediately. However, there are many uncertain factors in technology development that can greatly impact an application project and chances are that some are overlooked. In prior research, some typical problems have been identified that can be put in a checklist or guide that reminds the assessment team to consider these factors.

4.1.4. Provide overview of reuse readiness

For stakeholders that are not familiar with the details of the reuse case, e.g. within management, it can be beneficial to create an overview that characterizes the readiness and risks of the reuse case to make it comparable to alternative solutions and previous reuse situations.

4.1.5. Ease of use

The tool is intended as an initial overview and identification of what challenges might be faced when reusing a technology. Hence, to be perceived as purposeful it is advisable to not have a process that is cumbersome to initiate and use. Also, it is likely that it will be used rather infrequently by the same people, who thereby need to refamiliarize themselves with it before using it. As a result of the assessment, more thorough investigations and development efforts can be prioritized and initiated. This way, resources are allocated only after the overall feasibility and business case have been deemed sufficient for pursuing the reuse project.

4.2. The TERA tool and process

The proposed solution is a workshop for discussing technology reuse readiness, using a scorecard in the form of a Word template as a mediating tool that features questions regarding all the identified dimensions covered in section 3 of this paper. Each of the six dimensions for Technical Readiness and Capability Transfer Readiness is represented in the scorecard like the one shown in Figure 2. Business Case aspects are covered more briefly along with a recommendation to add an appendix according to the company's choice of format for such calculations. Each dimensions (e.g. Robustness shown below) was broken down into three to five factors to be scored and commented on as a collaborative effort by managers and subject matter experts from both the source and recipient organization, with around 5-10 participants in total for the workshop.

The process for filling out the TERA scorecard during a workshop is as follows:

1. The workshop starts with an initial "first-to-mind" assessment of the business case and readiness for technology reuse, with the purpose of capturing the most apparent factors for the reuse decision. This is completed separately by the participants of the workshop and is then summarized as a first step in the workshop.
2. Next, a more thorough examination of the technical and transfer readiness is performed, guided by a framework of dimensions and factors that typically affect technology reuse success. Scores on a scale from 1 to 5 shall be agreed upon by the participants for each factor. The purpose of the scores is to stimulate and guide the discussion towards a shared understanding of the case at hand. Accompanying each score is a confidence rating to allow participants to indicate their confidence in the given score. For example, if there is little agreement on a score or if the participants feel it's an uncertain guess, they can indicate a low confidence.
3. When each factor of a dimension has been assessed, the participants fill in recommended actions that can mitigate identified risks or in other ways facilitate the technology reuse case.
4. Scores and recommended actions are then summarized.
5. After reviewing the initial and thorough assessments made, a recommendation for whether and how to continue with the technology reuse initiative is compiled. Reviewing the "first-to-mind" assessments can also serve to evaluate the usefulness of conducting the full assessment.

B1. Robustness (Technical Readiness)

Influencing Factors	Assessment	Score (1-5)	Confidence (1-5)
B1.1. The source unit has extensive experience from using the technology in previous applications.			
B1.2. The performance of the technology is robust also when conditions change in the context for application.			
B1.3. It can be well predicted how the technology affects the operation and requirements of a new product and its manufacturing.			
B1.4. It can be well predicted how a new context of application affects the technology and its operation.			

Recommended Actions:

ID	Action	Responsible	Due Date	Time/Cost Estimate
AB1.1				
AB1.2				
AB1.3				
AB1.n				

Figure 2 A page from the TERA Word template, showing how to assess the dimension Robustness.

The result from a completed assessment is a summary of the preconditions for technology reuse and a list of recommended activities to mitigate potential challenges for technically adapting the technology to the new application and to ensure successful transfer of the necessary competences and experiences.

Key users have been exposed to several versions of the method along its development and the responses about its usefulness have been positive. The first versions of the TERA tool have been applied in three situations where personnel involved in technology transfer have been guided through a draft version tool and given the chance to assess its usefulness. The version of the TERA tool presented in this paper has thus gone through a first series of validation exercises. It will now undergo more extensive validation involving multiple organizations, which is left for future work at this stage.

5. Conclusion

A methodology featuring a scorecard and a process for completing it in a workshop format was proposed in this paper to meet companies' need for a structured approach to evaluation of technology reuse feasibility. The scorecard features nine dimensions, six related to reuse readiness and three related to business case, to be evaluated by a team of managers and subject matter experts. It differs from the widely popular TRL assessments on two main points: it is specifically designed for evaluating an already proven technology, although the application is new, and it is intended for earlier stages of planning for technology integration.

Based on the first set of feedback from users at the company, we conclude that the TERA tool provides an organized way of capturing information related to transfer of technology that was previously captured implicitly. Users claim usefulness already as is, which in this context is clearly positive. More rigorous validation is needed to judge generalizability, ease of use etc., which requires more situations and users to be exposed to TERA.

If the remaining validation is successful, use of the TERA methodology and tool will help companies improve quality of technology integration decisions, allow better collaboration between the transferring parties of technological competence transfer, and reduce unanticipated problems in technology application projects. In addition, the existence of a process for considering technologies for reuse will hopefully encourage and support companies to do more such assessments, leading to better reuse of technological competences that they have acquired.

There are some limitations to the use of the methodology that should be considered before implementation. In order for the assessment to work, there needs to be a clearly defined case with a technology to be reused, experts that can participate in the workshop and a target context of application. The scorecard and its accompanying process for completion can then serve as an initial investigation of the potential and challenges of transferring a technology to the new context of application. This is a situation where a TRL assessment would likely be too cumbersome or not applicable since no tests have yet been performed in the new environment.

A constant risk when using a checklist for evaluating a situation is that issues that are not covered in the list are more easily overlooked. The First-To-Mind assessment, a quick general reflection before heading to the guided assessment, is intended to hinder such oversights, but a participant who is familiar with the checklist may already be thinking along the lines of the dimensions of the tool at that point.

Finally, the business case aspects are not developed to the same extent in the proposed methodology as the readiness aspects. The reason is that companies normally have processes for such evaluations already, and it would be advisable for companies that use the TERA to decide on a template or format for a separate business case assessment to include as an appendix.

6. Future work

The next step after creation of the presented methodology is to test it on more real cases in industry to validate its usefulness and its capability for actually predicting future challenges in technology reuse. For generalizability it should preferably be tested on different types of technologies and in different industries. The assessment received great interest at a meeting with technology managers at another large company based in Sweden, and they plan to test the tool on real cases during 2015. Hopefully these tests will be made in time for presenting preliminary results at the 2015 CSER.

A possible way to extend and improve the methodology is to prepare recommendations of how to tackle low readiness in typical problem areas. As for now, it only supports the identification of low maturity without providing guidance on how to mitigate it. It is the hope of the authors that such support will be made available in future versions of the methodology.

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