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Translating Technology Management Research into Practice: System Design Characterization as an Example

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***Abstract*--The importance of translating research into practice is well established. Research has shown that management consultancies and other intermediaries provide a key mechanism to disseminate academic knowledge to industry. This paper presents a process for, and lessons learned from, translating a research output into a business improvement tool.**

System Design Characterization (SDC) was developed based on the theory of technical systems to support new product, service and system design. With the aim of clarifying design specifications, SDC encourages development teams to consider new factors, including environmental sustainability issues and stakeholder interests, in the engineering design process. The design specification is clarified through iterative examination of the interrelationships between existing and to-be-created elements of the new design, and their relative importance to the end customers.

SDC was initially created and stabilized as a research instrument, but was thereafter improved into a business tool. This paper first presents the theoretical basis and the original instrument developed for research. The methodology of procedural action research applied in creating the beta version for industry is then outlined. Feedback gathered in the course of developing the improved SDC is summarized to provide practical guidance to academics interested in a similar approach to disseminating research output.

I. INTRODUCTION

Many have recognized the importance of industry's adoption of academic research outcomes, and the failing attempts by researchers to translate knowledge they produce for practitioners [e.g. 20,26,27,29]. However, there are examples of successful industry adoption of academic research, such as the Fast-Start Technology Roadmapping [21]. Intermediaries, such as management consultancies, are often referred to as the main channel to disseminate such academic knowledge to industry [2,3,5]. Therefore, it is important to further investigate the role of intermediaries in knowledge translation, especially in areas that is important to businesses, but complex to manage.

One business process that is complex and difficult to manage is the new product development (NPD) process. NPD is reported as one of the most risky business activities, with about 25% commercial failures and 45% of expenditure on unsuccessful new products [12,14]. A company's ability to manage its NPD has been shown to strongly correlate to its profitability [30]. Early attention to risk, right from the early stages of design and development, can significantly reduce cost and lead time of new product introduction [6].

With a growing number of traditional manufacturing firms offering services to complement their products [31], the new product introduction now needs to also manage the development of systems of products and services, also known as product-service systems (PSSs). New PSS development poses even a greater challenge than the traditional NPD. This paper uses as an example, research output used to support the engineering design stage of new PSS development, to illustrate how a research outcome may be translated into a business improvement tool. The tool is called System Design Characterization (SDC).

SDC, in its original form as a research instrument, was developed using case study methodology, and was stabilized for companies of different sizes, countries of origin and industries through the procedural action research (PAR) methodology. As a research instrument, its purpose was for analyzing new PSSs under development in companies. PAR was further applied to translate the research instrument into a business improvement tool. This paper aims to draw practical lessons from this process of translating SDC from a management research instrument to a business tool used by practitioners for academics interested in bridging the gap between research and practice.

The following section presents a literature review of the challenge of knowledge translation as well as methods used for business tools development. Section III presents the SDC in its original form as a research instrument. This is followed by an explanation of why procedural action research method was selected for the knowledge translation. Section V presents the findings of the first action research workshop, where an adapted version of the SDC is tested. The discussion in section VI focuses on the role of facilitators in the workshops and the types and magnitude of changes required on the tool. The paper concludes with a summary of findings and their limitations, and some preliminary practical guidance for academic researchers who are working on or are interested in translating their work into business improvement tools for practitioners.

II. LITERATURE REVIEW

In this section, literature about the challenge of translating academic research output into business practice, and the methods used for developing tools for business and management are reviewed.

A. The challenge of translating academic research output into business practice

Several scholars have discussed their growing concern over the widening gap between research and practice in the field of management. They highlight how results from academic research are typically not found useful for solving practical problems. Some management journals have gone as far as dedicating special issues to this problem, highlighting how most of what management researchers present as findings and contributions to knowledge fail to resonate with practice [e.g. 1,8,26]. While the research-practice gap is recognized and increasingly discussed, it largely remains [2].

Different causes have been attributed to the research-practice gap. According to [2], these causes, also referred to as paradoxes, include: researchers' preference for producing knowledge over its translation and dissemination; incentives that encourage researchers to produce research rather than engage with practitioners; and differences between researchers and practitioners in 'language' and how they represent information. Some of these causes are institutional in nature, such as where policies and incentives surrounding career progression in the typical academic institution do not encourage research-practice collaboration. Resource and time constraints imposed on the academic environment may also play a role in hindering potential academic-practitioner collaborations [27]. Furthermore, the traditional academic publication process rates submissions for journals almost entirely on their theoretical contribution and does not require any practitioner application. Scholarly journals often lack practitioners in their boards or acting as reviewers [25]. These paradoxes tend to work in combination to pose the problem as manifested by the gap. This problem has been framed in at least two ways [32]:

- A knowledge production problem
- A knowledge transfer problem

The knowledge production problem, where the type of knowledge generated by researchers is not directly relevant or suitable for application by practitioners [32], may be solved by increased collaboration in defining and developing research between scholars and practising managers [27]. The knowledge transfer problem relates to the failures of translating and diffusing research knowledge into practice [32], and may be solved by more effective translation of management research output into frameworks, tools, etc., that managers can effectively apply [27], or assimilate into their established heuristics for decision making [11]. There is also the additional problem that research and practice are fundamentally different in the ontologies and epistemologies they follow to address problems.

It is important to note that not all scholars readily accept these problems that constitute the research-practice gap are worth solving, or that the typical solution offered are the appropriate ones. For example, McKelvey questions the ability of collaborations between research and practice to create any significant or novel research, and questions the motives scholars that work with practitioners [20]. In addition, McKelvey suggests that companies would be unwilling to collaborate because of the risk of sharing useful and sensitive information, upon which their competitiveness might depend with the outside world [20]. Kieser and Lener agree that the knowledge production problem should not be tackled by collaboration, as it does not necessarily lead to better research, but argue that the focus should be on knowledge transfer [13]. Hodgkinson and Rousseau vigorously disagree [9] with Kieser and Lener's argument [13], explaining that their submissions are inconsistent with available evidence. They cite contemporary and classic examples of collaborations between practitioners and scholars and show that these types of collaborations are becoming increasingly normal and legitimate.

One of the examples provided by Hodgkinson and Rousseau highlighted the role that intermediary institutions play in promoting relations between practitioners and scholars in the research process [9]. The roles of these intermediaries are discussed in greater detail by Bansal et al. to include [2]:

1. Identifying appropriate research questions, in such a way that they resonate with practitioners' concerns, but framed in a way that is researchable by scholars
2. Shaping knowledge production, in such a way that it has both the rigor of research and the necessary relevance of such knowledge to practice
3. Translating knowledge, especially in the aspect of re-shaping research output into tools, reports, and visuals that are easily digestible by practitioners
4. Disseminating knowledge, beyond the avenues of conferences and journals normally used by researchers, into wider and more varied means of reaching and enabling practitioners
5. Moving beyond ideas to action, such as to enable practitioners absorb, embed and apply research output to their specific contexts (e.g. through action research)

Note that it is possible to classify these roles of intermediaries as either addressing the knowledge production problem (the first two) or the knowledge transfer problem (the last three). While Bansal et al. discussed in [2] their personal experiences that intermediaries can facilitate the working together of researchers and practitioners, they did not provide specific guidance for researchers on how work, such as translating research output into usable formats by practitioners, might be carried out. Such guidance is important because as identified by Kimberly in [14: p.144] "researchers have a set of skills and competences that well serve the research community but that do not easily and naturally transfer into settings that demand effective, client-oriented problem solving-skills". It is this challenge that this paper addresses, to show how researchers' competences might be stretched in such a way to be applied to solving practitioner-oriented problems. The paper also aims to provide additional learning on points 3 and 5 of the roles of intermediaries presented above.

In the next sub-section, the methods for business tool development are reviewed.

B. Methods for business tool development

The purpose of business tools is to facilitate or improve activities of interest in an organization such as strategy development, design and marketing. The methods to develop business improvement tools that are based on academic research findings would naturally need to bridge the gap between research and practice. Action research, which is a family of approaches and practices [4] used for investigating issues among groups of people in social settings [18], is an appropriate method.

Many consider Kurt Lewin's social science studies in 1946 on minority problems and inter-groups relations in the U.S. [18] as one of the first action research studies. According to Lewin, action research is not to propose general laws of causal relationships between conditions and outcomes, but to diagnose specific situations for the application of the general laws [18]. In a cyclical manner, action researchers diagnose specific situations, plan actions, take actions, evaluate effectiveness of the actions and specify learning [18,29].

Apart from its application in social science studies, action research has been called upon to bridge the research and practice gap in organizational management [29]. Traditionally, organization studies employ positivist methodology, which is 'value neutral' in its epistemology [29]. Positivist researchers study participants as objects in order to generate knowledge through induction or deduction [29]. The epistemology of action research is different - knowledge is created through conjecturing. Action researchers and participants test out these conjectures through planned actions and evaluate the outcome through reflection. Knowledge generated from action research is situational and bound by context [24,29].

Given its epistemology, action research is also found to be appropriate for developing new process to support organization's strategy formulation [e.g. 23]. By using similar cyclical action research steps explained above [29], Platts et al. developed and tested their new manufacturing strategy process in workshops. They applied this new process in different situations and assessed its effectiveness [23]. The assessment criteria applied were *feasibility, usability* and *utility* of the process [22,23]. Feasibility assesses how well the process can be followed as laid down. Usability examines how easy it is to follow the process. Utility evaluates whether the process has resulted in the desired outcomes, and whether the participants and their organization found it useful [23].

Maslen and Lewis further formalized action research as a procedural approach [19]. They proposed a research framework for developing new procedure, and a testing framework for evaluating the new procedure developed. The research framework shows that the causal relationship between planned actions and their effect on participating organizations is impacted by contingent factors. The testing framework explores these contingent factors by applying the procedure in different contexts. The researcher is to identify different case studies to apply the procedure and track the success of each application. The development cases are primarily used for developing the procedure, and the test cases primarily for developing the contingent framework. The end result is the proposed procedure and its contingent framework.

In this paper, the details regarding how an output of academic research is translated into a business improvement tool (called the System Design Characterization or SDC) is presented, showing the influence of procedural action research (PAR) to ensure the knowledge generated is aligned with practitioner needs. The roles of the intermediary and the researcher, whose role it was to actively ensure that the research knowledge was appropriately translated into a form that is found usable by practitioners throughout this process, is also highlighted.

The context for the translation of research into a business tool is the Institute for Manufacturing (IfM) at the University of Cambridge, which is primarily a division of the University's Engineering Department. IfM has approximately 250 people and conducts research spanning Management, Policy and Technology issues related to manufacturing industries. Within the IfM, the Education & Consultancy Services (IfM ECS) unit has the primary function to disseminate IfM's research output. IfM ECS therefore acts as an intermediary organization between IfM researchers and practitioners in companies, industry sectors and governments. IfM ECS has a team of specialists dedicated to helping researchers translate their research into usable formats for practitioners. The research referred to in this paper was completed at the IfM, and translated for practice with the help of IfM ECS specialists.

III. SDC AS A RESEARCH INSTRUMENT

Before going into the method employed to develop SDC as a business improvement tool, it is necessary to first describe what SDC is as a research instrument. As a research instrument, SDC was called the PSS Characterization Approach - a five-step workshop process. To avoid confusion, in this section and the two following sections, the SDC as a research instrument is referred to as the "PSS Characterization Approach".

The PSS Characterization Approach was used to analyze new PSSs (product-service systems) under development by manufacturing and service-providing companies. The objective of the approach was to ascertain whether a proposed scheme, developed from research to characterize PSSs at early stage of their design, could clarify design specifications for the companies. This PSS characterization scheme comprised four characteristics: customer perceived value level, 'connectivity number', type and degree of connectivity and type of PSS configuration [34]. To reflect the broad range of decisions companies needed to make at the end of the engineering design stage, design specification in this research was defined to include the considerations of technical, procedural and stakeholder needs, where stakeholders can be both human and non-human in the environment.

The PSS characterization scheme was extended from the theory of technical systems developed for mechanical technical systems [10], and was inspired by the marketing concept of value-in-use [e.g. 7,17] and a social science theory called actor network theory [16]. The PSS Characterization Approach itself was a technical system that transformed design objectives into clearer design specifications [10], while considering what the new PSS would need from, and how it would impact on, its operating environment [28].

The PSS Characterization Approach (Fig. 1) was applied in company case studies and in each case, was deployed in a workshop setting. Each workshop began with the company's new product and service strategy already defined. Before carrying out step 1 (PSS Depiction), the company could choose to go through the optional step of *stakeholder identification* especially if it had not already identified the stakeholders of the new PSS. Fig. 1 shows the five steps - *depiction, abstraction, decomposition, representation and characterization* - and the two expected workshop outcomes.

Following the procedural action research (PAR) method proposed by [19], in order to build and stabilize the PSS Characterization Approach, companies of different industries and sizes were targeted for case studies. After each workshop, feedback was solicited from the participants. Together with the observations and reflection notes from the researcher, the magnitude of each required change on the workshop approach, and any contextual requirements for applying the workshop were also noted. The magnitudes of change to the workshop approach were classified as primary, secondary or tertiary change (see Table 1).

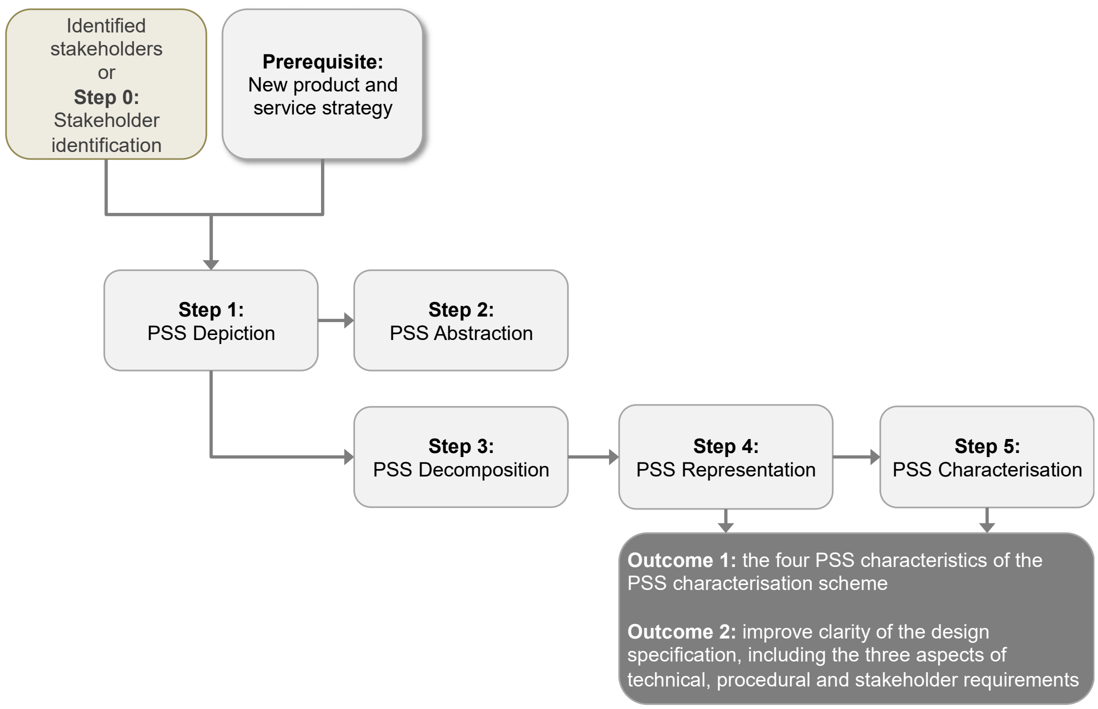

Fig. 1 The PSS Characterization Approach

TABLE 1 THE DEFINITION OF THE MAGNITUDE OF CHANGE

Magnitude of change	**Descriptions**
Primary	Change of the core content of a step. Add or remove main steps or sub-steps. Change the order of main steps. Add or reduce the number of symbols used in the tool Change the shape or color of symbols used in the tool.
Secondary	Change the order of the sub-steps. Add instructions into a sub-step. Digitalizing a main step or sub-step.
Tertiary	Clarify the wordings in an instruction. Clarify the key to the symbols used in the instrument.

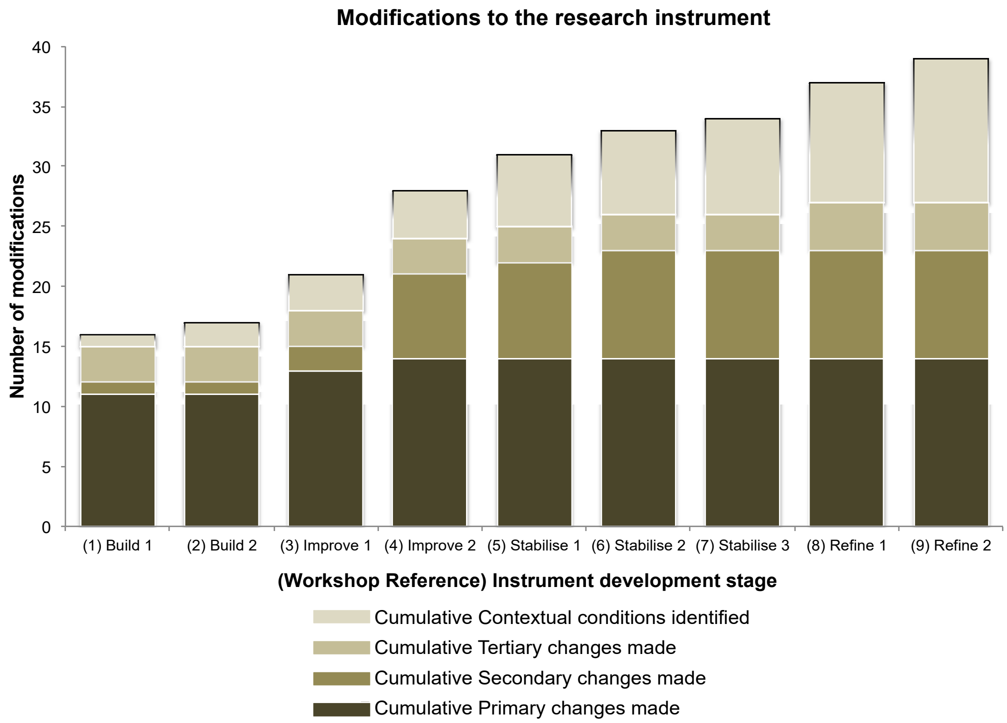

Fig. 2 Tracking of modifications to the research instrument [adapted from 33]

A total of nine workshops were conducted. Fig. 2 shows the modifications of the instrument, and the four phases that this research instrument had gone through - build, improve, stabilize and refine - in order to reach the state where it was fit for its purpose of supporting the systematic analysis of PSSs in further developing the PSS classification scheme. As seen in Fig. 2, the most changes made in the first two workshops were primary changes. The third workshop resulted in mostly secondary changes. After the fourth workshop, the number of contextual conditions identified increased while no further secondary changes were identified from the fifth workshop onwards, signaling the stabilization of the research instrument. At the final stage of refine, only one additional tertiary change was identified. It is logical to assume that with further application, more contextual conditions would be identified instead of changes to the instrument, leading to a more complete contingency framework for the application of the PSS Characterization Approach.

The PSS Characterization Approach was found to be feasible, usable and useful, the three criteria for assessing a new procedure proposed by [23], in supporting the engineering design process.

IV. METHOD OF DEVELOPING SDC AS A BUSINESS IMPROVEMENT TOOL

As summarized in the literature review on the method of business tool development in section II, action research is an appropriate method for business tool development. The PAR methodology [19] used for developing the research instrument (the PSS Characterization Approach), with the three assessment criteria of feasibility, usability and utility [22,23], was also selected for transforming the research instrument into SDC (System Design Characterization), now to be used as a business improvement tool. To overcome challenges associated with knowledge translation, the workshops to develop and test SDC under the PAR method were to be conducted with the help of a knowledge transfer intermediary. Fig. 3 provides a depiction of the approach used to create the SDC.

So that SDC as a business tool would be relevant to, and benefit companies in different industries and of different sizes, the companies to be used as test cases were targeted in different industries, country of operations and sizes. The companies should have new products, services or systems under development, which required clarification of their design specifications. The total number of workshops required for developing the SDC was not pre-determined. Instead, the strategy was to continue conducting the workshops until SDC became stabilized, that is when no further primary and secondary changes were identified, and perhaps only minimal tertiary changes and additional contextual conditions were identifiable.

To enable this strategy, after each workshop, feedback was to be solicited from the workshop participants on the three criteria of feasibility, usability and utility of the tool. Also, the workshop facilitators' observations and reflections were to be documented against these three assessment criteria.

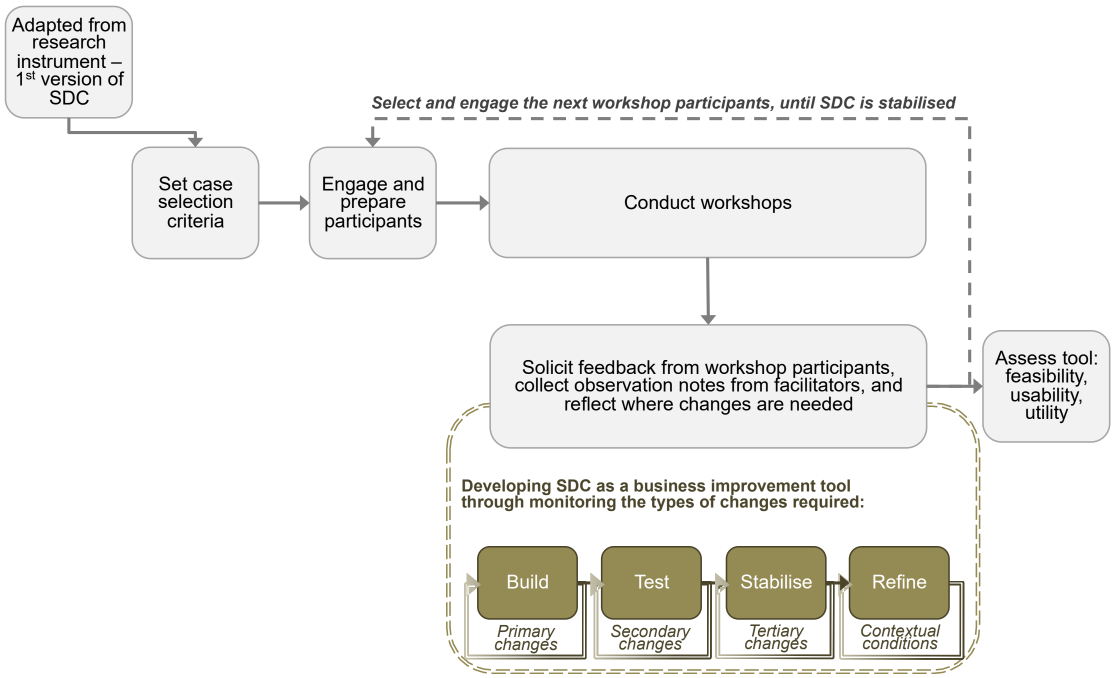

Fig. 3 The method to develop SDC as a business improvement tool

V. FINDINGS

At the time of writing this paper, only one workshop had been completed. This section presents the context of the first workshop and the reactions of the participants to the SDC's first version, which was adapted from the PSS Characterization Approach (i.e. the research instrument).

Before the first workshop, the researcher adapted the PSS characterization workshop after reflecting on what the most significant academic contribution of the PSS characterization scheme was. It was identified that the PSS configuration type [34] within the PSS characterization scheme was the most significant academic contribution. The sub-step to identify PSS configuration type, which was within step 5 or PSS characterization, was therefore moved up to become the first mandatory step after the optional step 0 of stakeholder identification (see Fig. 4). The intention was to focus the workshop participants to a particular 'configuration type' to design by requiring them to choose a type upfront. The original step 2 of PSS abstraction was also moved to become the last step, as this step was often referred back to at the end of the workshop during the PSS Characterization Approach development.

To give more visual guidance to the participants, two A0 size pages, printed with gridlines and legends, were prepared as templates for step 3 and step 4. A guideline about the five steps in the workshop was provided to the participants to read before the workshop.

A. Context of the workshop

The researcher expected that the first workshop would encounter many primary changes (see Table 1 for the definition of the magnitude of change). To avoid any adverse impact to a commercial offering, it was decided that the first workshop would be a business case about a hypothetical company developing a new PSS. The business case should be complex enough to test the feasibility, usability and utility of the tool, but simple enough to be completed within approximately four hours, a time period that participants can usually spare in a workday. The business case was about a local running club developing a new weekday run group. The new run group would be a new PSS, developed by the running club to align with its strategy of connecting local people. Four roles were involved in the business case: the running club manager, the running group leader, the marketing clerk and the procurement clerk. These four roles represented the interests of management, technical experts, market needs and operational needs respectively.

As the purpose was to develop a practical business improvement tool, four management consultants from the IfM ECS, who had an interest in new product/service development, were recruited as workshop participants. Each of them has between 20 and 35 years of industry experience before joining IfM ECS, and have held roles in general management, business development, marketing, new product development, manufacturing management, and project management. The participants were provided with the business case to read one week before the workshop and were asked to select their preferred role in the running club business case.

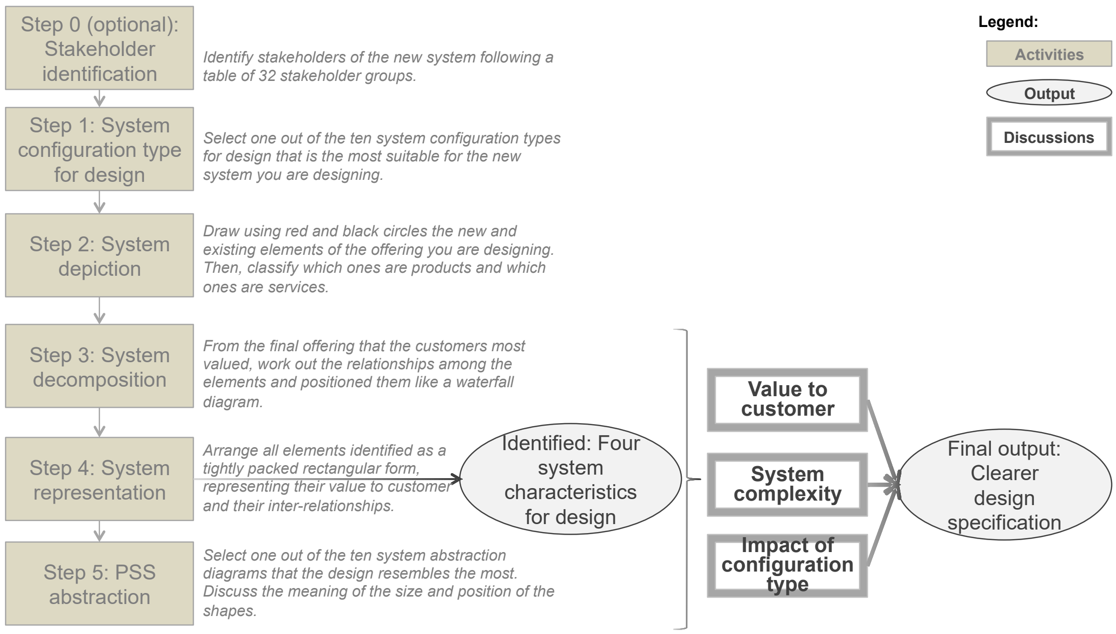

Fig. 4 The adapted PSS characterization process tested in the first workshop

The knowledge translator for this business tool development process was engaged in this workshop as the co-facilitator. A workshop facilitation guide was written and shared with the co-facilitator beforehand.

B. Assessment to the adapted PSS Characterization Approach (SDC's first version)

All participants had read the business case and the guidelines provided. However, they found the system configuration type for design too abstract to be relevant to the new PSS to be developed. In fact, the confusion created by this step was so much that the facilitators had to proceed without completing this step. Therefore, step 1 (system configuration type for design) was not feasible at all.

Step 2 (system depiction) was followed and completed without any difficulty, but the participants did not find this step adding much value to the design process. Upon reflection, the essential output of the step was the *elements identification table* (see Table 2), which was the input to step 3 (system decomposition).

Step 3 (system decomposition) was found to be feasible with the facilitators' guidance, but not easy to use. Visualization of the system decomposition, which was necessary for this step, had contained too many different colors and types of symbols. However, the participants found that overall, step 3 had high utility as they were able to discover many relationships among the system elements and with the operating environment that had been overlooked. Within this step, the participants suggested adding a procedure to indicate, on the decomposition diagram, which system elements customers would perceive as more valuable. This was taken on as one of points for improving the SDC.

Step 4 (system representation) was feasible and useful, but not very usable. The participants felt the process of completing this step tedious, but they saw the potential of seeing how the product portion and the service portion interacts within the system when the representation diagram was completed. The request was to automate this step as much as possible using computer software.

Step 5 (system abstraction) was found to be high in feasibility, usability and utility. The participants found the discussion of the relative size and positioning of the shapes representing the product elements and service components within a PSS meaningful and useful.

In summary, apart from step 5, all the other mandatory steps needed to be modified. Fig. 5 shows the overall feasibility, usability and utility of the five mandatory steps of the SDC. Even though SDC was stabilized in its previous format as a research instrument (i.e. the PSS Characterization Approach), many changes were still needed to make it practical for business use.

TABLE 2 ELEMENTS IDENTIFICATION TABLE (AN EXAMPLE)

Elements for delivering the functions	New (N) or Existing (X)	Product (P) or Service (S)
Evening running group	N	S
City run routes	N	P
Warm-up/Cool-down exercises	X	S
Suitable running gear	X	P

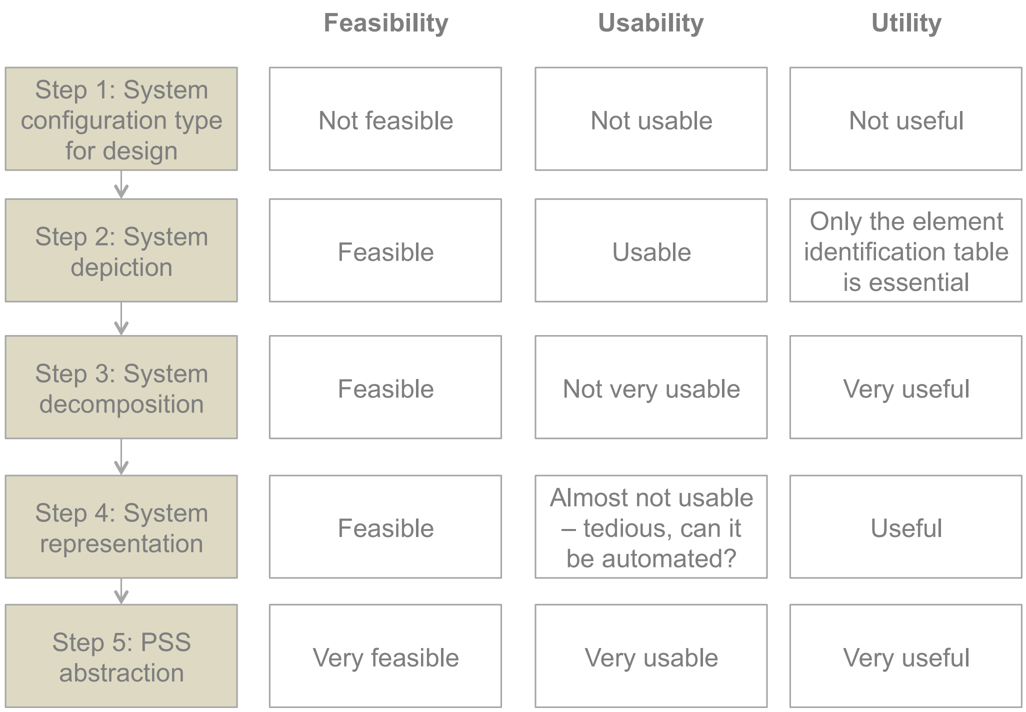

Fig. 5 Summary of findings

VI. DISCUSSIONS

A. Role of facilitators in knowledge translation

The two facilitators played different roles in this workshop. The main facilitator has over 10 years of professional facilitation experience in industry, and was also the original researcher who developed the SDC as a research instrument (i.e. the PSS Characterization Approach). Her primary role in the workshop was to guide the participants to follow the SDC steps, and to lead the feedback discussions on the feasibility, usability and utility of the tool. Her experience in industry allowed her to modify her style of facilitation and use 'language' that is more familiar to the practitioners. The co-facilitator is an employee in the IfM ECS whose specialty is in helping academic researchers translate their research outputs for practitioners. His main role in this process was as knowledge translator for the SDC. With his understanding of the purpose and theoretical basis of the SDC as a research instrument, and his interactions with industry and management consultants, his reflections on the comments and observations from the workshops were crucial to translating the SDC for business use.

Before the workshop, the co-facilitator put a lot of effort in understanding the research process and exploring how might practitioners view the SDC. He edited the workshop guidance notes to make it more practitioner-friendly, clarifying both the language and the process steps to be followed. The co-facilitator was also responsible for recruiting participants for the first workshop.

During each session of the workshop, which corresponds to a step in the tool, buffer time was planned for participants to ask clarifying questions. At the end of the workshop, additional time was planned to collect feedback from the participants on the process of applying the SDC tool and each step within it. The questions asked related to finding out which steps the participants found the most relevant and/or useful, and which steps are the most easy to use. The facilitators also took observation notes during the workshop. Immediately after the workshop, the facilitators exchange their observations, and over the days that followed, the facilitators independently reflected on them as well as the feedback from participants. Both facilitators then regrouped to discuss the changes that would be needed on the tool. Questions, comments and observations made during the workshop were scrutinized in an attempt to understand the underlying practical needs. Changes to the tool were suggested and debated against the criteria of feasibility, usability and utility. The proposals made by the co-facilitator were considered as more important than that of the main facilitator for translating the tool for practitioners. At the same time, the main facilitator had to push back on proposed changes that were not aligned with the theoretical basis of the tool.

The roles played by the facilitators before, during and after the workshop were in agreement to points 3 and 5 of Bansal et al.'s proposals [2] presented in section II. Their aims were to create the SDC from an output of research to a business tool that is more easily digestible by practitioners, and that practitioners can apply to their specific contexts.

B. The required changes to the SDC

The majority of the modifications required as a result of the workshop carried out were primary changes. No tertiary or contextual conditions were identified. This could imply that when translating a research output into a business tool, multiple iterations of design, testing (or application) and re-design of the business tool would be required before it is stabilized and ready for deployment. The example discussed in this paper suggests at least three iterations. The first for finding what type of changes are needed on the research output, if they were mostly tertiary and contextual conditions, and the second and the third to show that only additional contextual conditions are identified. The details of the required changes can be found in the Appendix.

Following the research method, Fig. 6 was prepared to track changes to the tool. This would also be a feedback to the case selection criteria (see Fig. 3).

To develop the business improvement tool for application across different industries, companies from different industries are to be targeted to participate in the future workshops. The resulting SDC, the beta version (see Fig. 7), will be used in the next workshop.

The changes to the SDC were based on the reflections of the observations and feedback obtained during the first workshop. The design of the roles of the facilitators as knowledge translators in the PAR methodology resulted in major changes to the SDC, moving it from its original research output format to a tool that is closer for practitioners to use in business environment.

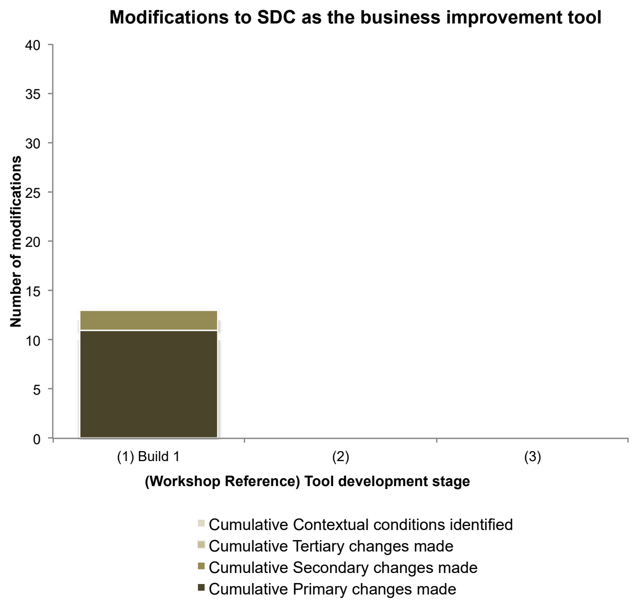

Fig. 6 Modifications to SDC as a business improvement tool

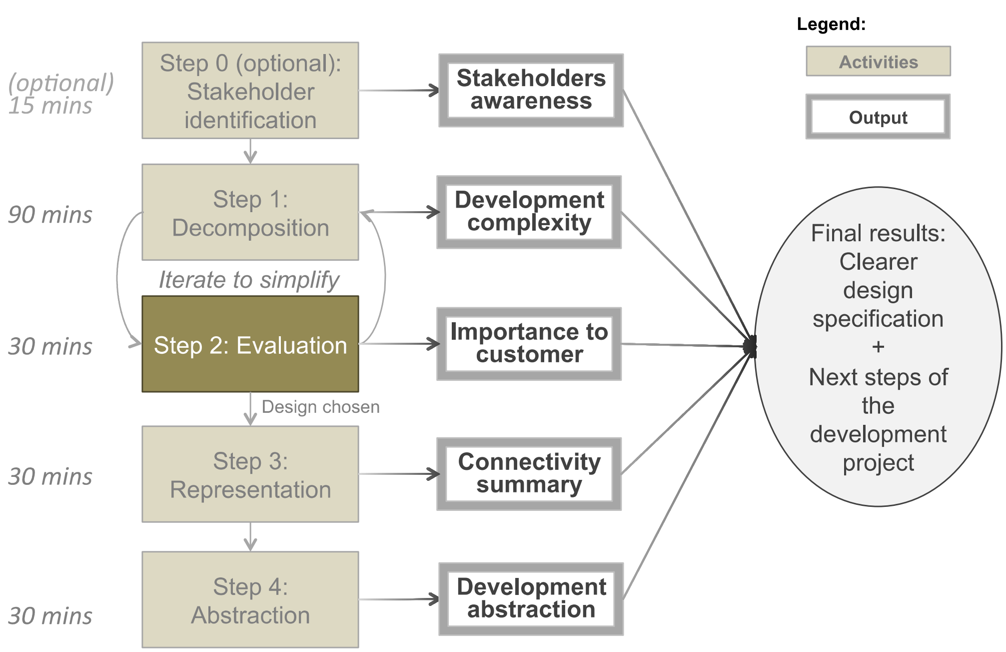

Fig. 7 SDC as a business improvement tool (the beta version)

VII. CONCLUSIONS

The recognition of the need to improve industry's adoption of academic research outcomes has motivated the authors to write this paper. Using the example of a research output named the System Design Characterization (SDC), an analytical instrument used in research that aimed at improving the clarity of PSS design specifications, this paper presented a process to translate a research output into a business improvement tool. In particular, the design of the roles of intermediaries in translating knowledge generated from academic research is detailed.

To help readers follow the steps taken to re-shape SDC for practitioners' applications, sections IV, V and VI presented the journey of knowledge translation in the specific context of the first workshop. Despite its utility and ease of application as a research instrument, it was found that four of the five mandatory steps of the SDC's first version required major modification to be feasible, usable and useful for practitioners.

The authors deliberated on the different roles of the two facilitators in the preparation, execution and reflection of the first workshop, and the importance of their background and skills in the knowledge translation process. The significance of speaking both the 'languages' of researcher and practitioner in moving the research output towards a business application was highlighted. The types of changes required on the tool were categorized, leading to the preliminary conclusion that at least three iterations are required when adapting a research tool for business.

The findings presented in this paper, although limited to the specific contexts of the first SDC workshop, have shown that a research tool can be systematically adapted into a business application. This can be achieved by adopting a procedural action research approach, and by carefully designing the roles of workshop facilitators. To show that the knowledge translation process presented is repeatable, the next step of this study is to recruit new case companies to apply the (beta version) SDC tool. The learning from the process of building, stabilizing and refining SDC as a business improvement tool can then be used to generate guidelines for academics interested in disseminating research output using a similar approach.

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APPENDIX

The required changes to the SDC's first version are shown in Table 3, and the magnitude of each change is classified according to the definition provided in Table 1.

TABLE 3 REQUIRED CHANGES TO THE SDC'S FIRST VERSION

Change descriptions	**Magnitude of change**
Remove the step to identify system configuration type for design	Primary
Reduce the depiction step into a pre-work task for the participants to identify all new and existing elements that are to be modified or involved in the new offering	Primary
Add a step, called Evaluation, after the Decomposition step, to evaluate the potential perceived importance of each elements to the target customers, that is arrange the importance of all elements in the decomposition diagram that are visible to customers	Primary
Add an iteration loop between the new Evaluation step and the Decomposition step to allow participants to simplify the design, simulate the impact of removing an element using 'connectivity number' as a measurement of design complexity	Primary
Instead of coloring the arrow shapes in the decomposition diagrams, put 2 in the arrow that needs to be colored black, and 1 in the arrow that needs to be striped.	Primary
Eliminate green sticky notes by using blue and pink for the infrastructural and operational environmental elements (note that color sticky notes are essential components of the SDC as a research instrument)	Primary
Introduce the sub-step of digitalizing the decomposition diagram, for reducing effort in building the representation diagram and in calculating the 'connectivity number' for simulating the design simplification in step Evaluation	Primary
Introduce new symbols: ^ > < v, on its own or with a number 1 or 2 on its left to represent the arrow shapes used in the physical diagrams	Primary
Reduce the complexity of the Representation step by only using the visible to customer elements to form the representation diagram	Primary
Remove the outer boundary of the representation diagram, which was representing the operating environment	Primary
Changing the Representation step into a digital-only step, with a digital template for calculating these values automatically	Secondary
Combine with the Representation step, a discussion with the participants on the value of the three system characteristics: potential value to customer, 'connectivity number' and type and degree of connectivity	Primary
Add in the concluding discussion of the Abstraction step, an instruction for the participants to agree on the next steps of the development project	Secondary