

A structural analysis of process development in process industry

A new classification system for strategic project selection and portfolio balancing

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A research project on the development of process technology in process industry led to recognition of the importance of a better classification of different types of process development. A new classification system and matrix have consequently been developed, using the dimensions ‘newness to the world’ and ‘newness to the company’. The distribution of annual company expenditures for process development in the matrix and the estimated usability of the matrix have been tested as part of a larger survey conducted among R&D managers in European process industry. In view of the favourable response from industry, it is argued that the matrix could facilitate company portfolio balancing of process development projects, and that it is also necessary to distinguish between different types of process development in academic research.

1. What is ‘new’ about a new process?

Fighting to stay competitive in a mature market is not an unusual position for a large group of industries often called process industry. Mature (sometimes diminishing) markets require specific competitive strategies for survival, often including both product improvements and improving cost competitiveness, to create a good price/performance relation for customers (Porter, 1980). The ability to be cost-competitive is related to some extent to a clear understanding of the dynamics of the total cost structure in the production process, but mainly to the ability to develop and introduce cost-efficient process technology in the production process. Different sectors of process industry need to assign different relative importance to product and process development, and the volume of process development work may even sometimes be

larger than that of product development activities. The importance of process technology development compared to the development of new products in the later stages of industrial development has also been stressed by Utterback (1994).

A matrix illustrating the importance of different types of product and process development for different types of process industry has been presented by Cobbenhagen *et al.* (1990). The importance of process development to industries operating in mature markets, especially when producing commodity products, is recognised by Hutcheson *et al.* (1995). The pharmaceutical industry still often gives higher priority to product development compared to process development, but as the time frame for process development increases, the need to have product and process development going on in parallel to shorten lead times is emphasised by Pisano (1997). The importance of

process development in many industries belonging to the process industry group is thus recognised, but process development, like product development, varies widely in its nature and scope from incremental process development to creation of highly innovative, radically different process technology (Freeman, 1990).

There is consequently also a need for a good characterisation of different types of process development and for an answer to the question 'What is new about a new process?'. Confusion is sometimes caused both in industrial R&D and in academic research when completely different categories and types of process development are compared to each other. The main research question for this study is thus related to what characteristics such a classification system for the development of process technology should have.

The development of such a classification system and matrix for the development of process technology in process industry is described below. The usefulness of this classification system has been tested in a survey addressed to R&D managers in European process industry, and the distribution of company process development expenditure among different areas of a matrix recorded. Four matrix areas have been tentatively labelled to create a simplified 'typology' for process development projects. The use of the process matrix for strategic project selection and portfolio balancing of company process development projects is further discussed.

2. Frame of reference

The following definitions have been used in this study of process development in process industry and were also explained to the respondents in the preamble to the questionnaire they received.

2.1. Process industry

In studies of product and process development, the term 'process industry' is often loosely used to denote a group of production industries without any clarification of what type of industries are referred to. The situation today is even more confusing, when new management concepts such as 'key business processes' are introduced.

The following intentional definition of process industry attempts to characterise this type of industry in a more descriptive manner:

Process industry is production industry using (raw) materials to manufacture non-assembled products in a production process where the (raw) materials are processed in a production plant where different unit operations often take place in a fluid form and the different processes are connected in a continuous flow.

Companies are normally grouped together in clusters of similar types of industries producing similar types of products and often using similar production processes. Those clusters are usually called industrial sectors, such as the chemical, automotive and agricultural sectors.

With the above definition of process industry, clusters of industries can be selected for a more operational definition of process industry, using the NACE codes for the classification of industries in the European Community (NACE, 1996), defining process industry as a subset of all manufacturing industry.

Industries proposed to be included under the heading of process industry have thus been selected from the NACE system. In the present study they are categorised as Mining and Mineral Industry, Food and Beverage Industry, Pulp and Paper Industry, Chemical Industry, Basic Metal Industry and Other process industry; see also Appendix 1.

2.2. Product and process development in process industry

Although product and process development in process industry can sometimes be considered as two sides of the same coin, since product development in practice often takes the form of development work in a laboratory, the lack of distinction between product development and process development often creates confusion both in the operational performance of industrial R&D and in academic research. To distinguish between the two terms, 'process development' is defined in this study as development driven by internal production objectives. Such objectives may be reduction of production costs, higher production yields, improvement of production volumes and product recoveries, environment-friendly production, etc. Thus in many sectors of process industry process development work is mainly prompted by the needs of production (internal customers). Correspondingly, 'product development' is defined as development driven by a desire to improve the properties and performance of finished products, even though the improvements may be achieved by modification of the process. Product development may aim at improving product properties, improving product quality (uniformity of composition), environment-friendly products, etc. These stricter definitions and the separation of product and process development activities do not however imply that there cannot be a combination of the two activities and objectives in a development project; they are given simply to underline the importance of distinguishing two different types of development activities and objectives. A process development project may offer opportunities for product development, just as the development of new products may be coupled with process development and cost reduction in the production process.

2.3. A classification system for product development

In 1982 the consulting organisation Booz, Allen and Hamilton presented a study of product development performance that included process industry (Booz, Allen and Hamilton, 1982). They concluded that it was important to distinguish between different categories of product development in order to better understand and position the company's product development efforts. The newness of product development was considered in two dimensions, 'newness of the product to the market' and 'newness of the product to the company'. This classification highlights the importance of considering not only how new a product is on the market, but also the importance of understanding the impact upon the company itself when it ventures into new areas of product development. A matrix was constructed along those two dimensions, classifying newness on a trichotomous scale: low, medium and high.

The use of such a classification system for product development activities can facilitate assessment of the company product development portfolio with regard to aspects such as:

- necessary company resources;
- a proper risk/reward balance for the product development portfolio;
- personal qualifications needed for different kind of product development.

The importance of a better classification of product development is gaining acceptance in industry, but the Booz, Allen and Hamilton product matrix has also been used in academic research and for the classification of different types of success criteria for product development (Griffin and Page, 1996).

3. Development of a new classification system for process development

The aforementioned study by Booze, Allan and Hamilton used the dimensions 'newness to the market' and 'newness to the company'. The importance of the aspect of newness to the company in the development of process technology has previously been pointed out by Linn (1984). Newness to the market, however, is not a relevant consideration for industries that are not developing new process technology to be marketed outside their own organisation. Newness of the process technology to the world is probably a better dimension in this case.

3.1. Selecting scales for the classification system

Newness of process technology to the world – innovativeness. The newness of the process technology to

the world is a dimension that characterises how well known or proven the process technology is outside the company. Newness of process technology to the world is the traditional dimension for classifying different types of development and is consequently also an important dimension to select when classifying process development. The degree of newness of a process technology can sometimes be related to whether the process can be patented, but since new processes are sometimes not patented but kept secret, the newness can also be estimated by how well it is described in professional publications. It is suggested that three degrees of newness of a process technology to the world should be distinguished:

- **Low:** the process technology is well known and proven (can often be purchased).
- **Medium:** the process technology is an improvement of previously known technology (incremental process technology development).
- **High:** the process technology is completely new and highly innovative (breakthrough or radical technology development).

Newness of the process technology to the company production system. One thing that often distinguishes process industry from other manufacturing industry is that production plants in process industry are seldom easily modified, and changes in the process configuration are often costly and investment-intensive. Because of this, the newness of process technology to the company production system is another important dimension in the classification of process development.

There are several possible ways to define the degree of newness of a process technology to a company, but before a company starts a process development project, one of the most important considerations should be how easily the process technology under development can be implemented in the future production system. The newness of a process technology to a company can thus be measured by the extent to which the introduction of a new process will affect the production plant/production line/production unit in terms of investment in new production equipment or a completely new production plant. Newness of process technology to the company production system has been chosen as the most readily understandable and usable dimension for professionals in process industry. It is suggested that three degrees of newness of a process technology to the company production system should be distinguished:

- **Low:** the new process technology can be used in existing process plants.
- **Medium:** the new process technology requires plant modifications or additional equipment.
- **High:** the new process technology requires a completely new process plant or production unit.

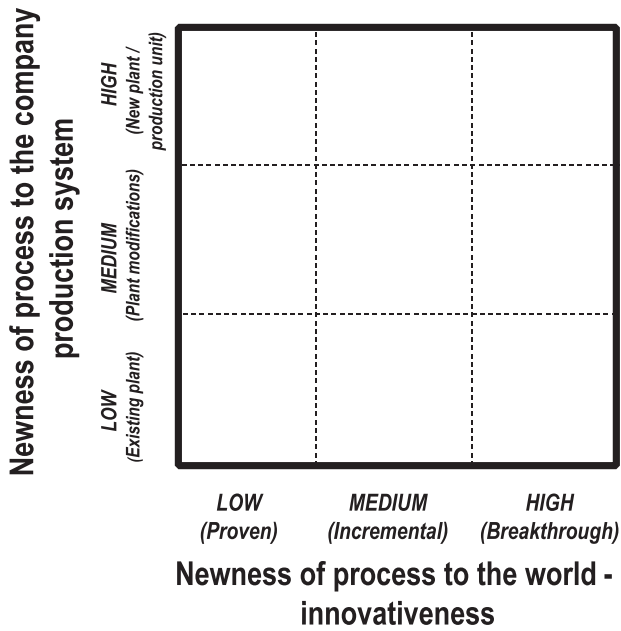


Figure 1. The proposed process matrix for classification of the development of process technology in process industry.

3.2. Creating a 'process matrix'

A matrix has been constructed in which the two selected ordinal variables rank the newness of process technology in two dimensions, both having trichotomous scales. This new matrix is presented in Figure 1, where the two dimensions define a nine-fold property-space.

The matrix can be used to position areas of company process development or a portfolio of company process development projects. But how important is a classification system for process development and how useful could the matrix be for process industry? More specifically, how is company process development distributed among the areas of the matrix? Those questions were put to R&D managers as part of a larger survey concerning development of process technology in European process industry.

4. A survey addressed to R&D managers in European process industry

The results presented in this paper are part of a larger research project concerning the development of process technology in process industry, in which a survey was conducted among R&D managers in European process industry during 1998 and 1999. The survey included a large (8-page) questionnaire about various aspects of process development. The results presented in this paper are the ones relating to an improved classification system for process development, and the usability of the proposed process matrix.

4.1. Research approach and methodology

It was decided to use a survey addressed to R&D managers as an instrument to get a first indication of the need for and usefulness of a classification system. In this study the R&D managers were asked to assess the *potential* usefulness of a new classification system they had not previously used. To facilitate this assessment, the respondents were asked to fill in the matrix using their own company data. The purpose of this approach was to force the respondents to get a 'hands-on' experience and feeling for the use of the new matrix and thus put them in a better position to evaluate the potential usefulness of the matrix afterwards. Before the questionnaire for the survey was constructed, the process matrix was explained to and individually discussed with eight R&D managers from companies selected from different sectors of process industry in Sweden and Norway, in association with some informal unstructured interviews regarding other parts of the total research project. Encouraging support from the R&D managers in this group prompted us to further test the relevance of the matrix on a larger group. The total questionnaire was pilot-tested on three R&D managers before being mailed to 327 process industry companies in Europe with a focus on Swedish process industry. The sample for the survey and the further conduct of the survey are described in Appendix 1.

4.2. Distribution of company annual expenditure on development of process technology among different areas of the matrix

Figure 2 shows the distribution of average annual expenditures on development of process technology in the total group of companies included in the survey. The mean values are shown as large figures and the standard deviations as small subscript figures. Out of the total annual expenditures on process development, 41% is spent in the area of proven technology/existing plant. This shows that the largest part of process development takes place in an area that could be called optimisation of available production systems. The second most important area, one that is often called process development by process engineers, is incremental process development/plant modifications, to which 26% of expenditures on process development are allocated. The third area in ranking is breakthrough technology/new plant, to which 10% of the resources for process development are allocated.

The first two of these areas add up to 67% and all three to 77%, leaving 23% spread fairly uniformly over all other areas of the matrix (3–5% in each area). The high standard deviations for all areas indicate that there is a wide dispersion between individual companies in the allocation of process development resources

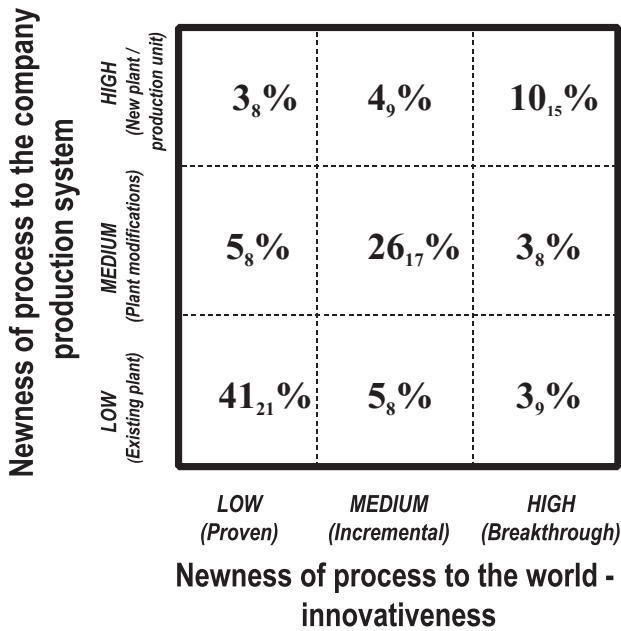


Figure 2. Distribution of company annual expenditures on development of process technology among areas of the process matrix (average figures for all companies in the survey). Mean values are shown as large figures and standard deviations as small subscript figures.

to different areas of the process matrix. Because of lack of space, the distribution of annual expenditures on development of process technology for each of the six aforementioned categories of process industry is not included here, but the general impression from Figure 2 holds good for all of them.

Two categories – Mining and Mineral Industry and Food and Beverage Industry – devote most of their process development expenditure (49%) to proven technology/existing plant. The minimum expenditures in this area (37%) are in Chemical and Steel and Metal Industry. If we add up the modified plant and new plant areas in the breakthrough technology column, we get a fairly high figure for both Chemical Industry and Steel and Metal industry (16–17%), indicating a high degree of innovative process development. The high standard deviations for all individual areas and for all categories of process industry indicate large individual variations within each category of industry.

4.3. Estimated importance of a better classification system

The main object of this study was not to determine the distribution of process development among different areas of the matrix, but to find out whether a classification of the development of process technology is considered to be important, and if so whether the proposed classification system and matrix could serve this purpose.

The question put to the respondents was: *Do you think it is important in your company to distinguish*

between process development projects of different nature and content? The response to the question is presented in Figure 3a.

There is no support for the importance of a better classification of different types of process development projects. Some comments from R&D managers:

- It is also important to co-ordinate the different types of projects in the matrix.
- All types of innovation often include pieces of technology that are both new and old.
- The picture given in the matrix may differ from year to year and also according to where the company is situated in the ‘investment chain’.

4.4. Usability of the new matrix

The next question to the respondents was: *Do you think that the new matrix is operatively useful for distinguishing different types of process development work?* The response to the question is presented in Figure 3b. There is support for the proposed new matrix. Some comments from R&D managers:

- Use of a matrix like this would speed up the innovation process.

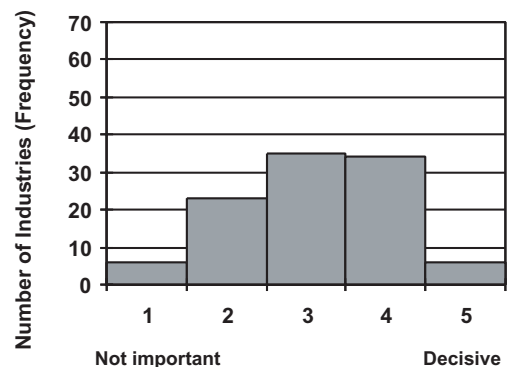


Figure 3a. Estimates of importance of a better classification system for different types of process development.

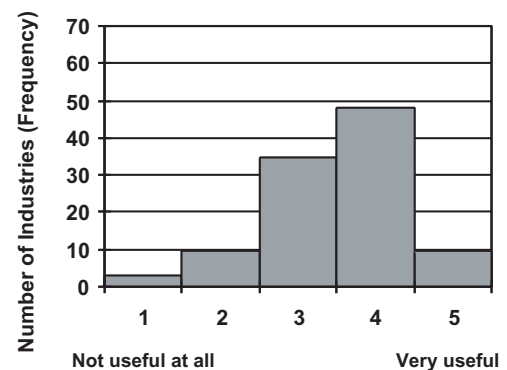


Figure 3b. Estimates of usefulness of the proposed new process matrix.

- The model is of instructive importance to understanding what you are going to do when you start a new project.
- Forms a picture similar to a market risk matrix. Regarding 'new plant', this can also include the dimension of new people.

5. Discussion of research results

5.1. General discussion of empirical findings

Summing up the proven technology column in the matrix for all respondents shows that about 50% of all process development work is associated with implementation of already existing process technology. This stresses the importance of the R&D organisation's ability to apply proven technology to existing production plants and production units. Thus in Food and Beverage Industry, 63% of all process development resources are spent on development of process technology without any innovative touch at all. There is a preference for the diagonal in the matrix, indicating that the more innovative the new technology is, the more changes in production plant are necessary for implementation. This association is plausible, but could also possibly be attributed to some extent to the denominations in the matrix. Since 80% of the respondents completed the matrix correctly, it is an indication that it was not considered too difficult or pointless a task, thus giving additional support to the usefulness of the matrix. It is interesting to note that those respondents who did not complete the matrix gave an even higher ranking to both importance and usability than the group that completed the matrix. This could possibly indicate that they did not have the figures at hand, but saw the need for them.

5.2. Reduction of the matrix to four areas and tentative labelling

In this study three areas were selected and named process optimisation, process development and process innovation to facilitate understanding and use of the matrix. After the survey was completed, input from the survey and further comments on the matrix suggested improvements in the denomination of the matrix areas. The structural dimensions and scales from the original process matrix are retained, but the number of areas in the matrix has been reduced to four, covering the total matrix and taking better account of both dimensions, a common practice in the analysis of sociological data (Barton, 1955).

The four areas are defined and labelled in Figure 4; this creates a simplified typology of process development projects that can facilitate use of the matrix for strategic project selection and portfolio balancing. The four areas in the matrix classify process development

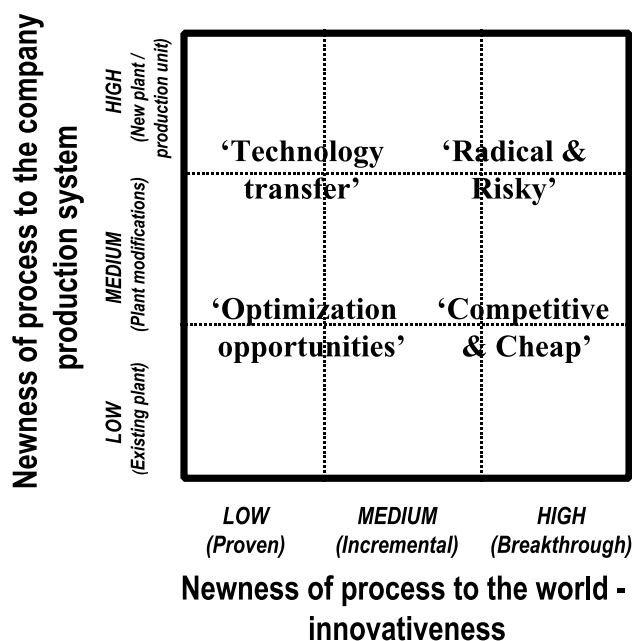


Figure 4. Four areas of process development in the process matrix and their denominations.

projects into four categories which are further discussed below.

Optimisation opportunities. The use of proven or incrementally improved process technology in an existing plant environment might not necessarily create a competitive production system for the future, but may nevertheless be of significant importance in a short-term production perspective. This type of process improvement is not the development of a new process, but the refinement and optimisation of an existing process. It does not necessarily require any new equipment at all, but only minor changes in process conditions or in flowsheets and process configurations.

Using mainly existing equipment and possibly new reagents, additives or raw material qualities reduces both the investment and the risk involved, making this type of process development attractive.

Technology transfer. Development of process technology in process industry is to a large extent dependent on collaborative efforts and projects with equipment manufacturers, contractors and suppliers of chemical reagents and materials (Hutcheson *et al.*, 1996).

Improving the production process in a company is thus often a matter of utilising already proven technology and applying it in part or as a whole in the company production plant. The newness of process technology is low, but the newness to the company can be high. The risk of experiencing start-up problems with the production unit or new plant is low. The risk of getting old technology without any competitive advantage can on the other hand be high (the vendor of a 'turn-key' plant is not likely to take undue risks).

Allocating company R&D resources to this area should be considered with care, and process development should preferably take place in collaboration with external partners.

Radical and risky. In this area we have medium-to-high newness in both dimensions – a real process innovation and breakthrough technology that is new to the company production system. Process technology in this area is of a kind that can make old plants or production units obsolete (Cobbenhagen *et al.*, 1990). Such a new plant can create a completely new and highly competitive production system, but the first player is often taking a higher risk. Depending on the size of the process and necessary capital for the investment, this type of development project should be approached with caution if contemplated by a smaller company.

Competitive and cheap. An interesting position in the matrix where the degree of newness is medium to high in the dimension newness to the world. Since this type of process development requires only moderate plant investment with minor new process equipment the risk is low, but the profitability could be high. This is an attractive area for process development and an area where initiatives should possibly be encouraged.

5.3. Validity and reliability of research findings

The respondents had not seen the matrix before and had little time to think about what type of process development work is associated with each area in the matrix. On the other hand the respondents must be considered to be very knowledgeable and well acquainted with process development in their positions as R&D directors or managers of R&D, and they completed the matrices well. Their ability to understand the matrix and estimate the usefulness of the matrix must thus be considered high, so the results can be regarded as valid.

The reliability of the figures in the matrix is influenced by the short time available for the respondents to fill in the matrix. This was after all only a part of a larger survey, so little time was available to make a good estimate of the company's total portfolio of process development projects and to position those figures in the matrix. More time, and probably discussions within the whole R&D management group, would have been needed to get reliable company estimates for the various areas of this matrix. The reliability of the figures in the matrix must be considered not so high.

The primary object of this exploratory part of the survey was to test the operational usability of the matrix for process industry. A secondary object was to

study the distribution of company process development resources among the areas in the matrix. The average percentage figures given for the individual areas of the matrix must be considered to be of an indicative quality and must thus be used with great caution. In view of the reliability of the data, no attempt has been made at a more detailed analysis of the results.

6. Implications for industry and academia

6.1. Using the matrix for company strategic project selection and portfolio balancing

A better characterisation of different types of development activities is advantageous for the creation of company R&D strategy and selection of a well-balanced portfolio of development projects (Roussel *et al.*, 1991). For this purpose the process matrix can be used to position portfolios of process development projects or to define and set priorities for company process development.

Projects can be marked with circles of different sizes indicating the volumes of research expenditure. Other project characteristics, such as type of technology, development time, etc. can also be flagged with different colours.

The project portfolio is thus well characterised and made more transparent for further analysis, and a more holistic picture of the company's process development strategy will emerge. At this point it might be appropriate to consider whether the balance between different types of process development activities is good or whether it should change in the future. What is the correct balance for the individual company? How specific is this balance for individual companies or sectors in process industry? What is right today and what should the targets be for the development of process technology for tomorrow? There are many interesting questions to be answered, some possibly by further academic research.

6.2. Implications for academic research

A matrix is a tool to facilitate the understanding of complex data and relationships between data. As such, the structure should gradually emerge until it reaches a clear and operational final structure.

... matrix construction is a creative – yet systematic – task that furthers your understanding of the substance and meaning of your database, even before you begin entering information. Thus the issue is not whether you are building a 'correct' matrix, but whether it is a helpful one ...

(Miles and Huberman, 1994).

Enough support has been given for the proposed new classification system to recommend the use of the matrix in further academic research too. The instrument for such studies might be more in the nature of a case study, allowing more time for the respondent to use the system and providing more reliable research results with more explanatory power. The question of how company process development should be distributed among the areas in the matrix could then be better answered with this type of improved contextual information.

7. Conclusions

A new system and matrix for the classification of process development in process industry have been developed. The importance of having a system for classification of process development and the usability of the new matrix have been tested in an exploratory survey addressed to R&D managers in European process industry. The importance of having a better classification system for process development was not considered to be very high, but on the other hand there was good support for usability of the proposed classification system and matrix. The distribution of process development resources among different areas of the matrix for companies and for different categories of process industries indicates that a large part of company total expenditures for process development is related to what can be characterised as optimisation of the available production process. The process matrix has been further developed into a model with four categories of process development projects. It is argued that the use of the matrix can facilitate company strategic project selection and portfolio balancing of company process development projects. The process matrix can also be used in further academic research on the development of process technology in process industry as an aid to avoiding the risk of comparing totally different types of process development – a comparison between apples and oranges.

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Appendix 1. The sample and the survey

The sample and the sample frame

The population for this survey can be classed as process industry 'world wide'. Since it is difficult to get direct access to R&D organisations, the sample unit is the company. The total sample was 337 companies from European process industry focusing on Swedish industry. For economic reasons and due to lack of a good sampling frame, the sample was not a simple

random sample but consisted of industries selected according to the following criteria:

Type of industry. Process industries were selected according to the previously presented definition. The types of industries were selected using existing statistical codes for European Industry (NACE). Industries from different sectors have been clustered together: Mining and Mineral Industry (NACE codes 13, 14 and 26); Food and Beverage Industry (NACE code 15); Pulp and Paper Industry (NACE code 21); Chemical Industry – including petrochemical, plastic and rubber but not pharmaceutical (NACE codes 23, 24 and 25); Basic Metal Industry (NACE code 27); Other process industry (NACE codes 28, 37, 40, 41 and 24.4 plus some other industries connected to process industry).

Geographical location. For reasons of convenience, most of the companies were selected from Sweden (easy to get in touch with and get information from). The total Swedish sample is 109 companies. A fairly large number of industries from other Nordic countries were also selected (Norway, Finland and Denmark). Total sample of Nordic countries other than Sweden: 80 companies. From the rest of Europe we selected a smaller sample of industries (Germany, the United Kingdom, France, the Netherlands, Belgium, Italy, Austria and Switzerland). Total sample of European countries other than Nordic countries: 148.

Size of industry. The firms contacted had at least 200 employees, often more than 500 employees, and often many more.

Innovation intensity. Some parts of the industry sectors presented above were excluded from the sample because of our estimates that the innovation intensity for this group of industries was too low; thus meat production and concrete production, for example, were excluded from the survey.

The conduct of the survey

The questionnaire was sent out to R&D managers in the respective companies. All questionnaires were sent to a specific person whom we had identified as the right respondent in the organisation. For practical reasons, the method of conducting the survey in Sweden differed from the one used in the rest of Europe. The Swedish survey was carried out according to the following scheme: telephone contact with companies, checking the data and confirming participation – mailing the questionnaire – telefax reminders – telephone reminder – new telephone reminder – final telefax reminder. The scheme for the Nordic and the European survey was: mailing the questionnaire – new mailings after new information (new contact persons or address) – telefax reminder – final telefax reminder.

Response rate

	Sweden	Other Nordic countries	Other European countries
Number contacted	109		
Number of mailings	99	80	148
Number of responses	78	18	16
Response rate	72%	23%	11%

The response rate is very good for Sweden, considering that the total number of respondents including those who declined to participate on the telephone before the mailing is included in the sample. For some sectors nearly all industries were included in the Swedish sample, making it close to a census for those groups. The response rate dropped dramatically for the rest of the sample because of the different design of the survey.