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Valorisation in the Process Industry: A Comparative Study of Five Cases

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Abstract: Process Intensification (PI) has large potential to make process industry substantially smaller in size, cleaner, safer and more energy efficient. But there are only few successful applications of PI when compared to the number of innovations demonstrated on laboratory scale. This research investigates ways to improve the chances of successful commercial valorisation of such innovative process equipment. A case study approach based on Q-methodology has been adopted in this research allowing an in-depth, multi-faceted exploration of complex issues in their real-life settings. Research findings show that there are four different perspectives in the process industry about valorisation of new technology. Three categories of critical success factors, namely Technology, Business, and Project Management are identified as being crucial for making a successful commercial application of new process equipment. A team that can independently integrate these three factors is essential for having successful valorisation. This is captured in a valorisation model.

Keywords: Valorisation, Innovation, Process Industry, Process Intensification, Project Management, Technology Management, Q-methodology

1. Introduction

The term valorisation is a theoretical concept coined by Karl Marx in his critique of political economy. Valorisation is the use or application of something (an object, process or activity) so that it makes money, or generates value. The BHR Group (experts in Fluid Engineering) describes PI as follows [1]: ‘PI technologies can challenge business models, opening up opportunities for new patentable products and process chemistry and change to just-in-time or distributed manufacture’. PI has been an active research field for the past few decades. Major multinational companies like Shell, DSM, Bayer, BASF are encouraging research in this field through dedicated funding at major universities and research organisations. TU Delft Process Technology Institute has a dedicated theme of research titled Process Intensification. The amount of resources being invested in this area is a sheer indication that there is enough being done in order to discover and develop breakthrough, innovative PI technologies. PI consultancy organisations are gradually increasing in numbers. Few networking platforms have also been established in order to bring together people interested in this field. For example, University of Newcastle hosts and maintains a forum called Process Intensification Network (PIN) where all those interested in the science, technology and application of Process Intensification can communicate effectively with others in the PI and related fields. This network’s membership and knowledge sharing has grown steadily in the recent past according to reports on their website. A similar network exists in the Netherlands and operates under the local Institute for Sustainable Process Technology (ISPT).

As far as the commercial implementations are concerned, process intensification technologies like, reactive distillation, dividing wall column distillation (DWC) and reverse flow reactors (RFR) have been implemented at commercial scale in the petrochemical industry [2]. However, the number of implementations is not satisfactory when compared to the amount of research carried out in this area [2]. There is comparatively less information about commercially operating

PI equipment both in literature and industrial databases. Thus one can infer that there is certainly a gap between Research and Development (R&D) and commercial implementation of the PI technologies.

Recognizing that gap the European chemical process industry established in 2008 EUROPIC – the European Process Intensification Centre [3]. EUROPIC is an industry driven platform for knowledge and technology transfer in the field of PI, that currently comprises circa 20 international companies based in Europe, USA and Asia, representing different sectors of the chemical process industry (bulk chemicals, specialties, pharmaceuticals, etc.)

The gap between R&D and commercial implementation can be understood using the Valley of Death analogy [4]. A difficult period, known as the valley of death, is experienced by all Small and Medium scale Enterprises (SMEs) as their need for funds increases and they rack up large accumulated losses before profits from sales can be realized. SMEs that engage in technology transfer and new product development face the greatest difficulties in making it through these challenging times [5]. This valley of death analogy can also be provided for Process Intensification technologies. Having invested significant capital for R&D in this area and a number of technologies being demonstrated on laboratory scale, it would not be incorrect to say that the time has come for the PI technologies to pay attention and carefully cross the valley of death; otherwise these innovations face the danger of being shelved even after demonstrating the value on a laboratory scale. This summarises the need to carry out a research that focuses on identifying ways to improve the valorisation process.

In this study, the focus is on valorisation of new and innovative Process Intensification (PI) technologies. The objective of this research is to investigate ways to improve the chances of making a successful commercial application (valorisation) of innovative process equipment. Firstly, it is to be understood that valorisation of innovative process equipment is an inherently challenging and complex endeavour, in particular, for Process Intensification technologies. Extensive scientific literature deals with the theory of technology commercialisation. However it seems insufficient to guide practitioners in the process industry, where multi-actors are jointly involved in the valorisation process. The challenges are even escalated due to different backgrounds and perspectives of the actors, which often lead to contested interaction among actors in valorisation processes. Hence we need to investigate the involved actors' perspectives about new and innovative technology in order to understand what lies behind their actions. Secondly, in order to valorise innovative process equipment, it is crucial to focus the research on the process industry and identify the success factors that are specifically relevant to the actors involved in valorisation.

A case study approach has been selected for this research. Process Intensification is chosen as a theme for the case study since this class of technologies is highly innovative and relatively new in comparison to the conventional processes that exist in the process industry. Q-methodology, which is a combination of quantitative and qualitative case study methods, has been used to design and execute the case studies. Analysis of the obtained results from Q-methodology provides answers on perspectives and critical success factors. The performance of the various technologies was analysed in the next step using a score-sheet type questionnaire, developed to measure the performance of each case individually. The results from the application survey were analysed together with results from Q-methodology to investigate the influence of perspectives on the performance of the cases. As a final step all results have been combined in a simple valorisation model.

2. Research Objective and Research Questions

The objective of this research is to facilitate and improve the chances of making a successful commercial application (valorisation) of new and innovative process equipment. The following research questions are asked to meet the research objective:

1. What perspectives (subjective viewpoints) exist among people in the Process industry about new and innovative process equipment?
2. What are the Critical Success Factors (CSFs) perceived by actors involved in valorisation?
3. How have the chosen PI cases performed in applying these CSFs?
4. How do the existing perspectives influence the performance of valorisation of respective PI cases?

3. Literature Review

3.1. Valorisation

The context of valorisation of technology can be best understood by reviewing the literature terminology that is often cited as 'Diffusion of Innovations' [6, 7, 8]. Diffusion of innovations is a theory that seeks to explain how, why, and at what rate new ideas and technology spread through society. Diffusion of innovations can be categorized based on the adopters of the technology starting from the innovator who develops it at the laboratory until the final taker who adopts the technology decades after the technology came into existence. Rogers defines an adopter category as a classification of individuals within a social system on the basis of innovativeness. In the book Diffusion of Innovations, Rogers suggests a total of five categories of adopters in order to standardize the usage of adopter categories in diffusion research. The categories of adopters are: innovators, early adopters, early majority, late majority, and laggards [9].

The adoption of an innovation follows an S-curve when plotted over a length of time [10]. The S-curve concept is a theoretical depiction and in reality transitions will not always be that smooth. Moore [8] argues that there is a chasm between the early adopters of the product (the technology enthusiasts and visionaries) and the early majority (the pragmatists). Moore believes visionaries and pragmatists have very different expectations, and he attempts to explore those differences and suggests techniques to successfully cross the 'chasm,' including choosing a target market, understanding the whole product concept, positioning the product, building a marketing strategy, choosing the most appropriate distribution channel and pricing. According to Moore, the marketer should focus on one group of customers at a time, using each group as a base for marketing to the next group. The most difficult step is making the transition between visionaries (early adopters) and pragmatists (early majority). This is the chasm that he refers to. If a firm can create a bandwagon effect in which enough momentum builds, then the product becomes successful. Moore's chasm is applicable for disruptive or discontinuous innovations. Adoption of continuous innovations (that do not require a significant change of behaviour by the customer) is still best described by the original technology adoption lifecycle. Confusion between continuous and discontinuous innovation often leads to the failure of high-tech products.

In this regard it must be clearly understood at this stage that the Process Intensification technologies fall under the category of discontinuous innovations since they demand a significant change in the behaviour of the customers. Here the term customer primarily means the 'process and chemical industries' where there is still a conception that 'bigger is better'. However, the successful valorisation of technology is all about effectively and efficiently crossing this chasm. So the first deployment of new process equipment must be impressive enough to cross this chasm.

The concept of valorisation of innovative technologies is often cited in the literature either individually or by combining three areas of research namely Innovation management, Technology management and Knowledge management [11]. Eveleens [12] has reviewed all three areas. He notes that the research on innovation and/or technology management has significantly increased over the past 35 years. The key reason for this interest is that innovation is of key importance for the survival of an organisation. And in Cooper's words, 'its war: innovate or die' [13].

There is a clear debate in the literature about what or when an innovation needs to achieve in order to call it successful. Authors differ in including [14, 15] or excluding [16] the post launch or commercialisation phase of the innovation process. But in all cases, innovation is not only the creation of an idea but also the implementation of it [12]. Summarising various technology management models, Eveleens suggests that the main phases of innovation and technology are: idea generation, selection, development and demonstration, implementation/launch, post-launch learning/evaluation, commercialisation. However, the major shortcoming in all the models is the lack of a clear depiction on how to bridge the gap between demonstration phase and deployment phase.

Following Eveleens' phases, the valorisation can be positioned in the transition from the demonstration phase to the first deployment (implementation) of the technology. In this research, the valorisation focuses on the first deployment or first implementation of capital-intensive innovations in the process and energy industry. It includes three sub-phases: pre-deployment, deployment and post-deployment. The market capture or commercialisation and replication of these innovations is not included in the scope of this study.

3.2. Process Intensification

The phrase Process Intensification as such is not something new [17], the term process intensification (PI) was probably first mentioned about four decades ago [18, 19]. Ramshaw was among the initial pioneers in the field of process intensification [1]. Over the last four decades, different definitions of this term have been published. PI is defined as [20]: 'Process Intensification is a term used to describe the strategy of reducing the size of a chemical plant needed to achieve a given production objective'. In a review of PI [21] it was proposed that: 'Any chemical engineering development that leads to a substantially smaller, cleaner and more energy-efficient technology is process intensification'. In this research, the definition provided by the European Roadmap for Process Intensification [3] has been adopted. This is the most recent definition for PI. 'Process intensification provides radically innovative principles in process and equipment design which can benefit process and chain efficiency, capital and operating expenses, quality, waste, process safety and more.'

The portfolio of PI technologies includes process-intensifying equipment (PI hardware) and process-intensifying methods (PI software) as classified in Figure 1 [22]. In this section an example each from PI hardware and PI software is provided for the sake of getting an insight into the PI world.

1. Process Intensifying Equipment (Example – Micro reactor)

Microreactors are chemical reactors of extremely small dimensions that usually have a sandwich-like structure, consisting of a number of slices (layers) with micro machined channels (10–100 μm in diameter). The layers perform various functions, mixing to catalytic reaction, heat exchange, or separation. Integration of these various functions within a single unit is one of the most important advantages of micro reactors. The very high heat transfer rates (even values up to 20,000 W/m^2K are reported achievable in micro reactors allow for isothermal operation of highly exothermic processes (also important in carrying out kinetic studies). The very low reaction-volume-to-surface-area ratios make micro reactors potentially attractive for carrying out reactions involving poisonous or explosive reactants (think about partial oxidation reactions [22]).

2. Process Intensifying Method (Example - methyl acetate plant)

This is one famous example in which a task-oriented integration of reaction and separation in a multifunctional reactor reduced the number of pieces of equipment from 28 to 3. It has also led to a dramatic reduction in energy consumption (85% reported). Interestingly this is one of the few cases mentioned in textbooks about Process Intensification being successfully commercialised.

The European Roadmap for Process Intensification claims that Process Intensification can address important needs of the process industry, even though these needs vary considerably between sectors. Based on applications the following sectors have been identified in the roadmap: PETCHEM (Petrochemicals, bulk chemicals), FINEPHARM (Specialty chemicals, pharmaceuticals), INFOOD (Food ingredients) and CONFOOD (Consumer food).

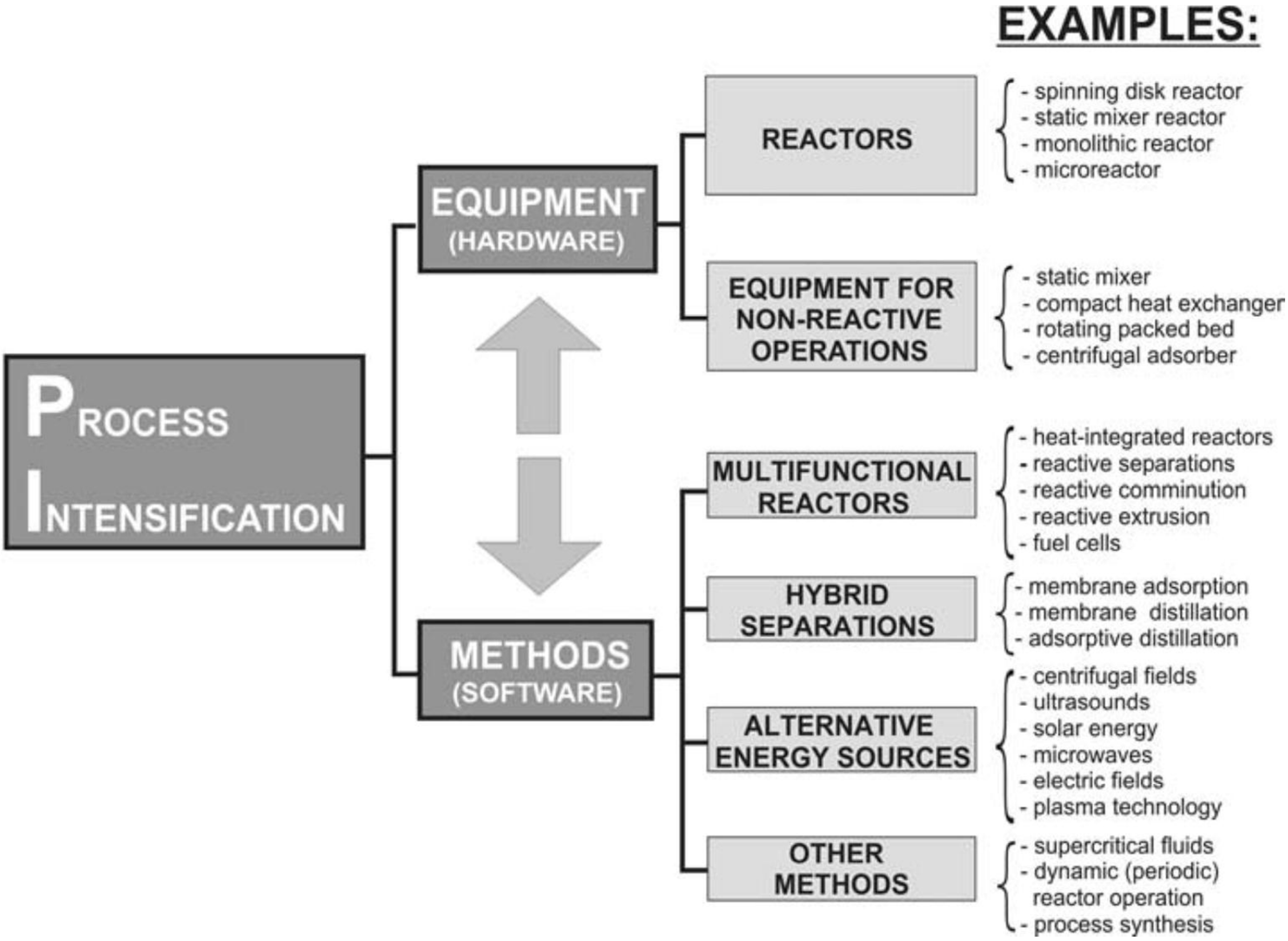

Figure 1. *Classification of Process Intensification (retrieved from [22]).*

PI technologies have been attributed with four drivers for innovation in the chemical process industry [2]: feedstock cost reduction, capital expenditure reduction, energy reduction and safety risk reduction. The philosophy of process intensification has been traditionally characterized by four words: smaller, cheaper, safer, slicker [22]. They also mention that equipment size, land use costs, and process safety are among the most important PI incentives. Apart from these, process intensification can (and should) also be placed in a broader context—the context of sustainable technological development.

PI technologies have been attributed with four hurdles for innovation: risk of failure by combining novel aspects, scale-up knowledge uncertainty, equipment unreliability and higher Safety, Health, Environmental risks compared to conventional technologies [2]. But, there is no explanation provided why these are considered hurdles and what can be done to overcome these hurdles. This topic is dealt with very superficially in the literature. One can notice that there is more information on drivers for PI than hurdles for PI. This literally does not help in understanding why it is difficult to valorise process intensification technologies. Furthermore there is not much information on actors and factors that are needed to realise successful valorisation. PI technologies seem to be finding it hard to cross the chasm and hence this theme is optimal for a case study related to technology valorisation.

3.3. Actor-Factor Framework in the Context of Q-Methodology

A Socio-Technical approach is used to systematically collect information about various actors and factors that are needed for valorisation of innovative technology. 'Socio-Technical system' for organisational development is a phrase coined [23]. This is an approach to research a complex organizational work design by recognising the interaction between people and technology in workplaces. The framework consists of various factors and actors that might influence the desired outcome i.e. successful valorisation of a technology. This is henceforth named the Actor-Factor framework.

Eveleens [12] classifies innovations along five dimensions and establishes the importance of such classification when considering innovation management and activities: (1) The first dimension is innovation type, distinguished as product-, process- and service innovations [24, 25]; (2) Second, the degree of novelty is considered. Sometimes, innovations are assigned [15] along an axis from incremental to radical. A distinction is made [26] between incremental, radical and systemic innovation or use is made [12] of incremental to radical dimension to distinguish innovations. The real determining factor is the customer [27]: in incremental innovation, one knows the customer and how to reach them, and in radical innovation, one does not. In one type of innovation the company operates on familiar terrain, whilst in the other it moves in uncharted territory; (3) Third, a distinction is made between innovations that took place in a private firm or in a public organisation. The comparison between these two is still not made often while it is suggested that the management of innovation in public organisations is different from that in private firms [28]; (4) As a fourth dimension, the size of organisation is considered. It could be interesting to see if management techniques are different in small organisations compared to large ones; (5) Lastly, the stability of environment is gauged to determine to what extent this affects the management style.

The specific technology management issues faced by firms depend on the context (internal and external) [11], in terms of organisational structure, systems, infrastructure, culture, and the particular business environment and challenges confronting the firm, which change over time. They also emphasise that an appropriate balance has to be struck between market ‘pull’ (requirements) and technology ‘push’ (capabilities). The firm’s knowledge base and capability are also mentioned as factors that influence the technology management framework. Knowledge base includes the firm’s technological competencies, knowledge of customer and supplier capabilities [11]. The firm’s capability results from an extended learning process gradually accumulating processes, procedures, routines and structures, which, when embedded, are often referred to in practice as ‘the way we do things around here’ [29]. It has been emphasised [30] that the dynamic nature of knowledge flow must occur between commercial and technological functions in the firm, linking to the strategy, innovation and operational processes, if technology management is to be effective.

There are several authors that see the innovation process not in a vacuum, but include some contextual factors. Authors that explicitly treat these contextual factors are [31, 7, 26, 32, 16, 15]. To illustrate this, they range from organisational factors to societal factors and from influenceable factors to external factors. Also, while some authors describe these factors extensively [31, 16], others treat them superficially [26]. From an analysis of the literature [12] the following main contextual components have been identified: Strategy, Culture, Leadership, Organisational structure, Resources/Skills and (links with) outside the organization.

4. Research Methodology

Q-methodology was developed originally in the 1930s as an innovative way to study people's subjectivity [33, 34, 35]. Since then, it has been applied in various fields of social science, in order to uncover patterns of perspectives within people's subjectivity [36, 37, 38]. ‘Q-methodology is a research methodology that permits the systematic study of subjectivity and the communicability of subjective perceptions in a discourse on a specific topic. It adopts the participant’s point of view and understanding as being central to its investigative procedures’ [39]. Recently, it has also been adopted in studies that particularly address policy and planning of renewable energy sources [40, 41].

Q-methodology can be used to uncover perspectives or subjectivity among the targeted respondents, without imposing predefined categories. The merit of Q-methodology is that ‘by allowing the categories of the analysis to be manipulated by respondents, the researcher loses the exclusive power to signify the reality of the researched’ [42]. Q-methodology differs from R-methodology (surveys and questionnaires) in that the latter asks respondents to express views on isolated statements, whereas Q-methodology identifies respondents' views in the context of the valuation of all statements presented [43]. The procedure for sampling respondents is usually different from that in R- methodology. Rather than random and large sample sizes, Q-methodology relies on purposive and focused sampling (smaller sample sizes).

Q-methodology comprises of six steps [44]:

(1) Definition of the ‘concourse’, the full range of discussions and discourses on the particular issue under study. Defining the concourse means identifying sources, either written or spoken, which contain ideas, opinions, preferences and knowledge claims on the issue under study.
(2) From the concourse, a large set of statements known as Q-set is generated. These statements should reflect the diversity of the concourse. This set has to be reduced to a manageable number (usually not more than sixty statements), while still reflecting the full diversity of viewpoints, claims and ideas. Preferably, the wording of the statements stays as close as possible to the original wording (and thus the original meaning) of that idea or opinion as found in the concourse.
(3) Identification of a group of respondents, referred to as P-set. As noted above, Q- studies use purposive sampling, which means that the P-set needs to represent as many different ideas, preferences and opinions on the issue under study as possible.
(4) Respondents do the Q-sorting activity, which involves

ranking the statements on a scale that represents significance or salience for respondents [45], such as 'most agree' to 'most disagree' (usually normally distributed). The Q-sorting task is often accompanied by an interview, in which respondents are asked to explain their sort - this helps to interpret the clusters and identify the perspectives.

(5) Data from the Q-sorts are statistically analysed, resulting in clusters of Q-sorts that are highly similar in their rankings of the statements (high correlation). This can be carried out using Q-factor analysis software (PQ-method [46]).

(6) Interpretation of the clusters obtained in step 5. The typical way to interpret a cluster in Q-methodology is to look at the statements that receive the highest and the lowest scores respectively for that factor. Additionally, the statements that distinguish most between one cluster and the other clusters are useful in interpreting the subjective viewpoints.

Based on the literature review, a brainstorming session with experts in the process industry and a discussion with representatives of a number of multinational companies from the process industry the actors and factors have been selected. The elements from all the three sources together form the concourse, grouped together under one umbrella and interpreted as 5 overarching actors and 6 overarching factors.

(1) ACTORS: The 5 overarching actors are: High-level Decision makers, Main Customer i.e. Process plant, Intermediate Customer, Technology Owner and Supporter.

(2) FACTORS: The 6 overarching factors are: Organisational factors, Human factors, Management, Business Drive, Technological Characteristics, Comparison (New vs. Proven Technology).

The concourse forms the basis for Q-set statement generation. To increase the credibility of the research, the statements must be diverse and address all elements of the overarching concourse as practically as possible. The statements need not have one to one order of correspondence with the listed elements. There can also be a couple of statements on the same factor or actor as obtained using different sources. There is no prescribed rule or way to develop the Q-set. Hence one may notice that the number of elements of overarching concourse is not equal to the number of statements. The only condition as per Q-methodology is that the statements must stay in the same tone, as it was obtained from the sources and diverse enough to address all the actors and factors. Also, as per Q-methodology, the Q-set must have a mix (but not necessarily in equal numbers) of affirmative and negating statements in order to avoid a bias in the respondent's mind. This statistically improves the robustness of the result. Taking these aspects into consideration, 42 statements are generated in total (shown in Appendix A).

The P-set are the respondents who perform the Q-sorting activity. It is important to select the P-set in such a manner that the respondents are diverse enough to provide different perspectives about valorisation of innovative process equipment. In this research the P-set is chosen from five different process intensification technologies. The respondents are chosen in such a way that more than one role within the same case is covered.

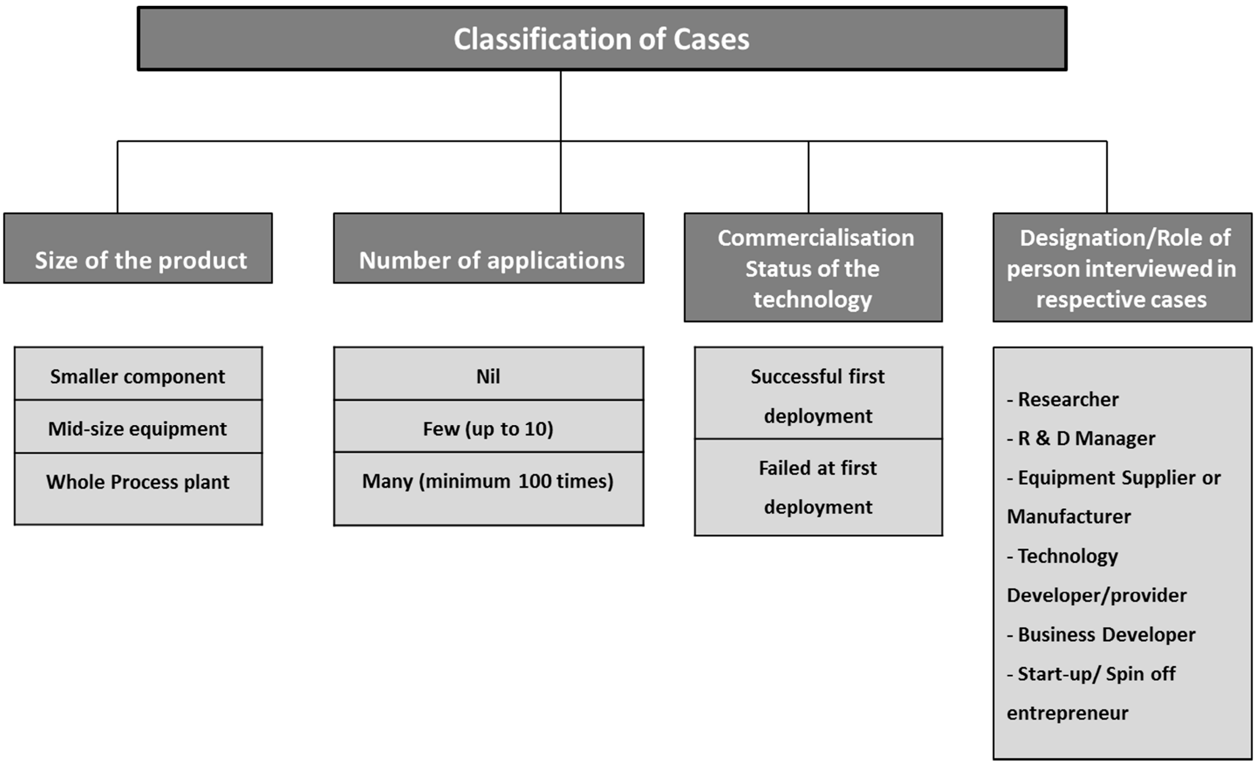

Figure 2. *Case Selection Criteria.*

In order to have a robust result, it is important to have a diverse classification of cases for data collection. The cases are categorised based on Type (radical or incremental), Size of the product, Number of applications, and Commercialisation status of the technology. Cases are selected keeping in mind that each category in the classification (Figure 2) is addressed by at least one case. This avoids similarity among the chosen cases. Apart from above mentioned categories, the designation/role of a person interviewed in respective cases is also chosen in such a way that they come from different backgrounds and with different experiences. This allows identifying different subjective viewpoints about technology valorisation. In addition to this classification, there is another important criterion based on practicality. The availability of information and interested respondents in the process industry with experiences from different type of Process Intensification technology is a practical criterion to choose cases. Five Process Intensification cases were chosen to conduct the explorative case study. In total 14 experts were interviewed across those 5 cases as can be derived from Table 1 (P-set).

Table 1. *Characteristics of the selected Cases and the People interviewed*

Name	Type	Size	Number of applications	Commercial status	Interviewees
Micro reactor (MR)	Radical	Mid-size	< 10	Successful 1st	Head of process technology, Head of Micro reactor research institute
Divided wall column distillation	Incremental	Mid-size	> 100	Successful 1st	Head of distillation, Head of business development, Operational excellence, Principal engineer
Expanded metal baffle heat exchanger	Incremental	Small	Few	Unknown	Inventor, Business developer
Supersonic gas separator	Radical	Mid-size	Nil/few	Failed 1st	Business developer, Technical marketing, CTO, CEO
Reactive distillation	Radical	Plant	< 10	Successful 1st	Researcher, Director of Technology

5. Perspectives on Valorisation

The case study interviews took place during a two-month period. Interviews typically lasted 60 to 90 minutes. The central task in the interviews was the Q-sorting activity, followed by a number of open questions to gather qualitative data for interpretation of the results. In the interview, 42 Q-statements were presented to the respondent. Respondents were asked to rank-order the statements according to a forced normal distribution with nine positions (Q-sort matrix) from most to least agreed according to his/her perspective. In ranking the statements the respondents were answering the question whether they agreed (most to least) with the statement as being important for valorisation (sorting question). The statements were printed on small cards. Respondents placed the cards on the normal distribution that was printed on a sheet of paper. Most disagreed statements were placed to the left and most agreed were placed towards the right hand side of the Q-sort matrix.

After performing all the interviews the data was analysed by means of the PQ method. First the respondents are clustered by means of factor analysis. Two methods have been used in the program: centroid analysis and principal component analysis. Both options returned the same result. Via an iterative analysis the number of existing clusters is derived. Subsequently factor rotation is applied by using the Varimax method. The factors are rotated until a strong significance is obtained for all 14 respondents on any of the 4 subjective factors. Factor loading of each respondent is presented in Table 2.

Table 2. *Factor Loadings with the defining Perspectives highlighted.*

Case	Respondent	Perspective 1	Perspective 2	Perspective 3	Perspective 4
Micro reactor	R1	-0.0171	-0.0533	0.3501	**0.7154**
	R2	-0.0315	0.0717	0.3086	0.6291
Supersonic gas separator	R3	0.0342	0.5648	0.5023	0.3596
	R4	-0.3713	0.3293	0.5499	0.2251
	R5	0.6296	0.1440	0.3155	0.0361
	R6	-0.3462	-0.0162	0.5718	0.2417
EM Baffle Heat Exchanger	R7	0.5681	0.0441	0.3745	0.3132
	R8	-0.3155	0.4507	-0.0480	0.3011
Divided wall 1	R9	-0.0481	0.2955	0.1170	0.7197
	R10	0.0973	-0.1095	0.7438	0.3061
Divided wall 2	R11	-0.0424	0.0222	0.4925	0.1766
	R12	0.2899	0.3172	0.3877	0.1909
Reactive distillation	R13	0.5436	0.1768	0.2486	0.3456
	R14	0.2607	-0.0155	0.6104	0.0410

Factor loading represents how much each respondent is inclined towards that particular perspective. The respondent's factor loading is considered significant if it is above +0.348 or below -0.348 (based on Q method: 2.25/SQRT (N) where

N = 42 in this study). If more than one perspective scores significant then the perspective with highest score is marked as the defining sort of that respondent. It can be seen that Perspective 1 and Perspective 4 have three respondents each, Perspective 2 has two and Perspective 3 has six respondents with defining sorts. The PQ method tool provides ‘most agreed’, ‘most disagreed’, ‘distinguishing agree’ statements and ‘distinguishing disagree’ statements for each generated perspective from the program.

5.1. Perspective 1 - Technology Sells Itself

Respondents with Perspective 1 are of the opinion that the technology sells itself. They believe that most of the time technology aspects are not a hindrance for valorisation. They are technically very sound and acknowledge all technical requirements for new innovation. They think that if the technology still fails then other actors involved have not contributed well enough or there could have been concerns with resource availability. They also have a strong opinion that equipment manufacturers are not willing to make an investment to support new process technologies and that is why most innovative technologies are not able to transfer from laboratory to commercial application. Though they identify the technology provider/researcher as a key actor for successful valorisation of a technology, they disagree on the statement that R&D support is important during (or after) technology deployment. Also it is interesting to note that business related statements have been given a low score in this perspective.

5.2. Perspective 2 - Meeting Business Targets Is Primary Objective

People with Perspective 2 consider the business owner as a key actor for valorisation of a technology. They are of the opinion that if a good business objective and strategy is in place then the technology provider has to anyway develop and deploy a new technology according to business needs. They consider the business owner to have a skill set including risk management, stakeholder management and a value proposition as crucial for successful valorisation of a technology. They feel that if valorisation fails despite of the business owner having all these skills then the technology is not good enough and it is time to choose an alternative technology. This perspective seems to have below average technical understanding; they fail to acknowledge the technical characteristics or rather are not in a position to understand them. They tend to oversee the potential of innovative technologies and the benefits that it could provide, when given some extra support, time and faith. For them, it is enough as long as business owner’s targets are met but which technology has been used is not their concern.

5.3. Perspective 3 - Believe in Both Technology & Business Factors (But Need More Time & Leadership Support)

People with this perspective consider both technical and business factors as equally important but they are highly expecting support from higher-level leadership to make the technology successful. They could be called believers and advocators who are ready to make required improvements in technology or business plan, until the technology succeeds. But they are in need of more time and support from other actors involved. They are looking for strong leadership for deployment of technology. They are not confident about meeting the technical promise right at first deployment and lack in process management skills but are willing to improve these aspects.

5.4. Perspective 4 - Integrating Technical, Business and Project Management Factors with Equal Importance Is a Key to Success

People with this perspective have a balance in attitude. A capability to handle a mix of technical, business and human factors is seen in this perspective. They give equal importance to all actors and factors and also have the experience in managing them successfully. Though they have experience with both direct and indirect business models, they are of the opinion that direct business models (convincing the end user or asset owner directly) ensure quick and effective deployment of new technologies. But an indirect business model can also work, provided some important human factors are taken care of. Communication and teamwork is of top priority to them. They believe that a best way to make an impression is to ‘Under promise and over deliver’. Above all, they have a very strong opinion that it is important for the technology to meet its promise right at first deployment. So it is crucial to focus on identifying a correct niche application instead of just hurrying to make a deployment. In their experience, an existing plant is the best place to deploy a new technology (especially process intensification equipment) as it can clearly prove its benefit over conventional technologies.

Three non-case interviews were conducted to verify the practicality of generalising the results in the future. It was concluded that there are no other perspectives other than the ones identified from these five cases. The general respondents also fitted into one of these 4 perspectives.

Table 3. *Correlation Scores among Perspectives.*

Perspective	1	2	3	4
1	1.0000	-0.1314	0.1398	0.0461
2	-0.1314	1.0000	0.5110	0.5021
3	0.1398	0.5110	1.0000	0.6052
4	0.0461	0.5021	0.6052	1.0000

The correlation scores among perspectives are listed in Table 3 (as obtained from PQ method analysis). It is interesting to note that Perspective 1 and 2 are negatively correlated which means that they represent opposite oriented viewpoints. In fact, Perspective 1 does not show much correlation with any of the other perspectives as well. This means that their willingness to pick the characteristics of another perspective is pretty low. Similar qualitative remarks can be made about other Perspectives as well. For example, both Perspective 3 and Perspective 4 have positive correlation with all other Perspectives. This means that people holding these perspectives have the ability to appreciate characteristics of other perspectives. This ability will possibly contribute to a better functioning of the team.

6. Analysis and Discussion

The actor set required for valorisation of process equipment includes Technology Provider, Business developer, Asset Owner, Operations Manager, Project Manager (within company or an EPC contractor) and Equipment Manufacturer. It was concluded from observations made during the case study that the actual number and combination of actors is case specific. This varies according to the business model that is being adopted (either direct or indirect business model). Through analysis of the interviews it was concluded that in order to have transparent communication and teamwork and to reduce the chances of a blame game, it is advisable to use a simultaneous process for valorisation instead of a stage gate model. The concept of a simultaneous model is to keep all the actors involved during all phases of valorisation.

6.1. Critical Success Factors

Critical Success Factors are selected by 1) Quantitative analysis - picking out consensually agreed and disagreed statements from the PQ method analysis (factors scores) and 2) Qualitative analysis - selecting some of the distinguishing key statements from each perspective (from their individual Q sorts) and by revisiting the case study interview discussions. A total of 22 CSFs were identified (Figure 3).

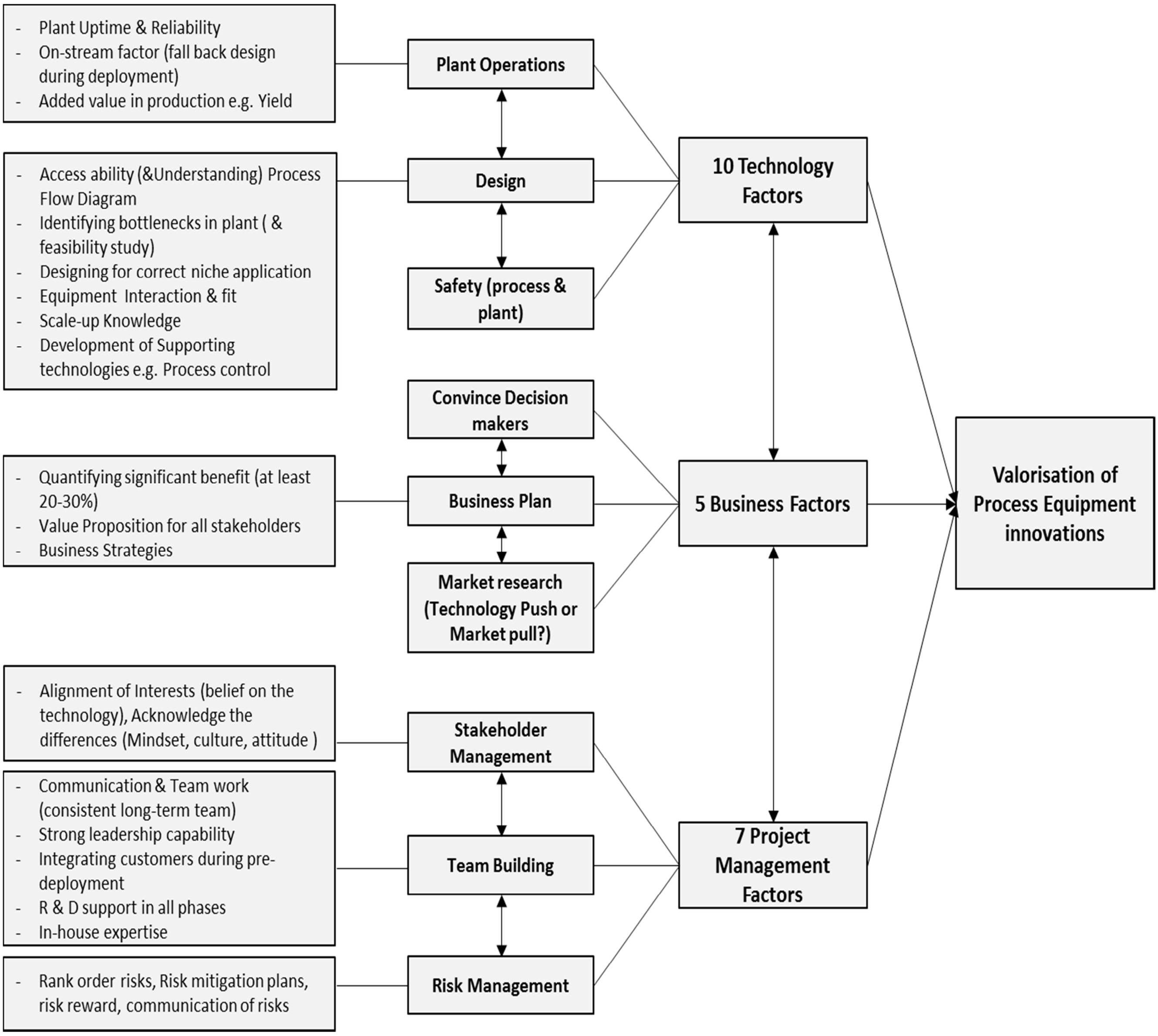

Figure 3. *Critical Success Factor Framework for Valorisation.*

With the help of observations made during the case study, it was possible to group these factors into three categories namely Technology factors, Business factors and Project Management factors. All three categories need to be addressed in order to have successful valorisation, which was also the point stressed by Perspective 4.

(1) Technology factors are further classified into Plant operations, Design and Safety. The plant operations block and Safety block in the framework interact with the Design block since all these factors have to be addressed while designing the technology for the chosen application;

(2) Business factors are subdivided into three blocks namely Convince decision makers, Business plan and Market research;

(3) Project Management factors include Stakeholder management, Team building and Risk management.

It would be interesting to understand how these factors were addressed in the cases chosen for this research and also what impact they had on the outcome of the technology. In order to do this, a score sheet for CSFs was designed (scoring range of 0-none, 1-poor, 2-average, 3-good, 4-very good). The most significant perspective loading in each case was chosen to answer how these CSFs were considered in their respective cases. The scoring of various CSFs for each case is represented in Figure 4.

6.2. Technology Factors Scoring for Each Case

Case 1- All the technical factors are either average or good. But the fall back design is poor which means that for first deployment the technology has to find a location in the process plant which is not critical to production or at least is temporarily not functional for maintenance reasons. Hindering a live process plant might not be a good option.

Case 2 - Development of supporting and complementary technologies have been very good (this case was multidisciplinary which combined aerodynamics, material science and thermodynamic principles). But it is interesting to note that interaction & fit with whole process plant was not considered during design of first deployment and this had a negative impact on the functioning of the technology.

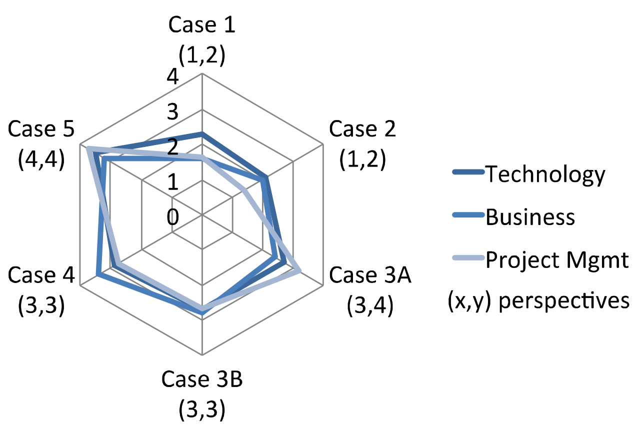

Figure 4. *Representation of the Influence of the Critical Success Categories on the various Cases in Relation with Perspectives.*

Case 3 - All technical aspects of this case are good. But it is difficult to conclude at this point of time as to why it was not adopted by the Dutch process industry compared to the German industry that has become a pioneer in this technology. This will become clearer when analysing the influence of perspectives that existed in the case.

Case 4 - All technical aspects are good. Added value in production due to this technology is very good. This explains why it received strong support from high-level decision makers.

Case 5 - The technical aspects score an average of 3.75/4 and this explains that great care was taken to address each and every factor individually. This is also an outcome of two Perspective 4 people working on first deployment of the technology.

6.3. Business Factors Scoring for Each Case

Value proposition was done poorly in Case 1, which is also due to the friction that existed (negative correlation between Perspective 1 and 2) in the team during initial days of the technology. Market pull is generally very poor for all these new technologies since the process industry is very conservative. But Case 4 alone had a good score for this factor since it was a management decision to deploy this technology as part of a new chemicals manufacturing facility.

6.4. Project Management Scoring for Each Case

Case 1 has a good risk management plan but it scores poorly on communication and teamwork. Case 2 failed to integrate customers during pre-deployment and this affected the technology's fit into the whole process plant. Case 3 and Case 4 had good project management aspects. In case 3 it was due to the presence of Perspective 4 and in case 4 it was due to a strong drive from top management. Case 5 is the best example of effective project management. Integrating customers during pre-deployment, having R&D support in all phases and very good communication and teamwork are highlights. The success of case 5 was a result of two people holding perspective 4 working consistently in the team for a long term.

To make a cross case analysis, the scores for all the factors within each category were averaged. From this analysis it is evident that the technology factors category has been addressed above average in all five cases. The business factors and project management factors have played a major role in deciding the outcome of the case.

From the final analysis it is evident that the cases with presence of Perspective 4 have performed high on all the Critical Success Factor categories. Perspective 4 are people who can independently integrate Technical, Business and Project Management factors together. This result is summarized in the spider web plot in Figure 4.

6.5. Valorisation Model

Based on the research findings and discussions, a valorisation model is proposed to facilitate and improve the success chances of valorisation of innovative process equipment. In this research it is concluded that in order to make the valorisation step, three sub-steps are required.

(1) Form core team - Selection of required actors for technology valorisation,
(2) Get the right Perspective - Coach the core team to become a 'Perspective 4 team' and
(3) Execute factors - Execute the 22 Critical Success Factors.

This model is graphically represented in Figure 5.

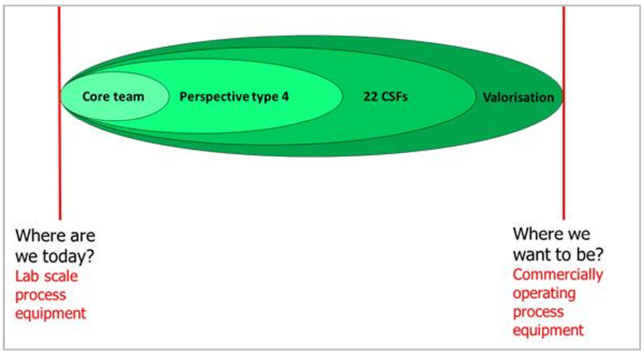

Figure 5. *Valorisation Model as developed in this Research.*

7. Conclusions

In the five cases that were investigated in this study four different perspectives were discovered. The first perspective holds the opinion that technology sells itself. The people with this perspective think that if the technology fails then other actors involved during valorisation have not contributed well enough. Considering meeting business targets as the primary objective is the conviction of the people holding the second perspective for successful delivery of innovations. Belief in both technology and business factors is the direction that the people holding perspective three are adhering to, but they need more time and support. But they expect the higher-level leadership to support them. Finally, the holders of perspective four have the capability to independently integrating all the technical, business and project management factors that are required for successful valorisation. In this study 22 Critical Success Factors (CSFs) were identified in total. These were grouped into three categories namely Technical factors, Business factors and Project Management factors. What was identified is that all these factors have to be addressed with equal importance in order to have successful valorisation. In fact, the cases that have considered all these 22 CSFs have performed better than other cases during their first commercial application. The technology factors category has been addressed above average in all five cases. The business factors and project management factors are the ones that have played a major role in deciding the outcome of the case. Especially the cases in which people holding Perspective 4 (who can independently integrate technology, business and project management) are present have performed high on all the Critical Success Factors. On the other hand, cases that had Perspective 1 and Perspective 2 representatives working together have performed poorly during first application.

The valorisation model proposed in this research can be used in a technology management process that adopts sequential phases of innovation or technology maturation. Generic sequential phases of technology maturation include Idea Generation, Selection, Developing and Demonstration, Implementation/Launch/Commercialisation [12]. This model fits at the end of demonstration phase where the technology has been demonstrated on a laboratory scale. The type of perspective could be identified for a person who has had previous experience with technology valorisation in the process industry. He/she can participate in the Q-sorting activity combined with an interview. This shall take no longer than an hour. The resulting Q-sort and qualitative comments made about the actors and factors can be interpreted using the results of this research and the perspective type of the respondent can be identified.

Following the discovery that a Perspective 4 team is needed to have a success in technology valorisation, the immediate next question arising is: How to coach a team to become a Perspective 4 type? The answer to this question is beyond the scope of this research. However the results obtained in this research could be used to develop a coaching strategy in the future. A combined interpretation of CSF categories (technology, business, project management) and perspectives can be used as a starting point for future research.

A few limitations of the current research have to be mentioned here. First, the Q-set forms the fundamental pillar of this research. The entire research relies on the credibility of the concourse and robustness of the statements generated. Considerable effort was invested to ensure the diversity of the concourse. However, there is a limitation that people outside the technology world have not been included in brainstorming interviews during development of the concourse. For example, one could include venture capitalists or bankers, who fund technology ventures and check if the results are affected. Secondly, the research did not establish the relative importance of the 22 Critical Success Factors that were identified. Further case studies have to be carried out to specifically investigate the relative importance of these CSFs for a variety of PI technologies applied. For example, the pharmaceutical industry could be included in the case studies. The order of execution of the CSFs must also be studied in order to operationalize the valorisation model. Finally, additional case studies need to be conducted to strengthen the claim of the influence of the Perspectives on the performance of the valorisation of the innovative technology.

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The authors are indebted to the interviewees who made time in their busy schedules to allow capturing their views on their cases and valorisation in general. Without their cooperation this research would not have been feasible.

Appendix

The Full Concourse used in the Q-sort During the Interviews

1. Safety has been and is the top most priority of the process industry. Hence it is very difficult to convince on deployment of new technologies.
2. New technology can be implemented only if it has added value in production (either higher yield or reduced time)
3. New technology must be either cheaper or faster (schedule) when compared to existing technology.
4. It is important to meet the technical promise right at the first deployment.
5. Scale-up knowledge is highly uncertain when translating the technology from laboratory to commercial scale and hence it is critical to have support from commercial actors. e.g. Business developer
6. Operators cannot be convinced unless the new technology ensures them a good plant uptime and reliability after it has been deployed.
7. While deploying the new technology, existing plant's on-stream factor must not be disrupted. Otherwise plant operators are not convinced.
8. It is crucial to have complementary/supporting technologies (e.g. process control, material science) in order to make PI feasible.
9. Business unit is convinced only when there are strong regulatory needs to implement the proposed new technology.
10. The business unit must have a significant risk taking culture in order to deploy new technology.
11. It is possible to convince the user if the new technology shows improvement on quality of the product. (User is ready to pay more for a better quality product)
12. Communication & teamwork among actors is a crucial factor. (But most often R&D, Operations, business developers are reluctant to talk to each other. They have different priorities, language etc.)
13. It is important to have an attractive value proposition for all the stakeholders involved. Especially for equipment manufacturer and business unit.
14. Stakeholder management and aligning of their interests is crucial for successful first deployment of technology.
15. Risk management is crucial for successful deployment (Defining risks, risk mitigation plans, communicating risks & a significant risk reward)
16. New technology can be implemented only when there is no alternative OR it must at least quantify a significant improvement/benefit over existing technologies. (rather than a minor step-change)
17. It is difficult to deploy only radically new/breakthrough technologies whereas incremental innovation/improvement of existing technology is easier.
18. Strong leadership support is needed to deploy new technologies.
19. Researcher invents/develops a new technology and sees deployment as somebody else's problem.
20. New technology deployment has a direct impact on reputation of the company.
21. Size of organization (e.g. large, medium or start-ups) is a factor that determines the intake & success of deploying new technologies.
22. Type of process industry (bulk or fine chemicals) is crucial factor to identify a possible first deployment for Process Intensification e.g. PI can be first deployed only at industry that produces high quality and low quantity products
23. PI cannot be deployed at an existing plant. Better to concentrate on deployment at new process plants.
24. Equipment manufacturers are not willing to invest in developing manufacturing facility to support new process technologies.
25. It is important to have a proper strategies and business plan for new technology deployment.
26. New technology is not able to compete with alternative technologies that have crossed the learning curve.
27. Availability of resources (budget & staff allocation) is a major concern during the deployment process.
28. It is important to integrate customers during pre-deployment/development phase of the technology.
29. Lack of in-house expertise and over dependence on external actors leads to slow/limited possibility to deploy new technologies.
30. It is important to have R&D support during technology deployment phase and also during post deployment phase.
31. Process industry users wait for the right moment to come e.g. energy price goes up or something goes wrong. Otherwise they are not interested for new technologies.
32. Compensation/ Insurance schemes must be agreed upfront before deciding to deploy new technology.
33. IPR sharing is a primary concern while transferring technology from lab to industry scale.
34. High-level decision maker (e.g. Business owner) is a key actor for new technology deployment.
35. Asset owner/operations plant manager is a key actor for deploying new technology.
36. Project manager (intermediate customer) is a key actor for deploying new technology.
37. Equipment manufacturer (also vendors & spare part suppliers) are a key actor for deploying new technology.
38. Technology provider/Researcher is a key actor for deploying new technology.
39. Human factors (mind-set, language, culture, and attitude) and business drive are more crucial success factors when compared to technology characteristics.
40. PI claiming to make process industry smaller is alone not good enough for commercialization. It has to have

other strong drivers for e.g. it is easier for new PI technology to be implemented if it finds a new operational domain (or application) so that it does not have to compete with other/existing technologies.

41. Missing standards and routines for operation limits the deployment of new technology.
42. Interaction/fit into the whole process plant is crucial for the PI technology since the new technology cannot work alone.

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