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Technology Management of the transfer of knowledge within stochastic modelling

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TECHNICAL REPORT
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IMM

PH-CONSULT

Introduction

The objective of the present report is to discuss the business aspects, describe the interaction and analyses the industrial relevance of the scientific results obtained in an industrial Ph.D.-project with respect to technology strategies and management. In this framework the interaction between the parties in the project will also be described.

The project is a collaborative venture between the Institute of Mathematical Modelling at Technical University of Denmark and the engineering consultancy firm, PH-Consult. It is funded equally by the Danish Academy of Technical Sciences and PH-Consult.

First the company and the Ph.D. project is introduced, followed by a description of the technological competence of the company in relation to the project. Then the *organisation of knowledge production* is discussed along with *marketing* and a *product life cycle analysis.* After the description of these concepts, the industrial relevance of the scientific results obtained is analysed.

Finally, visions of directions to go in the future is presented, after concluding remarks of the most important points of this report.

Lyngby, February 10th 1997

Contents

1 Company profile

PH-Consult is a small consultant company founded in 1984 and now run by three professors from Technical University of Denmark (DTU) and Aalborg University. All are highly esteemed and involved in both national and international committees concerned by urban drainage and receiving water quality. The firm specialises in waste water engineering, urban storm drainage and quality of receiving waters. All employees are civil engineers and some of these are also employed part time at DTU, to ensure consistent ties with students and the latest research.

The company has conducted several significant projects in Denmark and the other Nordic countries. Real time control, assessment of pollution transport in sewers, regulations for storm water pollution loads, and hydraulic and hydrological analysis of severe flooding events, are just some of the projects PH-Consult has been involved in. Besides this, the company has been closely involved in the development of the international computer program package MOUSE, which is a major tool in the planning and modelling of waste water and urban runoff.

1.1 Main areas of business

PH-Consult is the Danish agent for MOUSE and responsible for, and owner of parts of the program package that models rainfall, and the SAMBA module. SAMBA is especially made for computations of pollution loads and for optimisation in real time control. The international awareness and use of SAMBA has been increasing progressively since its introduction. Continuous development is being done on the SAMBA module, as well as on new programs. As an agent for the MOUSE program, the company conducts courses in the use of the facilities in the program. The courses are directed towards employees in the public service sector, such as city and rural management, as well as other consultancy firms.

It is the philosophy of the company to be at the leading edge of technological knowledge in their area of expertise. MOUSE uses a purely deterministic approach to modelling, while new research showed that a stochastic approach have some attractive features that would enhance the assessment and modelling of systems which in reality include stochastic variation. A stochastic description of the different processes that influence water quality would facilitate a better understanding of the involved phenomena. Thus, the Ph.D.-project was a strategic move to transfer the latest developments in stochastic dynamic modelling from researchers at the Institute of Mathematical Modelling (IMM), DTU, to the company.

1.2 Analysis of the company

PH-Consult (PHC) is one of those companies that Kreiner & Schultz (1993) calls a small *research-oriented spin-off* firm. There are very strong ties with the academic world and contracts are often secured through *networking*. The real benefits and information gained from conferences and meetings does not come from the presentations, but from the exchange of information in the corridors and during coffee breaks. Lots of ideas are discussed, though few turns into tangible projects. As quoted in Kreiner (1992) "Our business is learning and we sell the byproducts of that learning". This could very well be the motto of PHC. The man quoted is a leader in a large production company, which only shows that in modern industry, the borders between production and pure knowledge based companies are nearly extinct. Allready Parker (1961) stated thet trade in commodities transmits knowledge as well as goods and Dosi (1992) equates the production of commodities to the production of knowledge.

Since the strength of PHC is knowledge production, the human resource is an important element. Educational activities are pursued actively to continuously recognise the latest trends in new research areas as well as in the established fields. This is how Wright (1991), Lado & Wilson (1994) define *strategic human resource management*. New employees are usually found through networks and the ties to DTU as the company is also involved in supplying data, as well as guidance for individual and thesis projects.

The company is very small (less than 10), which is what Peters (1983) advises in order to keep lines of communications open. This will provide the climate and opportunity to pick up new ideas more easily (what he calls accidental breakthroughs). However, a small company cannot easily devote extensive resources into basic research and development. It becomes a balancing act to maintain just the right size. This is where a jointly funded Ph.D. project works as a link to speed up the technology transfer between university research and practical use of this research. In return, the university partner obtains insight into the implementation of theories.

Being small in size has the advantage that quick adaptations to changes in business scope is possible. Ulhøi (1992) calls this an opportunistic attitude to research strategy and states that it is necessary to adopt this attitude to cope with the dynamic business environments of today. However, this may also mean that promissing projects, that may otherwise be successful (scientifically or technologically), may be abandoned to follow a new lead or if these technology-induced business ventures imposes too high a risk on financial liquidity (Twiss (1987)). Then projects that have been put on the back shelf may come back to be realized. Small businesses must carefully consider the high financial risks involved with development projects. To quote Nelson (): "A firm with a narrow technological base is likely to find research only at the applied end of the spectrum, where research can be directed toward a solution of problems facing the firm, and where results can be quickly and easily translated into products and processes.

The strategy is basically the same as skippering a sailing boat. One has to continuously make small adjustments as the winds change or to take advantage of currents and tide. The more attention that is lavished on the correct handling of the sails, the better the boat will perform.

2 The Ph.D. project

In this section the background for the Ph.D. project is introduced, along with a brief technical explanation of dynamic modelling and the grey box approach. Also an application of simple statistical methods to calibrate a traditional deterministic model and a suggestion for filtering of measured data to provide the possibility of on-line monitoring, is outlined.

As a global recognition of water quality being one of the 21. century's biggest environmental concerns and the necessity to employ a holistic view of whole systems, rather than individual units, it has been acknowledged that this is a field in need of an intense research effort. However, the problems are very complex; not only in the system description, but also in the lack of sufficient data quality (Somlyódy (1994)). Then there are the whole aspect of analysing these data.

2.1 Background

In Denmark, the Water Pollution Act, (WPA) enacted in 1987 set standards for stationary waste water discharge that have resulted in investments of more than 15 billion Dkr. A combined sewage system has built-in storage basins to take some of the load when the sewage system cannot handle the extra strain during heavy rainfall. Rainfall is a powerful transient burden of the entire system, that may cause discharge of oxygen consuming components, resulting in lowered oxygen levels and possibly dead fish. Thus, the WPA-standards eventually may result in even further investments in renewal and restoration of the sewage system, as well as in the monitoring of the receiving waters.

Oxygen, measured as dissolved oxygen, is one of the most universal environmental factors to evaluate water quality in rivers and streams. The level of oxygen determines the kind of aquatic fauna that may exist, and thereby the trophic level of the ecosystem. The higher the trophic level, the higher order of animal life. and the larger the bio-diversity.

The essence of the problem involves three different components: The drainage system, the sewage treatment plants and the receiving waters. Each of these components are equally important and holistic treatments of the integrated system are surfacing. While the first two components have been the

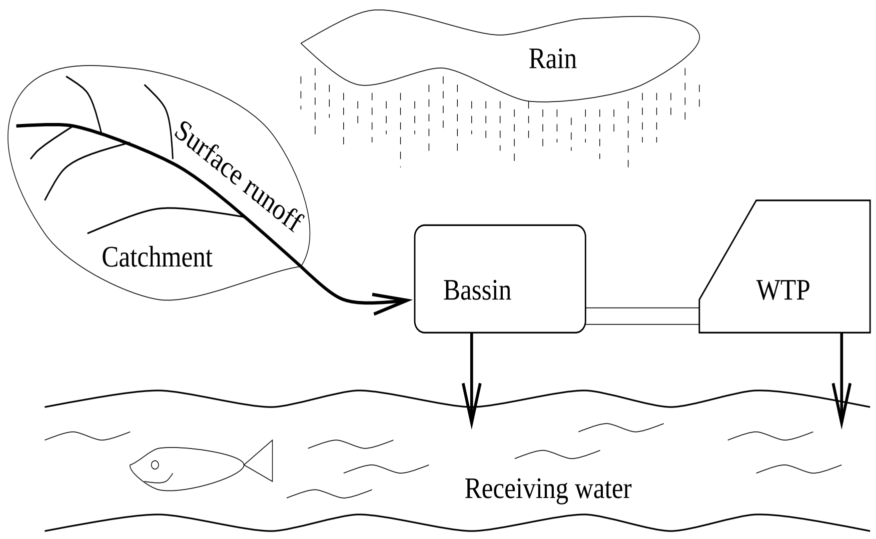

Figure 1: An integrated urban runoff system with the three componments: The drainage system, the waste water treatment plant (WTP) and the receiving water.

subject of much research, the receiving waters has not yet been submitted to such thorough investigation.

Within very few years, markedly improved measuring methods and equipment have resulted in still larger amounts of data. Thus, a pronounced need for statistically correct treatment of data had surfaced. At the same time the development in data treatment systems (e.g. computers) have supplied the possibility for much improved treatments. Presently, very large amounts of data are being collected at enormous expenses, while very little amounts have been spent on the data treatments that could lead to new knowledge. The situation is such that as yet, few statistically sound and consistent methods to treat these data have been developed. This, despite the fact that these data are very important to assess the WPA, as well as future initiatives for a better management and protection of the environment. Also the quality in monitoring programs is inconsistent at best and methods to assure a high quality in the painstakingly collected data needs to be developed as well.

2.2 Dynamic modelling

When modelling dynamical systems, such as the oxygen level in a river, new methods are being developed under the concept of so-called *grey box* modelling. This concept combines prior physical, biological and chemical knowledge about a given system with information from a set of data. Hence, it becomes possible to describe the total variation by introducing stochastic terms and thus describe the system through a set of coupled stochastic differential equations. Inclusion of stochastic terms is important in the modelling of complex systems where errors in measurements may be dominant. With respect to dynamic models for the level of oxygen in rivers, the knowledge of cause and effect is fairly complete. But variations, due to e.g. impact from rain events, makes it necessary to focus on stochastic models (see e.g. Jacobsen & Madsen (1996), Jacobsen et al. (1996b)). Better information is not necessarily more precise info and uncertainty is not ignorance – it is knowledge. Seemingly precise forcasts may hide uncertainties and thus provide less info than a forcast showing a range of possible values.

2.3 The grey box concept

To understand the grey box concept, a short introduction to the three model types most frequently used in the modelling of dynamical systems, is useful. These are divided by colours: Black box, white box and grey box.

Traditionally, *black box* models are identified on the basis of the data only and as such only an expression for a given set of data. The parameters may not have a physical interpretation and such models may not be representative of the general dynamics and physics of the system. A deterministic model is sometimes called a *white box* model. It is purely based on known deterministic equations for a system. Equations for complex systems are often combined with detailed equations for smaller sub-systems, which often have been subjected to various approximations. It is therefore difficult to quantify the uncertainty of the total model.

The grey colour, suggests that this model is a mix of the two previously described models. This kind of model combines available knowledge and known equations of the system with statistical modelling tools. Based on this, model parameters are estimated and these have physical meaning and may readily be interpreted. The three model types are envisioned in Figure 2.

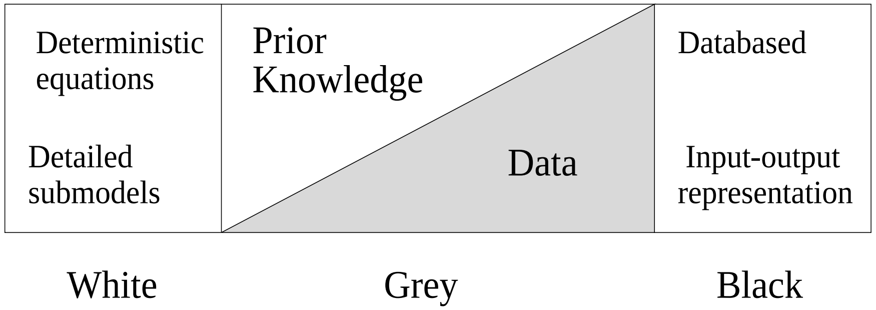

Figure 2: The grey box modelling concept. The shade of grey for a given model may be expressed as the relationship between the amount of knowledge and data available.

With any system, there is always uncertainties and phenomena that has not yet been detected or fully realized. For natural systems, such as rivers, meteorological effects are one example of uncertainty. Therefore, combining available knowledge with information from data is an optimal approach towards understanding a given system. The experience obtained by using the grey box modelling concept will thus be of major importance. Not only in modelling the dynamics of the oxygen content in a river, but also in modelling other complex dynamical systems. Eventually a model for the entire integrated system could be developed.

2.4 An automatic calibration procedure

Working with deterministic models always include a long and often tedious phase of calibrating the parameters of the model. An experienced operator can reduce the time spent on this task considerably, but still the time allocated to this problem is significant. The calibration task is usually solved by heuristic procedures, but is essentially an optimization problem.

A traditional statistic method, the so-called output-error method is used to calibrate system parameters for both runoff and receiving water quality. The output-error is a well known principle (Söderström & Stoica (1989)) based on the difference between a measured time series and a simulated output. By minimizing this difference, it is possible to find the parameters, which gives the best fit of the model to the measured data for that situation. Applied to a deterministic model, several parameters may be calibrated automatically using a measured time series. A Monte Carlo validation of the calibration routine was carried out for a synthetic case and it was shown that even with data contaminated by a quite high level of noise, the calibration method yield results that are not significantly different from known values (see e.g. Jacobsen et al. (1996d)).

2.5 Filtering data for on-line monitoring

In Jacobsen et al. (1996c) a maximum likelihood method for estimation of the parameters is used to simultaneous estimate the parameters in a differential equation, describing the variation of oxygen in a small creek, and the parameter in a low pass filtering of the solar radiation input.

The modelling involves a description of the influence from variations in water temperature and solar radiation. The latter affects the oxygen level via the photo synthesis process.

It had been shown that the simultaneous low pass filtering of the solar radiation data provided more precise estimates (Jacobsen et al. (1996a)).

The low pass filter compensates for the fact that the solar radiation is a high frequency signal (it oscillates within 5-10 minutes intervals) and a point measurement, which probably is measured some distance away from the main body of the river. Only the diurnal variations are of interest. The estimated filter enables an on-line monitoring of water quality. Thus, immediate assessment of receiving waters, as well as of data quality, is possible. The advantage is that this would enable remediate action to be taken much faster than today.

Technical design as in tangible items is not that present in these applications, rather it involves developments of tools in form of computer models and programs, which may aid in more accurate assessment of water quality during transient pollution events through implementation and information. These developments contribute in various ways to the company's competence.

3 Technological competence

In order to report on the technological competence of PH-Consult (PHC), the term *technology* should be defined first: Howard & Guille (1992) states that technology can be characterized as stand-alone, explicit knowledge that is easily contained, while technological competence is of a different nature. New technology is not only new processes, it is also new conceptions and acknowledgements. Technological competence is mastering the processes and the necessary framework, that the expansion of knowledge requires. Perhaps different levels of technology should be defined, such as done by Zeleny (1986), Coombs & Richards (1991) and shown in Fig. 3. In the following, a support net is defined as a requisite organisational, administrative and cultural structure. This involves educational activities and the adjustments needed to see a whole new perspective in otherwise familiar products.

It should be noted that Zeleny (1986) just labels the middle level of technology with that one word (technology). This was found confusing and therefore changed to *Regular technology*.

Levels of technology

Zeleny (1986):	Coombs & Richards (1991):
• **Appropriate** Doing known tasks in a known way	• **Enabling** Necessary, but not sufficient
• **Regular** Doing new tasks in a known way	• **Critical** Central and differentiating
• **High** Doing new tasks in a new way	• **Strategic** Emerging and competitive

Figure 3: Definitions of different levels of technology.

The traditional deterministic models (like MOUSE and SAMBA) that PHC is an expert user of is an *appropriate technology.* A base or *enabling technology* is one that is necessary, but not sufficient to keep the company competitive. It is essential to efficiency, reliability and quality. Although the programs are continuously updated and improved, the way they work is unchanged. An update with new features, requiring no support changes becomes *regular technology* untill the new features are so integrated, that they are not perceived as new and the technology is no longer a central and differentiating feature. Then it reverts back to being just an appropriate technology. If the programs are updated to a version that requires a new support network, it becomes *high technology.* This is the case if the program is updated to run in a Windows version on a 32 bit computer. Here the support net is changed as user education may be required.

Developing an automatic calibration routine, that may cut down on time required for this task (calibration by hand) is also an example of *regular technology.* A known task is performed in a new and different way (using a statistical method instead of a heuristic method), which also may require training in the use of the program. Such a technology may become a key or *critical technology* that could be central to a company's competitive edge. As such it would be a differentiating feature from the competitors.

A change from deterministic models to stochastic models involves a change of both the way the model is done, as well as a change in the support net. Therefore, this scientific achievement constitutes *high technology.* The knowledge of stochastic models can only be applied through information at the user end. Otherwise, the technology becomes inappropriate and useless. Pacing or *strategic technologies* are tomorrows key technologies. It could be these emerging new technologies from Research & Development that provides new and competitive opportunities.

The perspective for on-line (real time) monitoring is a development under the stochastic models. If the stochastic models are already in use, the addition of a possibility for on-line monitoring is just regular technology. If on-line monitoring was a whole new concept it would constitute a cultural change and it then becomes high technology. However, to develop on-line monitoring into early warning systems, for receiving waters, may require the organisational, administrative and educational activities that is the trademark of high technology. Thus, it is seen that it is in the regular and high technology areas the value and new frontiers of the Ph.D. project lies. Inherent in these activities, experience and knowledge is gathered in the area of design of monitoring programs. The developments then leads to several new niches of knowledge. "Firm specific knowledge arises when a firm acquires for itself competence, knowledge and skills in discrete technological areas" to quote: Coombs & Richards (1991). The different concepts of technology, along with the respective areas applied at PH-Consult is illustrated in Fig. 4.

Zeleny (1986)	Applied at PH-Consult	Coombs & Richards
Appropriate	Deterministic programs MOUSE, SAMBA	**Enabling**
Regular	Automatic calibration routine	**Critical**
High	Stochastic models On-line monitoring	**Strategic**

Figure 4: Definitions of different levels of technology with their applications to products of PH-Consult (PHC).

4 Organization of knowledge production

A barter economy is traditionally thought to be the trademark of developing countries, where goods and services are traded directly without the exchange of money. However, the term can also be applied to many informal collaborations in Research and Development (R & D) ventures today.

There is a widespread barter economy between universities and the industry which is almost always done through an extensive network. *Networking* is a very attractive, if illusive, strategy of forming fruitful collaborations. This can be informal networks based on something as spurious as common interests, such as having spent the student years in the same fraternity house, belonging to the same golf-club or fellowship or a chance meeting, it cannot easily be put into management strategies (Zeleny (1986)).

It may start as an idea which, when discussed in an informal discussion, leads to the discovery of a collaborative opportunity. Following this, that opportunity is explored and maybe tried out in small preliminary investigations to test the feasibility of the venture. If this is satisfactory, the last step is implemented as the crystalization of the collaboration (Kreiner & Schultz (1993)). Ulhøi (1992) states that networking helps couple *Management of Technology* and *Strategic Management*.

The reason, the coupling of the academic world and industry is so mutually beneficial, is that pushing forward new frontiers in science is only real useful when the theories are tried out in practice. Reversely, the experience gained in practical applications will lead to acknowledgement of new knowledge, which then can improve the theory. Knowledge and practice are mutually dependent of each other.

4.1 Collaboration between university and industry

The basis for successful collaborations between the academic world and industries that are knowledge based lies in the different backgrounds, expectations and roles of these parties. Where industry often have money and resources available, although with an obligation to show a profit, the university often have the specialised expertise with an obligation to push forward the frontiers of science in form of international publications. Universities may be said to have knowledge as a target, industry to have knowledge as a tool. If both parties' identities are tied to being competitive in either science or product development, collaboration through networking is very productive. "Collaboration between like-minded is not nearly as productive as collaborations between complementaries" quote: Rostrup-Nielsen (1996). This barter economy may be characterised as a shift in paradigms from optimizing production and rendering more effective services, to constant knowledge expansion (Kreiner (1992)).

Knowledge as a goal or as a way to reach a goal.

Knowledge is a difficult commodity to barter. There is no common currency, and the only rules are unspoken and not written down. The Danish society have no restrictions to the scientists and researchers it educates at great expense. This is an age-old tradition even back to the Danish astronomer

Tycho Brahe, who left the company (Denmark), so to speak, in 1597 when new management (new king) took over. Until then, lots of resources had been invested and at his disposal (Nørretranders (1996)).

In PH-Consult knowledge is sold as this constitutes the services the company lives by. This creates a dilemma between the sharing of information and the protection of ones own knowledge resources, which is a difficult balance. Institutional centers related to producing scientific and technological advances from R & D in collaboration with large corporations facilitates a greater contribution to innovative activity and may take care of the confidentiality problem.

As impulsively as these collaborations may arise, just as sudden they may die. Since no formal contracts exist, the relations have to be nurtured to continue to exist. If other more pertinent duties take priority, the collaboration may simply die out. The university have teaching obligations and the company have to attend to profit-making activities. Thus, *action rationality* may be far more critical than *decision rationality.* However, the relation may just be hibernating; waiting to become more active when time and resources allow.

A formalized collaboration, such as an industrial Ph.D. project, could bridge the gap between the two parties and keep the collaboration alive. The Ph.D. fellow alternates between the two settings and, by constantly working on the common goal, make the project stay high on the priority list through meetings with the supervisors.

4.2 Communication of knowledge

Publication of research results may cause problems with competition and confidentiality. With no formalities collaborative parties have to rely on discretion and fair play.

The openness of the research efforts from an industrial Ph.D. fellow is both an advantage and a risk. An advantage is the signal of seriousness to new research the employment sends the community. It's a signal that shows that

$\boxed{\text{We're on the leading edge of new technology}}$

This leads to the building of expectations of improvement and can generate a generous amount of goodwill (Howard & Guille (1992)). The risk is through the publications and communications of results, that informs of the progress in more direct ways than is usually the case. In PH-Consult the risk is less than in many other companies. Being tied closely to the academic world, the company is used to communicate new results at conferences and in trade periodicals. The central economic fact about the processes of invention and research is that they are devoted to the production of information Arrow (1962).

An industrial Ph.D. project is a one-person project, that because of its scientific nature of bringing new technology to the company may run largely on its own track, parallel to the other business efforts. This is where communication and information becomes important to keep motivation high and contribute to a sense of company identity. Klimstra & Potts (1988) states that a good project leader is curious and enjoy working with others to solve problems. As such, the leadership at PH-Consult is especially well suited as successful professionals in the academic world, where these elements are imperative for success.

Between a given technology (from the university partner) and its implementation (by the industrial partner) there is a duality, where learning and technical design merge with implementation and information. This is illustrated in Fig. 5:

4.3 Project management

Because of the size of the company, it makes no sense to talk about organisational structures, such as matrix or line functions organisations. It may

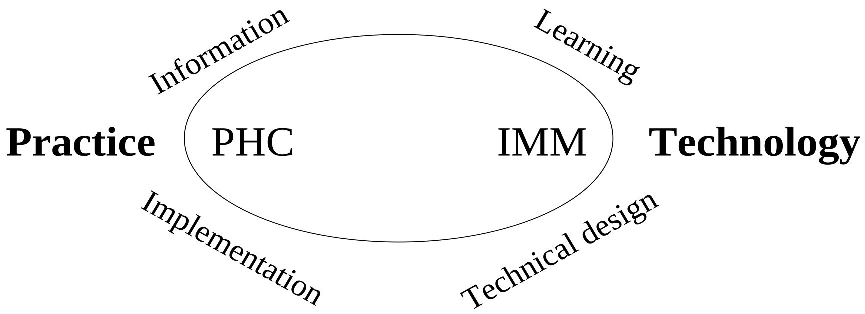

Figure 5: Duality between implementation and information. Adapted from Kreiner, K. (1992).

be likened to the so-called skunkworks teams (see e.g. Peters (1983), Klimstra & Potts (1988)). Skunkwork operations are project oriented teams that are put together to solve narrowly defined problems. They operate separate from other projects in large corporations to promote a small team identity and have been quite successful in several cases (see e.g. Sherman (1996)).

Pure project organisations have the advantages that it is output oriented and flexible with short communication lines and a holistic approach. The large production company disadvantage of duplications of people, skills and equipment in a pure project oriented organisation are not an issue in PH-Consult (PHC). However, if too many small individual projects are running at the same time, communications between projects may suffer. Also competition for 'best project' may occur, but that may only add to the overall quality in the company.

A project in PHC typically evolves around a specific problem. Either a present one, or if time, resources and other work permits, developments from problems uncovered in otherwise finished projects.

Typically, the start up of a new project (whether connected to a specific job or not) requires a description of the basis for the project, an outline of how to reach a given goal, and a time and activity plan. Also the budgeting must be attended to; specifically if acquisitions of new equipment are needed in order to go ahead with the project. Anyone in the company may be involved in such a project as there is no specific Research and Development department. The decision, however, lies with the management and depends on the presentation of the project and how the prerequisite work was carried out.

5 Marketing technology

Technical change can be viewed as either *demand-pull* or *technology-push*. These concepts describe developments after a demand has been expressed vs. developments that are pushed onto the consumer because someone finds it useful or sees a chance to make a profit. Dosi (1992) and Howard & Guille (1992) sees demand-pull as a market driven reactive mechanism based on a black-box of available technology, while Coombs & Richards (1991) state that the technology-push process probably predominates at the birth of a new industry or a new product and then progressively is moderated by the demand-pull process.

Schumpeter (1928) presented the technology-push concept early in the twentieth century, thereby bringing the subject of technological change to the attention of economists. Then, 34 years later Schmookler (1962) put forward his view of demand-pull. However, Schumpeter saw technology-push as a shortcomming and used it to argue his socialist conviction that capitalism was unstable and would eventually break down.

Innovation means putting productive resources to uses *hitherto untried in pratice*, and withdrawing them from the uses they have served till then (Schumpeter (1928), his emphasis). Thus, innovation means producing at smaller cost per unit, unless technology-push is involved (forcing upon the public a new commodity). Inventive activity is caused by individuals acting in response to expectations of future profits (Schmookler (1962)). A chronic tendency of technology to lag behind, as well as cultural lags (new technology may render obsolete pre-existing social arrangements and behavior patterns (e.g. the automobile)). Inventions comes at a price and the expected benefit depend on socio-economic change. Thus, the purely reactive mechanism relates to the so-called Schumpeterian view that *invention* is just an idea or sketch, while *innovation* is the new product or process (Coombs & Richards (1991)).

The concept of pure market driven vs. pure technology driven advances, however, are too crude to accurately describe a change (either abrupt or evolving), as there is much feed-back also.

It can be said that marketing today has evolved from salesman driven to market driven. This is partly due to many more companies that are in the knowledge business. Knowledge-based marketing works by:

- Involving the customer in the design/development process.
- Thinking in terms of a niche (market segment) the company can own or master.
- Using networks in all stages of product life, from supplies to the end user.

It is not a matter of aggressive or more intensive marketing, but of better marketing. In the words of McKenna (1991) knowledge and experience based marketing, represents the once-and-for-all death of the salesman.

Most projects between university and industry are inter-disciplinary. The inter-disciplinary projects may be said to couple technology-push with demand-pull. A client may turn to PH-Consult to find a solution to a specific problem, or the company finds new solutions to old problems through research, or from ideas discussed at various gatherings. Thus, it acts as a bridge between invention and innovation.

Invention $\Longleftrightarrow$ **PH-CONSULT** $\Longleftrightarrow$ Innovation

5.1 Company marketing

The company does not engage in aggressive marketing of its services. It is preferred that new projects are found through networks and referrals. Therefore there is no department of strategic marketing. However, such phrases as segmentation and positioning are central (about these concepts, see Reeder et al. (1987)). Being a so-called research oriented spin-off firm the company's business is oriented towards a very specific segment of the market, which is the public service sector such as city and rural management.

The key product of PH-Consult (PHC) is a software product, which it shares the rights to with another (and much larger) company. PHC, however, runs the service center to this product and gives courses in its use to the end users. This provides an advantage related specifically to positioning. The product is continuously developed along with other software products, prompting a dialogue with the end users. In turn this leads to a larger demand on the company's other services, which is using this software to solve specific problems. It is sound management decisions to contact potential customers at an early stage in development of new products (Rostrup-Nielsen (1996)).

The automated calibration procedure is only being developed for PHC at this point. However, in time it may be decided to develop it into a product for sale, along (or as an addition to) the traditional deterministic models. This could lead to more user courses to teach the buyers how to use it. The same could very well be the case with stochastic models, though this is further off in the future.

Obviously, not everyone believes that it is possible to convince a market it has a need, unless they have acknowledged it already (Reeder et al. (1987)). This is where the application of lead users is useful.

5.2 Lead users

To push a product forward a company can make use of the so-called lead users. This an early contact to potential customers, who can provide feedback on new developments. Urban & Von Hippel (1988) identifies lead users through two characteristics:

- Lead users face the needs that will be general in a marketplace – but face them months or years before the bulk of that marketplace encounters them.
- Lead users are positioned to benefit significantly by obtaining a solution to those needs.

These characteristics specifies and identifies a lead user. Making use of lead users is part of the *commercial validation* aspect, that Howard & Guille (1992) lists as one of the various stages in the realization of a new product, process or service. At this stage a prototype is often designed and optimized through iterations with lead users. The use of lead users can be seen to relate to the leader/follower concept. The leader is the innovator, while the follower, who may well be such a lead user, is the adoptor (Ulhøi (1992)).

PH-Consult (PHC) is such a lead user, with respect to the key software product (MOUSE), where another company develops the new versions. The company that develops the new versions are given valuable feedback and as a lead user PHC can often test a new concept or supply ideas for developments that they have discovered a need for.

PHC also often develops their own software and researches new products, such as an automated calibration procedure and stochastic modelling. As such they become the leader and may through their contacts from courses and the general dialogue with end-users identify lead users for their own products.

Lead user status

Lead user	Product	Leader
PH-Consult	MOUSE	Collaborator
Selected customers	Autocalibration routine	PH-Consult
Selected customers	Expert courses	PH-Consult

Early in the Ph.D. project a contact was made to all 14 counties (major municipalities) in Denmark. We proposed a test area set-up and they in turn had to provide data, collected in their receiving waters, which we then could use in the development of the stochastic models. Many were interested, but few had the resources or inclinations to go into such a venture. In the end two counties responded positively and PHC were eventually also involved with regular consultant projects for both these counties.

The two counties that responded positively both faced significant problems with their main receiving waters that needed to be solved in order to provide quality recreational facilities to its citizens. Thus, they were both positioned to benefit from participating. However, only one of these decided to invest the resources needed towards this goal at this point in time, as the monitoring program, that had to be initiated at their end, was quite extensive. There is reason to believe that in the future regulations governing environmental monitoring will result in guidelines for more extensive programs. Thus, the county that did go ahead with an extensive monitoring program faced a need before the bulk of the public municipalities. They needed a better assessment of the quality of their receiving waters through more advanced methods than are presently required by the Water Pollution Act (WPA). Following the WPA-plan in 1987, huge investments was carried out. Unfortunately, it does not seem that the problems these investments were supposed to eliminate have been abated to the extent it was hoped.

Strategic management involves an assessment of how many possess a similar technology, as well as an assessment of how useful a future customer might find a new technology. This show a successful application of an industrial Ph.D. project and a search for a lead user. A lead user can also provide input towards maturing a new technology, such as stochastic models. The apparant paradox: Teaching others to use the software, which is also used to provide services in terms of project solutions is a creative way of involving the end user and an example of global thinking (Gattiker (1992)) because it also may assure that the company obtains the contract.

6 The S-curve concept

A product life cycle may be divided into four stages (Lancaster & Massingham (1993)):
Stage 1 is the introduction where sales are slow. Then stage 2, the growth stage, follows with massive sales. Stage 3 is the stage of maturity, where sales even out until, at stage 4, they decline as shown in Fig. 6. This translates into an S-curve with sales as a function of time. It is important to know where on the life cycle a product is placed, in order to know what steps should be taken next.

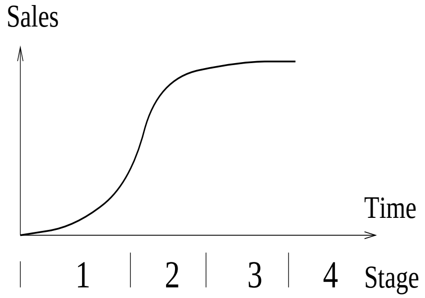

Figure 6: The different stages of a product lifecycle.

Just as a product may be described by a given S-curve, different products may be described by different types of S-curves (Lancaster & Massingham (1993)).

In a life cycle concept, S-curves are generally directed at specific products; but just as their patterns may differ to represent types of products, they can also be applied towards new technology in the knowledge business (see Fig. 7).

Shape **a**) is the life cycle of a technology that immediately captures the interest, display a quick sales period, whereafter it levels off to replacements

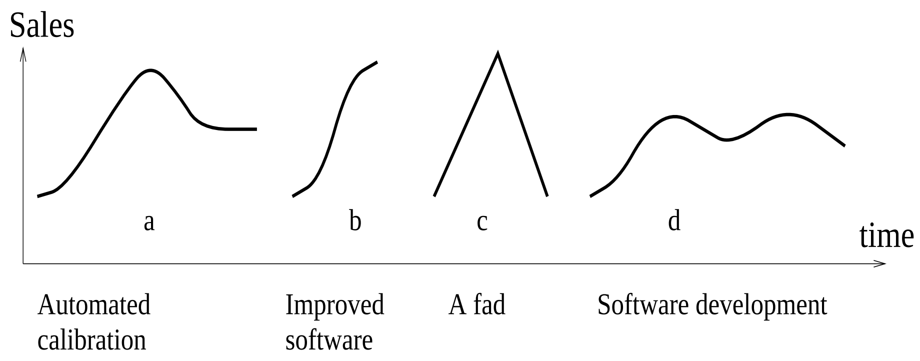

Figure 7: Four different types of S-curves, corresponding to different types of products.

and new users. This could be exemplified by a software product such as an automated calibration procedure that saves the user time and effort (Jacobsen et al. (1996d)). After it has been sold to all the existing customers, it will level off to be sold to newcomers mostly. The initial slope may be more or less steep depending on the introduction time-frame of the product. It would be the typical curve form of a knowledge technology that works.

Shape **b**) refers to new easily approachable products with substantial market appeal and little risk for the user. The cut-off indicates that it will be replaced by another product instead of reaching a stable level, such as improved or additional software. Shape **c**) indicates a fad, or a trendy novelty, such as *bells and whistles* (Cooper & Chew (1996)) on a software product. Bells and whistles are fancy additions that are not really necessary for a products use. In the knowledge business, this could be an invention that immediately shows great promise and everyone is eager to employ this new technology. Only, it turns out it wasn't as practical or realistically possible as first thought, e.g. it turned out to have a much too short lifespan.

The last shape **d**), is a modified shape a), where the product is replaced by a new product instead of levelling out. It is easy to apply this to the software industry. PHC's key software product falls in this category: From basic menu interface to (eventually) Windows based with icons and the works.

The new development is into stochastic modelling, on-line monitoring and towards more integrated models; starting with the investment in a industrial Ph.D. fellow to develop the stochastic model for receiving water quality, starts a new life-cycles on a brand new S-curve (Madsen (1996)). Failure or reluctancy to progress from one S-curve to another will eventually lead to stagnancy of the company (Howard & Guille (1992)).

The principles, however, can be extended to industry development as a whole (Lancaster & Massingham (1993)) and be linked to the leader/follower categorizations(Ulhøi (1992)). The followers make use of the experience (or learning) curve, which comes from the fact that a production team over time becomes both better and faster at assembling a specific product. Being a follower considerably down-sizes the need for an investment heavy research and development department. However, followers may also take advantage of a niche to develop their market segment. PHC, for instance, may be a follower with respect to their key software (MOUSE), because the new developments and versions of the software is maintained by another company, with whom they share the property rights. But PHC is the expert user who can advise as well as educate end users of the use of the software. In this respect, the company takes a leading role.

7 Research strategies

In this section the research strategies of the company will be summarised and the industrial relevance of the Ph.D. project, in view of these research strategies, will be outlined.

In section 3 it was shown how the knowledge products in PH-Consult falls into different categorisations of technology. It was argued that developments from the Ph.D. project fit into the key and high technology areas. Then, in section 4 it is described how knowledge organisation has its roots in a barter economy based on informal networks between collaboration parties. PH-Consults products are specific knowledge, which they develop and sell by making good use of of network opportunities. Through the employment of a Ph.D. fellow a collaboration becomes more formalised but may present some problems relating to the communication of the research results.

Section 5 defines the concepts of technology-push and demand-pull and argue how marketing today has progressed towards the latter more market driven approach, which is also followed by PH-Consult through their close customer contact. The new stochastic models developed in the industrial Ph.D. project may be categorized as technology push, while the requests for new features, through customer contact at courses is a typical demand-pull example. In this section it is also shown how PHC employs the concept of lead users and in fact is such a lead user itself with respect to one of their software products, where they take the role of a follower.

Finally, in section 6, the various products (in the form of both software and counselling) is related to the product life cycle concept illustrated as S-curves. Different products, as well as different technologies may have their own distinctive curves. Here, also the new products, developed in the industrial Ph.D. project are seen as the start of brand new life-cycles.

7.1 New technology

New technology is far from just hardware and equipment. Rather, it can be said to consist of hardware, software, and brainware. People and their network must be there too. As argued in section 3 high technology affects the structure, the network and the culture. It permeates everything and socioeconomics becomes important factors. Regular technology may be administered, while high technology must be managed because it changes the support net (Zeleny (1986)). Without that realization high technology may become misplaced and inappropriate. Certainly, technology-push carries large uncertainty with its implementation and may provide some unpleasant surprise as late as in the market testing stage (Howard & Guille (1992)).

Barbour (1980) describe technology as "The organisation of knowledge for the achievement of practical purposes". In relation to the support network, technology is viewed as two poles: Either a liberator that **does not** need to be controlled, or a threat that **cannot** be controlled, when in fact it is probably somewhere in between. Large scale technology is vulnerable because the networks frequently cannot keep up, leading to negative consequences. The enemy is NOT technology, but blind faith in it.

Science Finds - Industry Applies - Man Conforms

The above was the official slogan of the Century of Progress exposition in Chicago 1933, and it expresses both views. President Truman believed that poverty and misery could be abated by a small number of 'technological fixes' and made a point of that at his 1949 inaugural address. Ericson et al. (1990) warns against the Zeleny (1986) definition of high technology because of the needed network. This may create a possible trap and should be approached with utmost caution.

The new services PHC will be able to offer, as a result of the industrial Ph.D. project, are related to stochastic models both directly and indirectly. When matured, the stochastic models can supplement and augment the deterministic models that are the company's core competence. The grey box method has the advantage that non-linear relationships may be taken into effect. These have typically been linearised, which added to the overall uncertainty in the model. Grey box modelling further have the advantage that it is possible to test different model structures.

The automatic calibration routine will assist in a faster and more efficient use of time when working with these traditional models. If, or rather when, new and more detailed government regulations stipulates more advanced monitoring programs the work done with the filtering of data for use in online monitoring will perhaps be developed further. The company, through its unique position, might be able to influence such legislation because of the research they have invested in this area.

In this report, as well as in the Ph.D. project statistical methods are used to develop new technology in PH-Consult. There are also theories describing statistical methods to evaluate technological innovation. Twiss (1987) give examples of risk analysis applied to project comparisons and operational research techniques using linear programming to allocate resources between projects. A great deal may be learned by analysing historical data from earlier projects. Tanaka et al. (1993) also uses a statistical approach, he calls *Cost tables*, which he uses to predict the cost of new products, based on the expenditures on previous products. Spending the time, effort and money on these activities may help reduce the margin of error when establishing new technology. However, these methods have not been employed in this report, as there were not enough data to support such an analysis.

7.2 Industrial relevance

PH-Consults (PHC) technological strength can be characterised as *favourable* according to the Ericson et al. (1990) measure of technological strength. The term favourable cover the aspect that there is technological capacity to remain competitive and that the company is able to manage continued improvement in technology. This will sustain its position, though it may not have the capability to take technological leadership on a sustained basis because of its size. However, with the involvement in an industrial Ph.D. project an interesting step towards independent and creative technological directions have been taken. The use of academic links is vital to its capacity, as it provides a window to emerging science. This will not only strengthen the company; it also provides a most important interplay between research and industry that is beneficial to society (ATV (1996)).

When calibrating deterministic models, only **selected** events (when it rains, for instance) are used in the final modelling, even though there may be data from a longer period (in order to include the events needed). Stochastic modelling, however, use **all** the data collected to identify the model and estimate the parameters of this model. In reality, a monitoring program never yield perfect data. Errors occur in the equipment, as well as vandalism (either intentional or not) from bypassers and playing children. Statistical methods may be taken into use to repair the data so the entire series may be used (see e.g. Jacobsen & Voss (1994)), or a sufficient segment is taken out and used. The significant difference is that the final time series of data includes the wanted events, as well as the periods in between these events.

PHC is in possession of the knowledge which are key to their niche. These, however, may also be characterised as base technologies, as the company is not the only one in possession of this knowledge. At the same time, through the links to the academic world and the employment of an industrial Ph.D. fellow, it has access to knowledge that can result in new strategic technologies. The firm is in the *specialized supplier* business, by the definition of Coombs & Richards (1991) and it is taking the necessary steps to remain there.

8 Conclusion

An industrial Ph.D. project was initiated to develop stochastic models and gain experience with data treatments, based on statistically sound principles. The idea was a result of the intensive network with DTU. It had long been recognised that stochastic models had something new to offer as a supplement to the traditional deterministic models the company is known for. Some smaller collaborative ventures had already been established between the university partner at Institute for Mathematical Modelling and the founder of the company. Data had been supplied for a master's thesis that directly lead into the present project.

The main points of this report show that PH-Consult is a knowledge based company, working through networks and inter-disciplinary contacts. The marketing approach used by PH-Consult is in line with the market driven concepts that are dominant today and contracts are often secured through networks, as well as through a dialogue with the users of their present products. A product life cycle analysis, aided by the S-curve concept, has been carried out and related to the developments of the industrial Ph.D. project. It has been shown that PH-Consult employs the lead user concept and in some respects is a lead user itself. With the active participation of other lead users the company may mature their products, so that their services may include the use of stochastic models. Thus, the competence resulting from the industrial Ph.D. project will enhance the services PH-Consult will be able to offer.

Finally, the industrial relevance of the scientific results obtained is analysed, in the framework of various research strategies.

Stochastic models have the advantage over deterministic models, that the parameters estimated carries with them the dimensions of uncertainty of their size, based on consistent statistics. This uncertainty gives an indication of which variables it makes sense to concentrate on and which are so uncertain that more research will have to be done on the processes which they govern. Deterministic models, on the other hand, have their strength in their detailed descriptions of the processes involved. Thus, the two types of models supplement each other and PH-Consult's knowledge and experience in both fields may result in a more holistic approach and better service to its customers.

Furthermore, with the experience PH-Consult has gained in working in different ways with real data from large monitoring programs, their service in giving advice can form the base in a well structured monitoring program. There, the following modelling (both deterministic and stochastic) may yield answers that result in a more correct identification of the problems encountered. The often very large investments that follow such monitoring may then be reduced significantly or at least be used where they really mean a difference.

Finally, with the concepts described and put into use, the technological advances from the industrial Ph.D. project may be summed up as follows:

Technology results

Grey box models	**Calibration routine**	**On-line filtering**
High technology	**Regular technology**	**High technology**

8.1 Visions for the future

Several software products have been developed, as concepts more than as finished products. These will need to mature and possibly be exposed more to lead users before they can be developed into end products. At their present stage they can be used internally in the company by an expert user, as no interface have been developed. After further developments, these products could enter the marketplace:

- The auto-calibration routine.
- The stochastic models.
- The possibility for on-line filtering and monitoring.

The stochastic models of the receiving waters could further be developed and expanded to complete integrated models. Integrated models would be very useful in managing the environment, which is the new trend in environmental protection. In turn this would provide the company with a competitive edge that could be an international advantage and secure EU projects as well.

After initiating the industrial Ph.D. project, several other ventures have been established. For example a center for information technology in the environmental sector (CINTEM) involving several other partners. It is reasonable to believe that the established interaction between the Institute of Mathematical Modelling and PH-Consult will continue. The company, as well as the university will be able to benefit from the strengthened ties; both on other fronts and as a continuation of the developments from the Ph.D. project.

"*Technology does nothing, have no value, in itself. It is the PEOPLE who makes the choices, who manage the technology, who does something*". Quote: Urs Gattiger.

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