FACTORS THAT CONTRIBUTE TO EFFECTIVE RESEARCH IN AN ENGINEERING DEPARTMENT

by

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MINI-DISSERTATION

submitted in partial fulfillment
of the requirements for the degree

MAGISTER INGENERIAE

in

ENGINEERING MANAGEMENT

in the

FACULTY OF ENGINEERING

at the

RAND AFRIKAANS UNIVERSITY

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JUNE 2004

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Summary

The topic of Research and Development practice is explored with focus towards the environment of a research-type department, namely an engineering faculty. The aim is to explore those factors that aid engineering research personnel in being able to carry out effective research. In this manner, with relevant literature study, a survey is constructed with the intent of obtaining some characteristic information of an engineering department. From this conclusions can be drawn as to the current strengths and weaknesses of the department, relevant statistical analysis performed, and references made to theoretical models of organisational effectiveness.

Opsomming

Die onderwerp van Navorsing en Ontwikkeling praktyk word ondersoek met fokus op die omgewing van 'n navorsing tipe department, naamlik 'n ingenieursfakulteit. Die doel is om die faktore te ondersoek wat ingenieursontwikkeling personeel help om effektiewe navorsing te verrig. Op hierdie manier, met 'n relevanteliteratuur studie, is 'n opname saamgestel met die doel om sekere karakteristieke informasie van 'n ingenieursdepartment te verkry - van hieriut kan die sterk en swak eienskappe van die department verkry word, relevante statistiese aanalises gedoen, en verwyssings gemaak tot teoretiese modelle van organisasie effektiwiteit.

Chapter 1

Introduction

1.1 Problem Statement

Improving the efficiency and effectiveness, with regard to employee behavior, of business-type organizations is a well-explored and popular topic. One of the fundamental goals of senior management is to find methods to help the employee within that organization perform – in this regard management needs to ask the right questions, such as what is needed to keep employees motivated, for example. This large and complex field on human behavior and the improvement thereof for business practices has been explored and continues to be a major topic for business researchers. However, with regard to research and development (R&D) organizations, less has been written about the improvement of these environments. In general, methodologies for improving the effectiveness of research laboratory environments need attention; environment in this instance is to be taken on the broadest level and entails *all* aspects that have an influence on the employees in a research-type environment. Just as with business-type organizations, the challenge is to pose the 'right' questions when wanting to find out how to assess and improve the effectiveness of research-type organizations.

1.2 Justification

The justification for wanting to improve the effectiveness of these environments cannot be undermined; it is well accepted that research forms a fundamental building block of business projects. As noted by [6], research in the sciences has affected many areas of modern living; not only has it generated advances in the scientific fields of communications and energy generation but also caused technological advances in health care, financial services, transportation, agriculture, entertainment, management of industry, military security, networking and so forth. It is challenging however to measure the effectiveness of research organizations directly with business profit. Ultimately the organization needs to prove to investors that any research capital granted will be a good business decision. For this to be done, it firstly needs to be shown that an organization is able to produce new ideas that are of quality with the aim of creating new products or processes.

1.1 Aim

The environment of a research-type organization is unique: unlike with a business-type scenario where financial gain is the underlying aim, research-laboratories have the goal of creating knowledge. The set of rules that might make a business successful could be completely inappropriate for a research laboratory. Management structures also differ – in a business many different hierarchical structures exist but these are not as clearly defined for research labs, especially research departments of universities. Most importantly however, is that the people who work in a research environment are highly unique – the factors that aid in their motivation are necessarily different from an employee in a more general business.

The aim of this dissertation is to explore those factors that help improve employee performance in a research-type organization. More specifically, the end goal is to identify known attributes that lead to successful research through a survey. The survey is used to obtain the current status, as well as the importance of these attributes in an engineering department from employee opinion.

1.4 Breakdown Structure

The structure of this dissertation is to firstly study research and development practices from a broad angle and then narrow the focus to those specific aspects that lead to excellent research and finally use those aspects to survey an engineering department. The following gives a brief breakdown:

Chapter 2 explores the topic of 4th generation research and development (R&D) practices as seen in [1]. In this regard the shortcomings of 3rd generation R&D are examined and the need for 4th generation practices is noted. Two topics that is fundamental to 4th generation R&D are studied, namely the concepts of tacit and explicit knowledge, and the difference between continuous and discontinuous innovation.

Chapter 3 examines studies in which related work has been done. The findings of other teams, from [2] and [3], with regard to motivational factors are briefly given. Two case studies, as seen in [3] and [4] are also explored and their results noted; the first examines the work environment at the research laboratories at the CSIR and the second at the U.S. Department of Energy (DOE) laboratories. From the DOE study, 36 attributes that lead to successful research are identified. These attributes are used to compile a questionnaire such that a survey can be performed on an engineering department. In this chapter the Competing Values Framework is also identified.

Chapter 4 gives the results from the survey conducted at an engineering department. Averages obtained from the questionnaire are given and graphical representations will show the final results of the survey. Statistical analysis will also take place and relevant conclusions drawn.

Chapter 5 will comment on the findings found in chapter 4 and end with the conclusion in which the aspects explored will be brought together.

Chapter 2

4^{th} Generation Research and Development

2.1 What is 4^{th} Generation Research and Development (R&D)?

In trying to improve the environment of research-type organizations, such as an engineering faculty, it will be seen that the management concept – the management processes, the managerial people, and the management of knowledge – is of fundamental importance. Identifying areas within the research environment that need improvement is of little use and a frivolous task if that knowledge is not taken and used to implement strategies that will ultimately better that environment. In this case, it will be the task of management to perform such activities. Broadly speaking, what is needed is the management of knowledge, technology and innovation that encompasses all the tasks of managing the research environment. 4^{th} generation R&D provides the thinking that is needed in being able to manage a research environment successfully, implementing new innovation business processes to already-established business processes that support innovation with the correct methods, activities and allocation of resources. The goal of 4^{th} generation R&D is the design and testing of technologies that satisfy existing needs as well as latent, unmet needs. This calls for participatory research [1], in which stakeholders test product and service prototypes to define new competitive architectures, infrastructures, capabilities and platforms for technologies.

2.2 The Problem

From the above it can be seen that ultimately, 4^{th} generation R&D places focus on the customer; in the new global economy of the Knowledge Age, customers have more choice about the products and services they wish to buy. To therefore remain competitive in the global market, companies must offer unique value by the development of new products and services – innovation is critical to success in a highly competitive market. However, as stated by [1], despite continuing emphasis on innovation, large corporations have a poor record as innovators: 50% to 80% of all products fail. The reasons for this failure could be widespread and complex but it is generally accepted, as with most failures of this nature, that the high rate is due to incorrect focus; most R&D groups focus on the scientific assessment of new products but it is in fact the customers' point of view that matters most. A new R&D management style is therefore required by which the true needs of the customer are determined and satisfied.

2.3 The Evolution of R&D Management Models

Before examining 4th generation R&D practices in more detail, it is instructive to see how 3rd generation R&D is lacking as a management model.

Unlike 1st and 2nd generation R&D which places emphasis purely on the creation of knowledge, essentially driven by science push [1], in 3rd generation R&D, the core processes are explicit customer feedback, corporate strategy and discovery research in technology.

As seen in the following figure, taken from [1], in 3rd generation practice customer feedback is collected by marketing staff in the form of surveys. Top management then defines strategy while R&D focuses on the development of new technologies; this then forms the basis of new technology development.

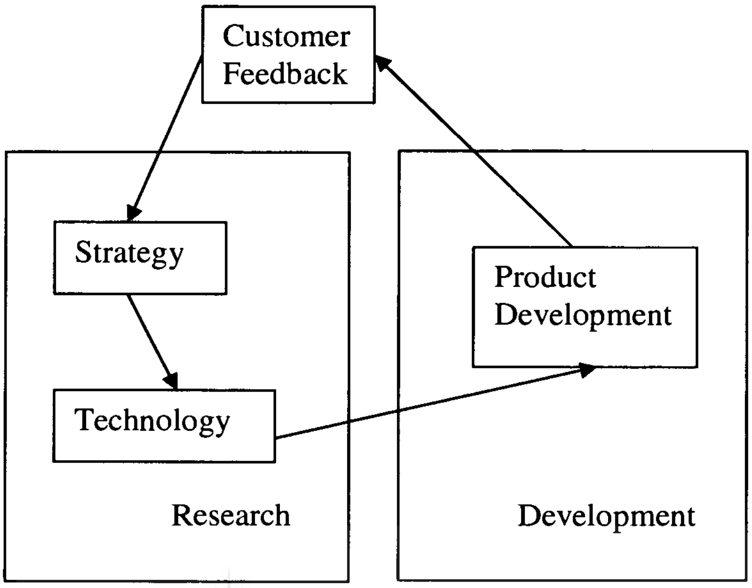

Figure 2.1 3rd generation R&D practice

Since the primary customer feedback comes from sales data that reflect purchase decisions rather than user experiences, the knowledge gained does not include latent needs arising from the performance of the product or service. In 3rd generation practice, since only explicit needs are noted, innovation is bounded within existing dominant designs, with existing competitive models assumed to be true.

In 4th generation practices however, as seen in [1], stakeholder participation occurs in the manner of continuous feedback from ongoing use – this is channeled through a so-called 'knowledge channel'. Lead customers and stakeholders also participate in research where they experience prototypes of new technologies in the context of real-world infrastructures.

The following figure, taken from [1], shows how this contrasts with 3rd generation practice where this learning exposes unmet tacit (defined later) needs, which are fed back to technology development:

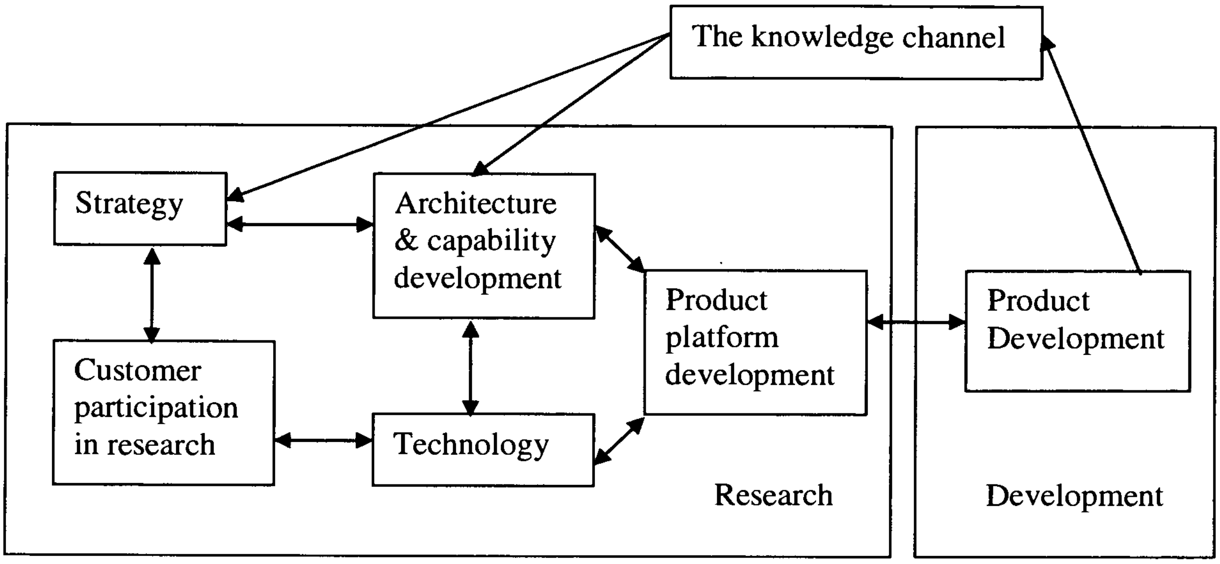

Figure 2.2 4th generation R&D practice

Since this approach is based on tacit and explicit needs being discovered through the knowledge channel plus tacit and explicit needs exposed in research, innovation is enabled to discover and define new dominant designs. This contrasts to 3rd generation practice by getting customer feedback from both purchase and use, enabling a better understanding of these tacit and explicit needs throughout the life cycle of the product. 4th generation practice aims to implement the popular concept of 'thinking outside the box' by looking outside of existing dominant designs. A broader scope of knowledge concerning both old and new technologies is aggregated within and outside of the organization.

In summary, the difference between 3rd and 4th generation R&D practices is in how innovations are conceptualized; 4th generation recognizes that latent needs are expressed in tacit knowledge.

The concepts of tacit knowledge and explicit knowledge are used above frequently and forms a fundamental aspect of 4th generation R&D. The next section covers these concepts in more detail and should aid in the understanding of how to implement a 4th generation model.

2.4 Tacit and Explicit Knowledge

In order for 4th generation R&D to be successful, it is necessary that researchers work more closely with customers, the idea being that a customer needs to *experience* what is possible in order to determine what may be of value in the future. The process of quantifying *that* customers experience is where the challenge lies, a subject addressed by studying the difference between tacit and explicit knowledge.

Explicit knowledge falls into the information domain; it refers to the knowledge gained from reading literature or attending lectures. It can therefore be seen to be very factual knowledge. Tacit knowledge however, is a much deeper form of knowledge that is often difficult to quantify. Tacit knowledge is described as the experience of something and enables us to recognize the correct 'feel' of doing a particular task, for example holding and using a hammer. Tacit knowledge can be seen as being part of everything we do or say, inherent in our thinking it is deeply embedded in the way we work. The distinction between tacit and explicit knowledge is well expressed by David Pye, [8], in his discussion of the difference between design, which is explicit, and workmanship, which is tacit. " *Design is what, for practical purposes, can be conveyed in words or by drawing; workmanship is what, for practical purposes, can not. The intended design of any particular thing is what the designer has in his minds eye: the ideally perfect and therefore unattainable embodiment of his intention. The design which can be communicated – the design on paper in other words – obviously falls short of expressing the designer's full intention, just as in music the score is a necessarily imperfect indication of what the composer has imaginatively heard.*"

In trying to identify of what a customer defines as value, it can therefore be seen that tacit knowledge plays a critical role. It is the gaining of this tacit knowledge that is ultimately the aim of 4th generation R&D, trying to search for discontinuities. The challenge is obvious; since tacit knowledge exists in an inexpressible form, the customers are usually unable to express the factors that constitute value that they require, it does no good to ask customers to explicitly state what they want because they probably can't tell you much about their tacit sensibilities. This means that market research done in the conventional way of using for example focus groups or interviews is likely only to produce explicit knowledge; as noted by [1], standard market research techniques are extremely weak in ways of predicting how people might behave with a product they barely understand, therefore being of little use in the breakthrough of a product or service.

Japanese companies, however, are a good example that the task of gaining and use of this tacit knowledge to address new, unrecognized or unmet needs is very possible, producing many product breakthroughs using technology that originated in the West. A classical example, as seen in [1], being the transistor radio commercialized by Sony while the transistor was actually invented in California. Sony Chairman Akio Morito identified a new market for portable radio's whose unmet needs the existing radio manufactures had not recognized.

To help visualize how tacit and explicit knowledge are shared and transformed, Japanese professors Ikujiro Nonaka and Hirotaka Takeuchi, [7], developed a matrix that describes the transitions between tacit and explicit forms.

	to tacit	to explicit
from tacit	**Socialization**	**Externalization**
from explicit	**Internalization**	**Combination**

Figure 2.3 Tacit and Explicit Knowledge

The upper right quadrant in figure 2.3 shows that when tacit knowledge is made explicit it is externalized, made manifest in spoken words, writings or tangible objects. This should be the aim of researchers, **rendering the hidden tacit forms explicit** and therefore applicable to the innovation process. The lower left quadrant shows that explicit knowledge is made tacit when it is internalized through experience – a pilot reads the F-117 instruction manual and then flies the aircraft to develop a feel for flight that cannot be expressed. The matrix also shows that tacit knowledge can be shared from one person to another without being made explicit, the process of socialization. Finally, in the fourth quadrant, combination occurs when explicit knowledge is shared and integrated through learning.

In summary, success in creating new designs depends to a significant degree upon discovering new tacit knowledge, and then transforming it into an explicit form so that an innovation team can discuss it, refine it and apply it in their innovation process.

Another form of distinction between 3rd and 4th generation R&D is the *how the technology is used*; this next section studies the difference between Continuous innovation, characteristic of 3rd generation practices, and Discontinuous Innovation, the aim of 4th generation R&D.

2.5 Continuous and Discontinuous Innovation

In its basic form, continuous innovation takes place by building on existing knowledge within existing markets. It can be seen to occur within the boundaries of the 'known world' of an organization and is therefore limited to existing infrastructures. Although it works when the future competitive requirements of customers can be met within existing competitive architectures, it is characterized by inward, convergent thinking and fails to challenge underlying strategies or assumptions.

In a typical continuous innovation scenario, the customer needs would be identified, progressive refinements would then be made to existing technology to satisfy those needs, thereby increasing focus and increasing specialization. It would seem that this is a logical progression of steps and should be successful in satisfying those customer needs but as Joe Marone, extracted from [1], Dean of Rensselaer Polytechnic Institute has commented, "*We know that there is overwhelming emphasis on the virtue of continual incremental improvement, yet everytime we look at any successful company that has emerged over the last 30 years in a technology intensive field, and in fact throughout any period of industrial history, you will always find a pattern of big leaps* *into major new product lines, which are then followed by efforts to stay ahead. And yet while we know an awful lot about practices of continual improvement, we seem to know very little about how to handle discontinuous innovations. It may well be that the practices that we have learned for continuous improvement are not only inappropriate for discontinuous innovation, but may actually be detrimental.*"

In light of the above comment, the necessity to move from continuous to discontinuous innovation is highlighted – in the highly competitive world, especially in technology intensive fields, it seems that this shift might become more than a manner to obtain strategic advantage, but rather be a necessity in order to simply remain on par with other organizations.

But what exactly is discontinuous innovation? By definition, [1], it makes use of new knowledge, in one or more dimensions of a product or service, to create an environment that has significantly different performance attributes. As opposed to continuous innovation, discontinuous thought is characterized by lateral or divergent thinking, by looking outside of defined boundaries. This would require that discontinuous innovation fall outside existing markets or market segments and when successful, goes so far as to extend and redefine the market, exposing new possibilities. It entails the discovery of new knowledge related to both market need and technological capability.

The above 'definition' sounds exciting and worthy of being applied but experience will show that there is a difficulty – achieving successful discontinuous innovation means the creation of new knowledge. This is a challenging task as such knowledge will certainly not be obtained within the confines of existing boundaries but will require creative, lateral thinking. The question might therefore be asked, how does an organization achieve this, or are there any techniques, to start the process of discontinuous innovation?

As commented by [1], what is needed is so-called "forced questions"; meaning asking the right questions about the limits of existing capabilities and thereby probing at the edges of existing knowledge to understand what new possibilities may exist that have not yet been recognized or considered. Deep, fundamental questions need to be asked about the evolution of companies, markets and industries in order to obtain leadership in this regard.

Discontinuous innovation can therefore be seen to be dramatic; it is not just bringing change in the simple sense by affecting products or services, but also the infrastructures that are fundamental to their use. This would include the extensive chains of distribution that may involve hundreds of affiliated and competing companies and industries. An analogy of this could be drawn, for example, from the shift from a typewriter to personal computer, completely unpredictable before the microprocessor.

Such change is inevitable when the requirements of customers can no longer be met within the existing framework of capability. However, as noted by [1], it may seem that not only will discontinuous innovation satisfy these needs, but also create new customer needs – this is an often-debated topic of whether an organization should embrace new technology to satisfy needs *or* create needs. The reality is however, that new knowledge creates new capabilities and the new combinations of knowledge, tools, technology and processes change the underlying character of customer needs by changing the boundaries of what is possible.

It can be seen that as a result of such drastic change, entirely new rules of competition will be created – this could result in the closure of entire companies or even industries as new rules are being made. One classical example of this is the company who was in the business of making slide rules. Their domination in the calculation instrument field gave them the false sense of security and they failed to embrace the new technology of pocket calculators with the end result of complete business loss. Another good example, taken from [1], is the case when there was a global infrastructure to distribute kerosene for lighting and another for cooling. Both were highly developed, extremely sophisticated for their times and highly profitable for extended periods. But both are now mostly forgotten, displaced by the evolution of technology in the shift from one dominant business model to another. Discontinuous innovation has the ability to affect all industries; recent example include the huge paradigm shifts that have taken place in the computer and communication industries, affecting such companies as IBM and AT&T. Ultimately, no business can fully protect itself from the impact of discontinuous change.

Having said this, change in itself does not automatically lead to success – for discontinuous innovation to be successful, there must be significant improvement on a performance axis, this could include features, benefits or cost. Dean Joe Marone, is quoted in [1], "*The performance gain must be five to ten-fold or have a 50% reduction in cost or both.*"

It is now instructive to examine some of the barriers hindering the implementation of discontinuous innovation. As already stated earlier, effort is required in being able to think laterally or 'outside the box' with the aim of creating new knowledge. Contrasting to this, continuous innovation is relatively easy to achieve, drawing upon the existing market framework, infrastructure and tacit knowledge of customers, suppliers and other stakeholders. Because progress is made incrementally, continuous innovation does not require conceptual leaps, massive amounts of new knowledge or the risks that are involved in dealing with the unknown – ultimately making it the more comfortable option. As Chip Holt, interviewed by Langdon Morris [1], Corporate Vice President of the Wilson Center for Research and Technology of Xerox observed, "*People have the tendency to focus in on the things they're most comfortable with and work them to death.*"

The question might be asked, is it possible to 'get away' with continuous innovation techniques? It is worth emphasizing again, the reality of today is that change and development takes place at an exponential rate - technology leads to the creation of new knowledge and this in turn leads to the development of new technology, a feedback cycle from which there is no escaping.

This is graphically shown, taken from [1], in the following figure:

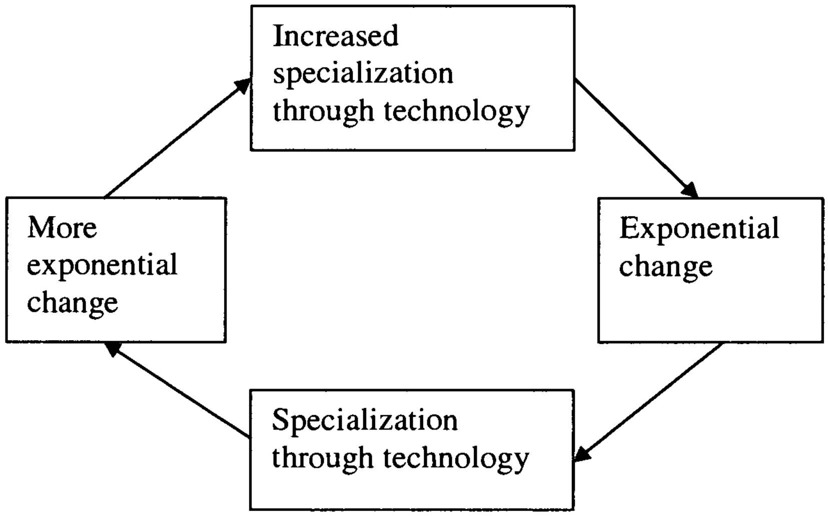

Figure 2.4 Positive feedback in technology driven markets

If you want to remain viable in a competitive market, you must engage in the same cycle of development that your competitors are pursuing - it is no longer enough to merely keep up through incremental innovation.

2.6 Summary

The major theme of this chapter was the exploration of 4th generation R&D practice. The need to obtain greater advantage in an age of intense business competition is one of the main reasons for the evolution of such practices. In examining 4th generation R&D, it was necessary to study 3rd generation R&D, noting its main characteristics, but more importantly seeing its shortcomings as an R&D practice. One such limitation is that the needs of customers are reflected purely by purchase data – this information does not reflect the true requirements of the customer, such as that which would be obtained from user experience, and only produces so-called explicit knowledge.

4th generation practices has evolved out of this with one of its main themes being the focus on true customer needs in developing technological products and processes.

This is made possible by having lead customers and other stakeholders being more actively involved in the research of the product or process by experiencing the use of prototypes in a real world scenario.

4^{th} generation R&D has become a large and involved field, however, the scope of this chapter was to explore two major subjects of 4^{th} generation R&D – namely continuous and discontinuous innovation, and the need for tacit instead of explicit knowledge.

Continuous innovation is focused on the existing needs of the customers while discontinuous innovation is driven by questions about the future needs of customers. Discontinuous innovation strives to create new knowledge, and by thinking 'out of the box', involves the possible creation of completely new industries with different rules of competition. The challenge in this is the creation of new knowledge - 4^{th} generation R&D dictates that researchers need to work jointly with customers in order to obtain this tacit knowledge. Tacit knowledge requires that customers must experience what is possible in order to determine what may be of value for the future – the process is not driven by technology itself but rather how technology is used. Only after these tacit needs are exposed and understood is it effective to consider the role of technology in fulfilling those needs.

The purpose of this chapter is to give a broad starting point in the study of organizations that are involved in research and development. The next chapter deals more specifically with examining the effectiveness of research-type departments.

Chapter 3

Assessing the Effectiveness of a Research-type Department

3.1 Introduction

As stated in the introduction, the inspiration for this section stems from the concern that the levels of performance in research-type laboratories are, as with any business-type organization, prone to deficiencies. In particular, the environment in which research is done can be improved such that the research persons are able to perform more efficiently. It is instructive to reiterate that relatively little work has been done in this area as compared to a more general business-type organizations where extensive knowledge is available for helping management to improve the work environment. It will be seen, however, that there is correlation between the factors that help improve the business-type environment and the research-type environment, especially when it comes to issues of teamwork, integrity of management and other people related factors.

From the outset, the first aim is to understand the key elements in research environments that contribute to the ability of staff to conduct their tasks more effectively. Only once this knowledge is acquired, is it possible to start examining possible tools or processes for improving such environments. Although there are cases where good work has been done in substandard conditions, for example as seen in [2] Russian weapons scientists working in poor conditions or computer software and hardware developers working in a garage (the beginnings of IBM and Microsoft!), it is fundamentally assumed that working in an excellent research environment increases the likelihood of producing excellent research. The converse is also true – excellent research accomplishments and the emphasis of excellent research in itself, contributes to a good research environment.

All this work is done with management in mind, for it is ultimately these persons who have the resources and authority to make real changes. Understanding the attributes that lead to excellent research coupled with the tools and processes to help improve those attributes should help managers improve the research environment and therefore the organization's effectiveness. It must be noted that when surveying an engineering department, it will be treated with a business sense i.e. that their exits 'managers' in some sense of the word, although it is realized that the hierarchical structures are necessarily different from a true commerced organization. Demonstrating that an organization is effective would indicate to investors that an organization has a good chance of producing new ideas and products and therefore provide a good return on investment. As noted by [2], however, showing that an organization is 'effective' is a difficult task, especially in research – a possible solution would be the use of employee attitude surveys or peer reviews. Although peer reviews could be seen to be generally well regarded by researchers, they fail to identify important characteristics of the environment and typically only provide information at the project or program level. As a result, research managers need a more effective mechanism to identify key elements needed to improve the environment.

In trying to identify these key elements, two literature cases will be examined where empirical studies took place with the aim of assessing and improving the research environment; the first case deals with the work environment in the Research and Development laboratories under the Council of Scientific and Industrial Research (CSIR), the second with a study done at two U.S. Department of Energy (DOE) laboratories, in which the *Competing Values Framework* model is examined.

3.2 Results from other studies

Before examining the results found in the case studies, it is interesting to note the findings of some other teams who have been looking at similar environments. For example, W.C. Tuttle and H.L. Smith [referenced in 3], looked at assessing the job satisfaction of research scientists, while R. Tagiuri [referenced in 3] did a study aimed at determining the key factors in the work environment of R&D managers that are vital for minimizing their dissatisfaction level.

Work done by other teams is summarized as follows, highlighting their findings relating to the research environments:

- Menon and Shamanna [referenced in 3] have indicated that **interpersonal relationships** that prevail within an organization are influenced by the nature of work carried out in that organization. Interpersonal relationships are an important factor in the environment, and changes the satisfaction an employee receives from his/her job and therefore directly affects productivity.
- Lambert [referenced in 3] has found that jobs that provided employees with the opportunity to do a **variety of tasks**, provided they were personally meaningful, promoted job satisfaction and involvement and therefore promoted intrinsic motivation.
- Sharma and Bhaskar [referenced in 3], in their study of engineers in a public-sector undertaking in India, have considered **recognition and appreciation** as important determinants of job satisfaction.
- Pelz and Andrews [referenced in 3] observed that the performance of scientists increased when tasks like **decision-making** and **goal-setting** were carried out in a **participative fashion**. They also found that the performance of scientists was high when they experienced a sense of **belonging to a group**, headed by a competent leader.
- Amabile *et al.* [referenced in 3] made use of the wisdom that R&D is no longer an individual effort but largely a team contribution and therefore the factors that motivate research teams are important. Their study in the work environment surrounding project teams in a large company found that **high-creativity projects** were significantly higher in job satisfaction, contributing environmental factors being freedom, positive challenge, supervisory encouragement, work-group supports, organizational encouragement and sufficient resources. Conversely, job satisfaction was low due to the following contributing environmental factors – organizational impediments and excessive workload pressure.
- Related to the importance of **team leadership** shown by Pelz and Andrews, Jain and Triandis [referenced in 3] have observed that in high innovation groups, the supervisors were more active participants and were especially

helpful to group members for critical evaluation, administrative aid and a help in thinking about technical problems.

- Relating to **technical expertise**, Brown *et al.* [referenced in 3] found that this factor appears to have been more highly valued in high-performing groups than low-performing groups. It was also observed that groups assigned to a technical task with a **measurable outcome** are most likely to start off in the correct direction if they focus on the task from the outset.
- The Minesota Innovation Research Program [referenced in 2] suggests that perceived innovation effectiveness is a function the of characteristics of **innovation idea, leadership, procedures and relationships,** and **organizational context**.
- In F.E. Udwadia's paper [referenced in 2], which puts forth the Multiple Perspectives Model, creative behavior and performance are tied to three perspectives: **individual characteristics** associated with creativity, needed **technical resources**, and **organizational practices** and **managerial actions**.
- A National Research Council [referenced in 2] study identified five pillars of a world class Army research, a development and engineering organization – **customer focus**, **resources and capabilities**, **strategic vision**, **value creation**, and **quality focus**.
- Finally, J. Hurly [referenced in 2], in a study based on interviews with Nobel Prize winners, describes characteristics and resources that lead to scientific discovery – the need to be **free to think and experiment**, **respect for scientists' freedom** and **autonomy**, and **staffing that allows cross-disciplinary** discussion were all identified.

The above points highlight just some of the factors that have been shown to be of importance to researchers, scientists and engineers.

Work done by Santanu Roy and Sunil K. Dhawan [3], gave some pointers towards improving the work environment in CSIR laboratories. In particular, an empirical study took place in the R&D laboratories under the CSIR in India, where the factors affecting the motivation of scientists in their work situations and also the factors affecting the overall satisfaction of the researchers within their work groups, were explored. This section aims to summarize their findings.

3.3 Case Study – The CSIR Study

Santanu and Dhawan did a study on scientists' perception on the work environment in R&D organizations functioning under the CSIR with head quarters in New Delhi (not South African CSIR). The strategy they used was to create a questionnaire and release it to randomly selected scientists in three separate research laboratories, in all 208 scientists participated. Furthermore, the dimensions of the work environment were divided into two categories, namely; related to work groups and related to the overall organizational system. Questions related to work groups covered the following work climate factors - human resource primacy, communication flow, decision-making practices, technological readiness, senior scientists influence, junior scientists influence, goal clarity and motivational conditions. The second part of the questionnaire was on work-group processes, relating to the following eight factors – coordination, group decisions, knowledge of the job, information sharing, motivation to achieve objectives, group adaptability, confidence and trust and overall satisfaction with the work group.

3.3.1 Results

With regard to analysis of the questionnaire, cluster analysis was used to determine those factors that contribute significantly to **motivation**, with the aim to understand those factors necessary to provide a climate that will motivate the scientists in their work situations. The three factors found to be of most significance in all three laboratories are:

- Human resource primacy.
- Communication flow.
- Decision-making practices.

In addition to these three factors, goal clarity was found to be important in lab-2 and lab-3, and technological readiness in lab-2.

The study found it surprising that items related to organizational policies and the nature of the work itself did not appear as motivational forces. In this regard it was taken the scientists are satisfied with these factors or do not consider them important. In the second part of the study, those factors and forces that contribute significantly to the overall satisfaction of the scientists with their work groups, was found. The following table summarizes those significant factors for the various groups:

	Significant factor
Lab – 1	Information sharing
	Group adaptability
	Making Group decisions
Lab – 2	Confidence and trust
	Group adaptability
	Making group decisions
Lab – 3	Confidence and trust
	Coordination
	Making group decisions

Table 3.1 Overall work group satisfaction

3.3.2 Conclusions

The authors [3] concluded that if management wants to motivate the scientists towards a better performance, a suitable infrastructure of decision-making involving scientists at different levels, and a proper system of communication – upward, downward and parallel, across the entire organization, be developed. It is found that better communication systems can help scientists to update knowledge in their areas of interest, improving general awareness. Other factors found to be of importance were human resource primacy, decision-making practices and technological readiness. Therefore adjustments should incorporate two aspects - improvement in the working conditions and regular upgrading of technology.

Concerning the satisfaction of the scientists in their work groups, group adaptability, information sharing and making group decisions are three factors that need emphasis.

3.4 Case Study – DOE

Work done at two U.S. Departments of Energy national laboratories, [2], to develop a process for assessing and improving the effectiveness of research organizations forms the basis of the core aim of this dissertation. Here, 36 attributes were identified by scientists as important to creating an environment that fosters excellent research. The approach was to conduct half or full-day sessions in which interviews were conducted, questionnaires set up, exercises performed and panel reviews conducted. The goal of the study was to explore two fundamental aims in improving the environment. The first aim is learn those elements that help employees of this type of organization (scientists, engineers, general researchers), perform their work at higher levels of performance, namely to conduct excellent research. The second aim is to explore those elements, such as development tools and processes that help with improving such environments.

An important part of the work was the use of the Competing Values Framework: proposed by R.E. Quinn and J. Rohrbaugh, [9], the framework helps to investigate criteria used by organizational theorists and researchers to access and conceptualize organizational effectiveness. Three dimensions are identified as underlying conceptualizations of organizational effectiveness – organizational structure, organizational focus, and means-ends continuum. As described by [2], Organizational structure distinguishes between those activities and attributes that emphasize the organization's flexibility, adaptability and breadth, versus those that stress control and stability. Organizational focus contrasts an emphasis on internal issues such as the well-being of the people within the organization versus external issues, such as the development and well being of the organization itself or its relations with entities outside itself. Finally, the means-ends continuum reflects the contrast between the concern for the objectives of the organization, such as productivity or human resource development, and the means by which it achieves these objectives, for example goal setting or enhancing moral.

These three value dimensions are used as axes with which to organize four of the most common theoretical models of organizational effectiveness – the human relations model, the open system model, the rational goal model, and the internal process model. The following figure illustrates the above points of the Competing Values Framework, extracted from [2]:

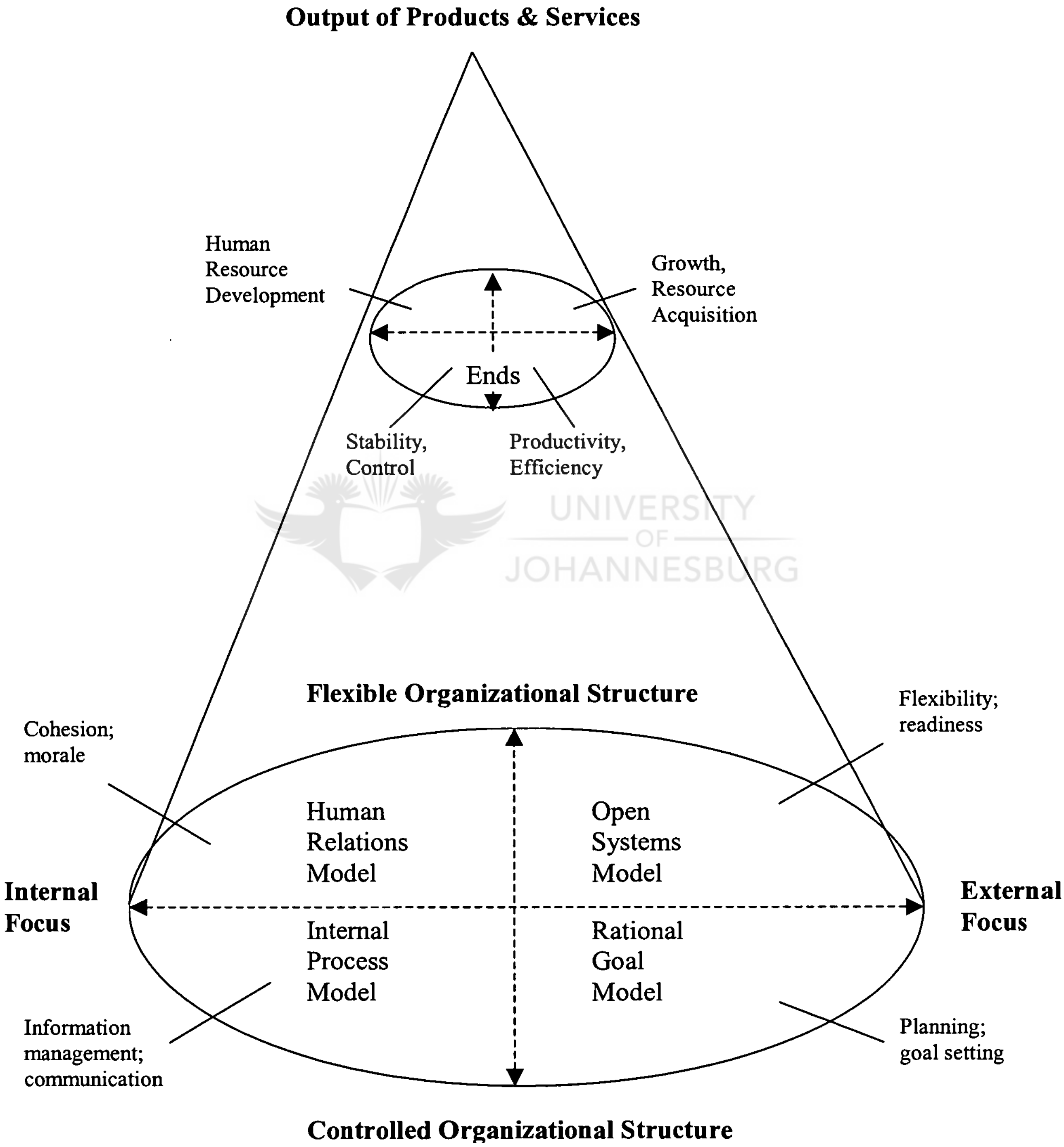

Figure 3.2 The Competing Values Framework, incorporating four common models of organizational effectiveness

The Competing Values Framework captures a wide range of views on what is important in the research environment as well as addressing the tensions that exist between focusing internally and looking outward, between striving for flexibility or innovation and trying to provide stability. The framework also recognizes that different individuals will emphasize different sets of means and ends within an organization depending on their personal values and the type of organization.

3.4.1 The 36 attributes and the Competing Value Framework

Before seeing how the 36 attributes correlate to the Competing Value Framework, it is necessary that the attributes be listed within their categories:

Human and Resource Development

1. Great facilities and equipment
2. Quality of colleagues
3. Strong research competencies
4. Sufficient support staff
5. Sufficient and unfragmented funding
6. Opportunities for personal development
7. Rewards for merit
8. Competitive salaries and benefits
9. Respect for people

Innovation and Cross Fertilization of Ideas

10. Funding and freedom to pursue new ideas
11. Sense of challenge and optimism
12. Autonomy in scientific management
13. Adequate time to do research and stay current
14. Commitment to critical thinking
15. Internal cross fertilization of scientific and technical ideas
16. External collaborations and interactions
17. Effective external reviews

18. A reputation for excellence

Management and Internal Processes

19. Fair and well planned resource allocation
20. Decisive and informed senior management
21. Integrity of line management
22. Value-added line managers
23. Internal cooperation and teamwork
24. Good internal communication
25. Efficient internal systems and processes
26. Efficient lab services
27. Competitive overhead rates

Setting and Achieving Relevant Goals

28. Clear and compelling research vision
29. Continuity in funding and research themes
30. Investment in future capabilities
31. Good relationship with sponsors
32. Systematic process for identifying project opportunities
33. Strong foundation of basic research
34. Integrated and relevant R&D portfolio
35. Good project planning and execution
36. Appropriateness of laboratory's measures of success

As already mentioned, these 36 attributes have been identified by scientists as being important to creating an environment that fosters excellent research. It is noted that the attributes are organized into four distinct sections, namely Human and Resource Development, Internal and Cross Fertilization of Ideas, Management and Internal Processes, and Setting and Achieving Relevant Goals.

These four sections can be arranged to fit within the four quadrants of the Competing Value Framework, with reference to figure 3.2; this can be seen as follows:

- The Human Relations Model falls within the first quadrant of the framework. It emphasizes a view that values internal focus and flexibility within an organization. Therefore a good organization from this perspective is one that stresses good morale and cohesion, and results in human resource development – the attributes in the section of Human and Resource development would therefore make up this model.
- The Open Systems Model, stresses flexibility and external focus as being essential to organizational effectiveness – the attributes in the section of Innovation and Cross Fertilization of Ideas, make up this model.
- The Rational Goal Model places emphasis on the value of control and stability over flexibility and readiness. An effective organization in this sense is one that has extensive planning and goal-setting which results in productivity and efficiency – the attributes in the section of Setting and Achieving relevant goals makes up this model.
- Finally, the Internal Process Model values control and stability, but unlike the rational goal model, the focus is internal. Information management, communication systems, and the internal structures and routines that provide employees with a sense of organizational continuity and security, are key features – the attributes in the section of Management and internal processes make up this model.

3.5 Summary

This section aims to narrow the focus, from R&D in the broad perspective set by the previous chapter, to more specifically studying the assessment of R&D organizations. The goal in trying to assess such organizations is to improve their environment such that the researchers are able to better perform their tasks and ultimately carry out better research.

This section examined work done in this field and specific aspects that researchers identified as being important to them in being able to improve their research was made.

Two case studies were examined in which survey work was done – the CSIR study identified significant factors that scientists believed helped in their research. The second study identified 36 attributes of the research environment that lead to excellent research, forming the main topic of this section. Another topic of this section was the Competing Values Framework. It was seen that the 36 attributes could be arranged within this framework and created four distinct models, emphasizing different aspects of the environment according to the focus and organizational structure. In the next chapter, the results from the survey questionnaire that was constructed, is given.

Chapter 4

Results of Survey

The following section gives all the findings obtained from the survey conducted in the **Engineering Department** at the **Rand Afrikaans University**. There were a total of **12** participants. All participants are permanent staff at the department and actively involved in research projects.

The survey was constructed with the aim to obtain:

1. The *current status* of a particular aspect within the department.
2. The rated *importance* of that particular aspect within the department.

The questions were constructed with the goal of finding the current status and importance of the 36 attributes, discussed in *chapter 3*, which leads to effective research. The questionnaire structure was developed along the lines proposed by Cooper and Schindler [5].

4.1 Individual questions

The average result of the individual questions are given in Appendix A together with the complete questionnaire:

The following questions are highlighted as most important with the regard to **need for improvement**. This is found if a significant difference occurs between the *current status* and the *importance* of the aspect. In this survey, this would mean that the aspect got an average rating of *below-average* with regard to current status and an average rating of *very high importance* with regard to importance.

- Ability to attract and retain top quality colleagues.
- Adequate blocks of time, free from distraction, with which to think, be creative, perform and publish research.
- Effective computer support

The following questions are highlighted as being **Good** with regard to current status. These questions were also considered of High importance or very high importance:

- Good laboratory space and physical work environment
- Stimulating and challenging work
- The freedom and authority to direct the course of one's research
- The freedom and authority to pursue new ideas
- Commitment to the scientific method
- Support for attendance at conferences

4.2 Mean Results of an Engineering Department

The following gives the average result for each of the 36 attributes listed in the previous chapter:

Human and Resource Development

1. Great facilities and equipment

   Current status **Average**

   Importance ***High importance***

2. Quality of colleagues

   Current status ***Below-average***

   Importance ***Very high importance***

3. Strong research competencies

   Current status ***Average***

   Importance ***Very high importance***

4. Sufficient support staff

   Current status ***Average***

   Importance ***High importance***

5. Sufficient and unfragmented funding

   Current status ***Average***

   Importance ***High importance***

6. Opportunities for personal development

   Current status ***Average***

   Importance ***High importance***

7. Rewards for merit

   Current status ***Below-average***

   Importance ***High importance***

8. Competitive salaries and benefits

   Current status ***Below-average***

   Importance ***High importance***

9. Respect for people

   Current status ***Average***

   Importance ***High importance***

Innovation and Cross Fertilization of Ideas

10. Funding and freedom to pursue new ideas

    Current status ***Average***

    Importance ***High importance***

11. Sense of challenge and optimism

    Current status ***Average***

    Importance ***Very high importance***

12. Autonomy in scientific management

    Current status ***Good***

    Importance ***Very high importance***

13. Adequate time to do research and stay current

    Current status ***Below-average***

    Importance ***Very high importance***

14. Commitment to critical thinking

    Current status ***Average***

    Importance ***High importance***

15. Internal cross fertilization of scientific and technical ideas

    Current status ***Average***

    Importance ***High importance***

16. External collaborations and interactions

    Current status ***Average***

    Importance ***High importance***

17. Effective external reviews

    Current status ***Below-average***

    Importance ***High importance***

18. A reputation for excellence

    Current status ***Average***

    Importance ***High importance***

Management and Internal Processes

19. Fair and well planned resource allocation

    Current status ***Average***

    Importance ***High importance***

20. Decisive and informed senior management

    Current status ***Average***

    Importance ***High importance***

21. Integrity of line management

Current status ***Average***

Importance ***High importance***

22. Value-added line managers

Current status ***Average***

Importance ***High importance***

23. Internal cooperation and teamwork

Current status ***Average***

Importance ***High importance***

24. Good internal communication

Current status ***Average***

Importance ***High importance***

25. Efficient internal systems and processes

Current status ***Average***

Importance ***High importance***

26. Efficient lab services

Current status ***Below-average***

Importance ***High importance***

27. Competitive overhead rates

Current status ***Average***

Importance ***High importance***

Setting and Achieving Relevant Goals

28. Clear and compelling research vision

Current status ***Average***

Importance ***High importance***

29. Continuity in funding and research themes

Current status ***Average***

Importance ***High importance***

30. Investment in future capabilities

Current status ***Average***

Importance ***High importance***

31. Good relationship with sponsors

Current status ***Average***

Importance ***High importance***

32. Systematic process for identifying project opportunities

Current status ***Average***

Importance ***High importance***

33. Strong foundation of basic research

Current status ***Average***

Importance ***Very high importance***

34. Integrated and relevant R&D portfolio

Current status ***Below-average***

Importance ***High importance***

35. Good project planning and execution

Current status ***Below-average***

Importance ***High importance***

36. Appropriateness of laboratory's measures of success

Current status ***Below-average***

Importance ***High importance***

The following attributes are highlighted as being **Below-average** with regard to current status:

- Quality of colleagues.
- Rewards for merit.
- Competitive salaries and benefits.
- Adequate time to do research and stay current.
- Effective external reviews.
- Efficient lab services.
- Integrated and relevant R&D portfolio.
- Good projection planning and execution.
- Appropriateness of laboratory's measure of success

Appropriateness of laboratory's measure of success

The following attributes are highlighted as being **Good** with regard to current status:

- Autonomy in scientific management

The following, figure 4.1, gives a graphical representation of the quantitative findings, displaying the current status, the importance and need for improvement:

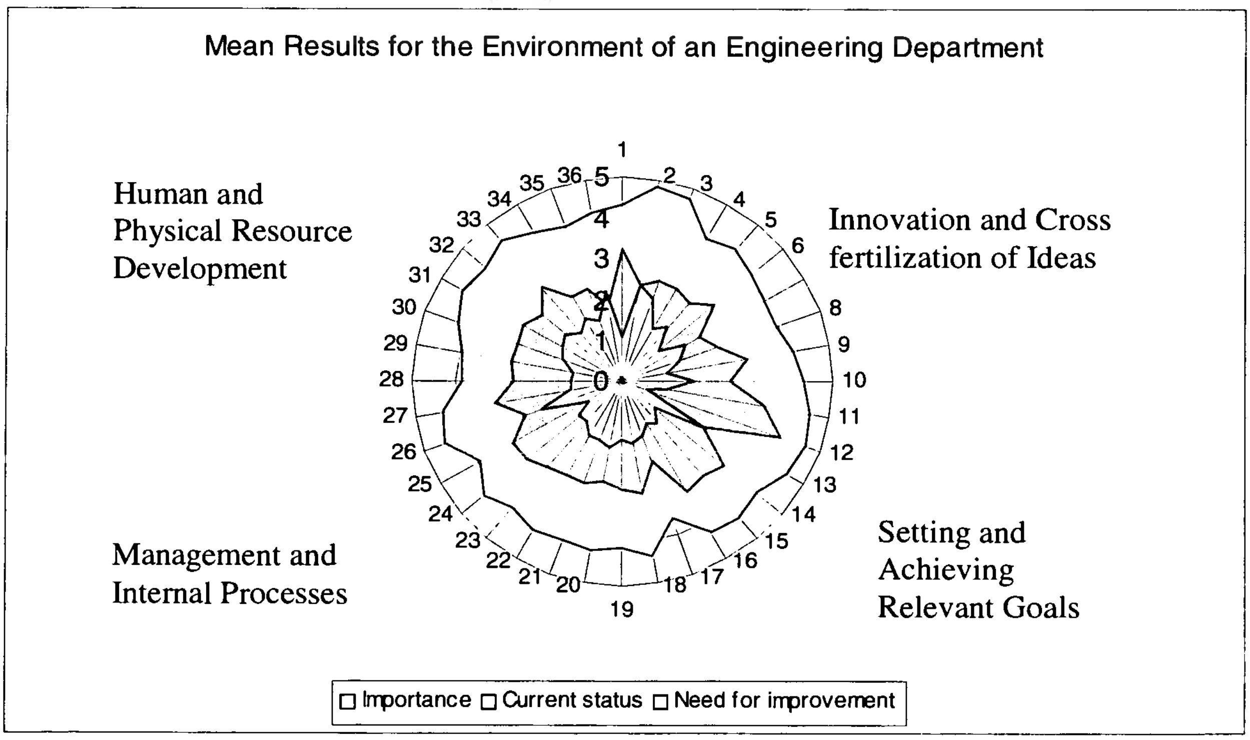

Figure 4.1 Mean results of an engineering department

4.3 Statistical Information

This section makes use of some statistical analysis. In this regard, the first aspects examined are the participant trends in which it is noted how the participants answered the questionnaire. Next, each individual attribute's mean and variance are found with regard to current status and importance. The standard deviation between each attributes current status and importance is established and a T-test performed on each attribute 'pair'.

4.3.1 Participant Trends

The first useful information to obtain is the average rating given by each of the 12 participants for all the attributes. This is shown in the following table:

Participant	Average Rating given for Current Status	Average Rating given for Importance	Standard Deviation
1	3.15	4.29	0.80
2	3.26	4.34	0.77
3	2.60	3.66	0.75
4	2.95	4.17	0.87
5	2.83	3.93	0.78
6	2.85	3.96	0.79
7	1.71	4.92	2.27
8	2.55	3.84	0.91
9	2.60	3.77	0.82
10	1.77	4.39	1.86
11	3.00	4.92	1.36
12	3.44	4.40	0.68
MEAN	**2.72**	**4.22**	**1.05**

Table 4.1 Average participant rating for all attributes

The above table shows that there was a close correlation between a participant's rating for the current status of an attribute, and the importance of that attribute. The standard deviation between the two ratings for 9 of the 12 participants is below one. It can therefore be seen that if a participant gives a poor rating for the current status of an attribute, it is likely that participant gives that rating a low importance, for example.

A graphical representation of the above is given as follows in figure 4.2:

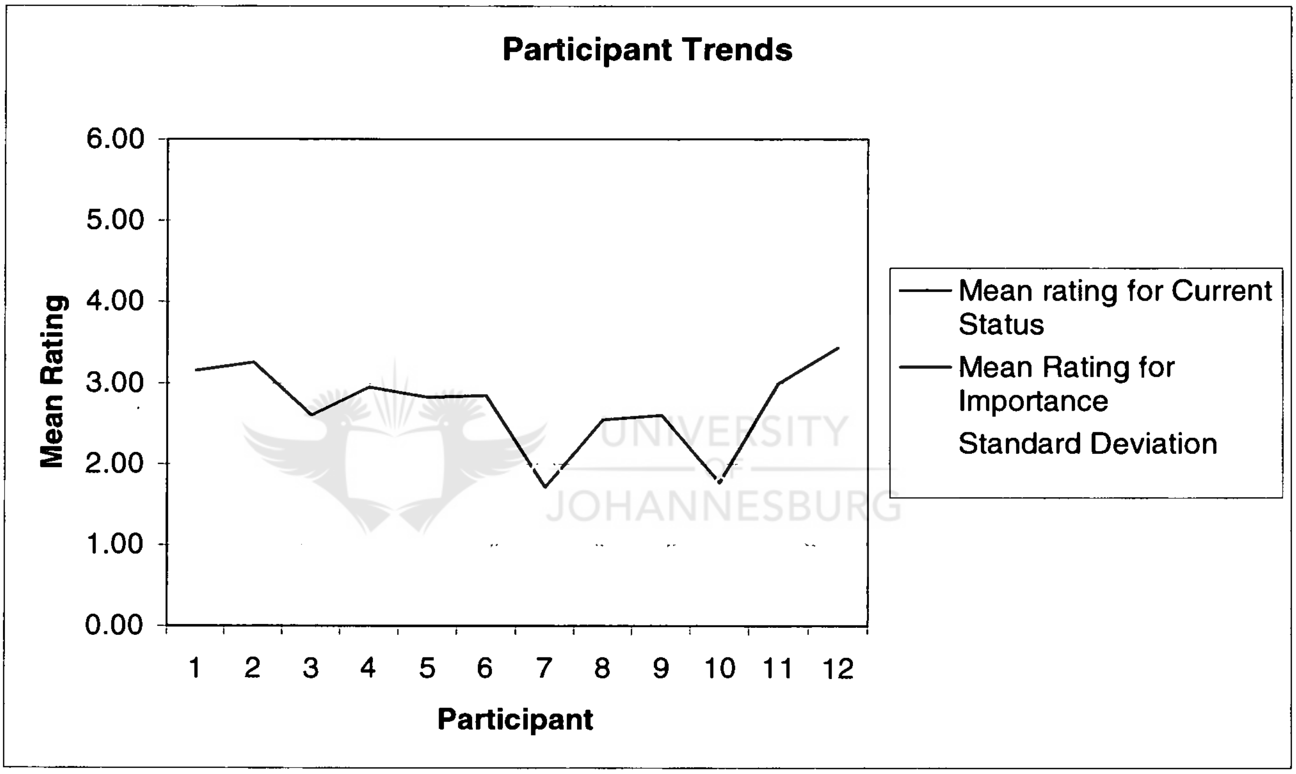

Figure 4.2 Participant trends

4.3.2 Attribute Analysis

The following gives a table of all 36 attributes, showing:

- The Mean and Variance for each attribute's current status and importance.
- The standard deviation between each attribute's current status and importance (attribute pair).
- A T-test, the theory found in [5], between each attribute's current status and importance.

Attribute	Description	Mean	Variance	Standard Deviation for Attribute Pair	T-test for Attribute Pair
1	Current Status	3.22	0.79	0.925	0.002352637
	Importance	4.31	0.35		
2	Current Status	2.42	0.27	1.313	2.44965E-11
	Importance	4.83	0.15		
3	Current Status	2.58	0.81	1.308	1.27045E-06
	Importance	4.75	0.20		
4	Current Status	2.58	1.17	1.214	0.001521082
	Importance	4.04	0.75		
5	Current Status	2.50	0.45	1.068	1.24038E-06
	Importance	4.21	0.34		
6	Current Status	2.92	1.31	1.078	0.008676489
	Importance	4.04	0.43		
7	Current Status	2.14	0.47	1.146	4.02251E-06
	Importance	3.92	0.55		
8	Current Status	2.46	0.75	1.030	0.00010028
	Importance	3.92	0.31		
9	Current Status	3.03	0.84	1.010	0.005622524
	Importance	4.11	0.65		
10	Current Status	2.61	0.72	1.133	1.3088E-05
	Importance	4.33	0.34		
11	Current Status	3.42	0.45	0.788	0.000174173
	Importance	4.50	0.21		
12	Current Status	4.04	1.29	0.950	0.11246015
	Importance	4.67	0.38		

Attribute	Description	Mean	Variance	Standard Deviation for Attribute Pair	T-test for Attribute Pair
13	Current Status	2.25	0.57	1.345	1.18388E-07
	Importance	4.50	0.45		
14	Current Status	3.19	0.35	0.810	0.000494295
	Importance	4.23	0.43		
15	Current Status	3.04	0.79	0.988	0.00030668
	Importance	4.38	0.28		
16	Current Status	3.08	0.45	0.917	0.000600372
	Importance	4.25	0.57		
17	Current Status	2.13	1.32	1.404	0.010045349
	Importance	3.54	1.70		
18	Current Status	2.79	0.52	0.981	5.6719E-06
	Importance	4.33	0.20		
19	Current Status	2.67	0.97	1.096	0.000558947
	Importance	4.08	0.45		
20	Current Status	2.50	0.77	1.090	2.24778E-05
	Importance	4.17	0.20		
21	Current Status	2.63	0.69	1.024	4.46143E-05
	Importance	4.13	0.28		
22	Current Status	2.67	1.01	1.091	0.000273785
	Importance	4.17	0.25		
23	Current Status	2.75	0.57	0.970	0.000469179
	Importance	4.00	0.55		
24	Current Status	2.96	0.57	0.924	6.02765E-05
	Importance	4.29	0.25		
25	Current Status	3.00	0.36	0.846	0.005388475
	Importance	3.92	0.67		
26	Current Status	2.46	1.07	1.285	1.83774E-05
	Importance	4.46	0.20		
27	Current Status	3.08	1.36	1.122	0.004683911
	Importance	4.33	0.42		
28	Current Status	2.61	0.38	0.866	7.13141E-05
	Importance	3.83	0.37		
29	Current Status	2.71	0.66	0.977	0.001560507
	Importance	3.88	0.60		

Attribute	Description	Mean	Variance	Standard Deviation for Attribute Pair	T-test for Attribute Pair
30	Current Status	2.67	1.15	1.139	0.000531685
	Importance	4.17	0.33		
31	Current Status	2.75	0.57	1.139	2.72181E-05
	Importance	4.42	0.63		
32	Current Status	2.50	1.18	1.245	0.000141533
	Importance	4.25	0.39		
33	Current Status	3.00	1.45	1.189	0.001276209
	Importance	4.50	0.27		
35	Current Status	2.42	0.81	1.197	3.23439E-05
	Importance	4.17	0.52		
35	Current Status	2.42	0.99	1.141	0.000171984
	Importance	4.00	0.36		
36	Current Status	1.92	0.63	1.367	2.84421E-07
	Importance	4.17	0.52		

Table 4.2 Attribute analyses

From the above table the following can be noted:

- Concerning the **Means** of the attributes,
  - Attribute 36 (Appropriateness of laboratory's measures of success) has the lowest value with regard to current status.
  - Attribute 12 (Autonomy in scientific management) has the highest value with regard to current status.
  - Attribute 17 (Effective external reviews) has the lowest value with regard to importance.
  - Attribute 2 (Quality of colleagues) has the highest value with regard to importance.

- Concerning the **Variance** of the attributes,
  - Attribute 2 (Quality of colleagues) has the lowest variance with regard to current status.
  - Attribute 33 (Strong foundation of basic research) has the highest variance with regard to current status.
  - Attribute 2 (Quality of colleagues) has the lowest variance with regard to importance.
  - Attribute 17 (Effective external reviews) has the highest variance with regard to importance.

- Concerning the T-test for each attribute pair. The asymptotic significance (p-value) for **all** attributes is less than 0.05. It can therefore be said that there is significant statistical difference between the current status and importance of each attribute.

- Concerning the standard deviation between each attributes current status and importance, the following gives a graphical representation:

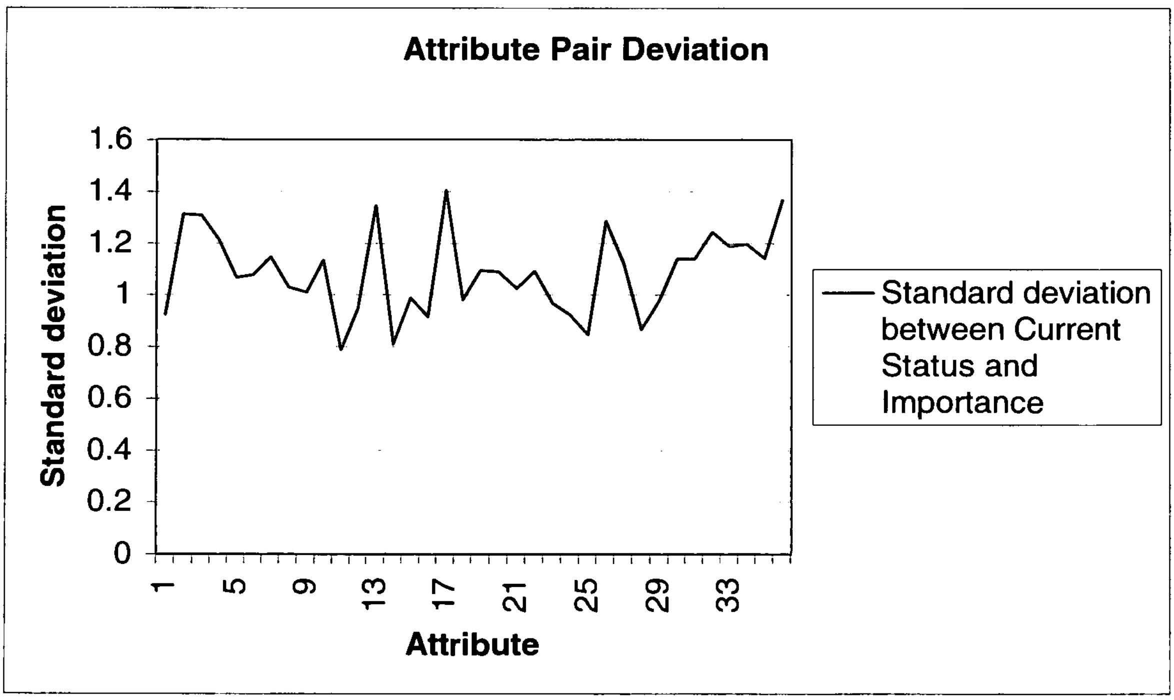

Figure 4.3 Attribute Pair Deviation

From the above diagram, the following are noted as high points giving the greatest standard deviation:

- Attribute 13, Adequate time to do research and stay current.
- Attribute 17, Effective external reviews.
- Attribute 36, Appropriateness of laboratory's measures of success.

From the above diagram, the following are noted as low points giving the least standard deviation:

- Attribute 11, Sense of challenge and optimism.
- Attribute 14, Commitment to critical thinking.

4.4 Summary

This section gave details of the survey that was constructed and its main results. The 36 attributes identified in the previous chapter form the basis of the survey – a number of participants (12) at an engineering department (RAU) completed the questionnaire. From this the average results were taken and a number of noteworthy points made as well as all the average results for all the 36 attributes given. A graphical representation showing the average results of the engineering department was given, highlighting the current status, the importance, and the need for improvement of each of the 36 attributes.

Relevant statistical results taken from the data of the questionnaire was given. This analysis involved examining the participant trends in which it was noted how the participants answered the questionnaire. Next, each individual attribute's mean and variance were found with regard to current status and importance. The standard deviation between each attributes current status and importance was established and a T-test performed on each attribute 'pair'. Attributes that were at the extreme values (highest and lowest) were noted, and in the case of standard deviation for the attributes, graphical representation given.

Chapter 5

Deductions and Conclusion

5.1 Deductions

This section aims to highlight some the most significant findings of the survey. The following points are noteworthy aspects of the environment at the Engineering Department at the RAU:

- No attribute obtained an overall current status of **Poor**
- No attribute obtained an overall current status of **Outstanding**
- All attributes were considered as either of **High Importance** or **Very High Importance**
- Regarding the individual questions in the survey and as already noted in the previous chapter, three points are highlighted as being essential for improvement – that is, their current status is **below-average** and they are considered of **very high importance**, namely:
  1. The ability to attract and retain top quality colleagues.
  2. Adequate blocks of time, free from distraction, with which to think, be creative, perform and publish research.
  3. Effective computer support.
- Regarding the individual questions in the survey and as already noted in the previous chapter, one point obtained a current status of **Good**, namely:
  1. Good laboratory space and physical work environment.
  2. Stimulating and challenging work.
  3. The freedom and authority to direct the course of one's research.
  4. The freedom and authority to pursue new ideas.
  5. Commitment to the scientific method.
  6. Support for attendance at conferences.

- Regarding the attributes which lead to effective research and as already noted in the previous chapter, seven attributes obtained a current status of **below-average**, namely:

  1. Quality of colleagues.
  2. Rewards for merit.
  3. Competitive salaries and benefits.
  4. Adequate time to do research and stay current.
  5. Effective external reviews.
  6. Efficient lab services.
  7. Integrated and relevant R&D portfolio.
  8. Good projection planning and execution.
  9. Appropriateness of laboratory's measure of success.

- Regarding the attributes which lead to effective research and as already noted in the previous chapter, one attributes obtained a current status of **Good**, namely:

  1. Autonomy in scientific management

- Regarding the attributes which lead to effective research, two points is highlighted as been essential for improvement – that is, its current status is **below-average** and it is considered of **very high importance**, namely:

  1. Quality of colleagues.
  2. Adequate time to do research and stay current.

From the statistical information found in the previous chapter, a number of deductions can be made:
Regarding participant trends, it was found that there was a close correlation, except for two instances, between a participants rating for each attributes current status and that attributes importance. It can therefore be estimated that if a participant gave (for example) an *average* rating for all questions, that participant would likely give a rating of *high importance* for all the questions.

Regarding the variance obtained for each attribute, the opinion distribution was least spread out for the attribute detailing **quality of colleagues**, with respect to current status *and* importance. There appears to be the greatest opinion distribution spread for the attribute highlighting **strong foundation of basic research** with respect to current status and attribute **effective external reviews** with respect to importance.

Regarding the T-test (two-sample assuming unequal variance) performed on each attribute, it was found that the p-value for all attribute pairs was less than 0.05. It can therefore be said that there exists significant statistical difference (95% sure difference exists), between each attributes current status and importance, with the current status being less than the attributes importance.

Regarding the standard deviation that exits between an attributes current status and importance, it was found that the attribute highlighting **effective external reviews** was most dispersed from the mean value and least dispersed for the attribute highlighting **sense of challenge and optimism.**

Although only a few attributes have been highlighted in this section, full details of the analysis that took place can be found in the previous chapter. The next section concludes this chapter.

5.2 Conclusions

In surveying the factors that lead to effective research in an engineering department, the strategy was to firstly look at Research and Development from a broad point of view with no focus toward a university department such as an engineering faculty. In this regard, 4^{th} generation R&D was studied. It was necessary to note the shortcoming of 3^{rd} generation R&D and also examine some select concepts that make up 4^{th} generation practices, namely the ideas of tacit and explicit knowledge, and of continuous and discontinuous innovation. Although this chapter was handled as if it would be applied to a more general business-type environment, its concepts can and should be applied to a department that carries out research such as an engineering department. It was therefore necessary to study 4^{th} generation R&D practices, although briefly, as a step towards to finding factors that lead to effective research.

Chapter 3 dealt with assessing and improving the effectiveness of research type organizations. By studying work done in this field through the use of case studies, the main attributes that scientists identified as being important for them, was identified. Factors that improve the working environment, including physical attributes such laboratory space, and psychological issues, are identified as being important such that a researcher will not only be motivated, but also have the right tools, to carry out excellent research. The main concept used from this section was the identification of 36 attributes which researchers highlight as being important to their environment; it is from these attributes that a questionnaire was constructed in order to perform a survey at an engineering department in which an average rating could be obtained for each attribute, showing its current status and importance. Another important concept coming out of this chapter was the Competing Values Framework: the 36 attributes were seen to be categorized into four distinct models that are arranged within the framework.

From chapter 4, a number of results are highlighted from the survey. These are points which were particularly noteworthy as either been in need of improvement, or are currently below-average as a current status, or has a good rating as a current status. It is beyond the scope of this dissertation to suggest possible solutions to any problems or the implementation of corrective strategies, but merely to highlight the factors that need attention. The reasons for certain of the findings and strategies or methodologies to implement could be scope of further work in this field.

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Appendix A

Survey questionnaire

The following questionnaire forms part of the mini-dissertation work required for the completion of the Engineering Management Masters Program. The study involves *Factors that Contribute to Effective Research in an Engineering Department.*

Student: Mr. G van Winsen
Supervisor: Prof. JHC Pretorius
Co-supervisor: Prof. L Pretorius

Instructions:
Please complete the following questionnaire by rating (your opinion) the following aspects of your research department that form the attributes leading to effective research.

For each statement:
1.
Please tick one block that you believe most accurately describes each aspect in the *current* status of your environment, according to the following criteria:

1 - Poor
2 - Below-average
3 - Average
4 - Good
5 - Outstanding

2.
Please tick one block indicating the *importance* you attain to that aspect, according to the following criteria:

1 – Of no importance
2 – Slight importance
3 – Considerable importance
4 – High importance
5 – Very high importance

For any queries contact:
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Attaining to human and physical resource development:

The accessibility of needed equipment:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

State-of-the art equipment in key areas:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Good laboratory space and physical work environment:
Current status
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Ability to attract and retain top quality colleagues:
Current status
1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ■

Existence of critical mass of staff and research projects in selected research areas and disciplines:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ■

Sufficient technical support personnel:
Current status
1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Sufficient administrative support personnel:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Sufficient funding to cover staff:
Current status
1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Levels of funding consistent with realistic project expectations:
Current status
1 □ 2 □ 3 ■ 4 □ 5 □
Importance
1 □ 2 □ 3 □ 4 ■ 5 □

Opportunity to advance within the organizational hierarchy:
Current status
1 □ 2 □ 3 ■ 4 □ 5 □
Importance
1 □ 2 □ 3 □ 4 ■ 5 □

Opportunity to advance within one's professional field:
Current status
1 □ 2 □ 3 ■ 4 □ 5 □
Importance
1 □ 2 □ 3 □ 4 ■ 5 □

Monetary and non-monetary rewards tied to merit:
Current status
1 □ 2 ■ 3 □ 4 □ 5 □
Importance
1 □ 2 □ 3 □ 4 ■ 5 □

Laboratory promotion for national/international recognition:
Current status
1 □ 2 ■ 3 □ 4 □ 5 □
Importance
1 □ 2 □ 3 □ 4 ■ 5 □

Internal forms of recognition:
Current status
1 □ 2 ■ 3 □ 4 □ 5 □
Importance
1 □ 2 □ 3 □ 4 ■ 5 □

Salaries high enough but fair within the laboratory structure:
Current status
1 □ 2 □ 3 ■ 4 □ 5 □
Importance
1 □ 2 □ 3 □ 4 ■ 5 □

Benefits comparable to those of other known laboratories:
Current status
1 □ 2 ■ 3 □ 4 □ 5 □
Importance
1 □ 2 □ 3 □ 4 ■ 5 □

Respect for diversity of other people:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Trust and respect for other people regardless of education or job classification:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Management support for balancing work and home:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Attaining to innovation and cross fertilization of ideas

Resources available to pursue new ideas:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Management supports risk taking:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Management can recognize good new ideas:
Current status
1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Enthusiasm for work:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ■

Optimism that scientific and non-technical problems can and will be solved:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ■

Stimulating and challenging work:
Current status
1 □ 2 □ 3 □ 4 ■ 5 □
Importance
1 □ 2 □ 3 □ 4 □ 5 ■

The freedom and authority to direct the course of one's research:
Current status
1 □ 2 □ 3 □ 4 ■ 5 □
Importance
1 □ 2 □ 3 □ 4 □ 5 ■

The freedom and authority to pursue new ideas:
Current status
1 □ 2 □ 3 □ 4 ■ 5 □
Importance
1 □ 2 □ 3 □ 4 □ 5 ■

Adequate blocks of time, free from distraction, with which to think, be creative, perform and publish research:
Current status
1 □ 2 ■ 3 □ 4 □ 5 □
Importance
1 □ 2 □ 3 □ 4 □ 5 ■

Individual and organizational commitment to internal constructive criticism:
Current status
1 □ 2 □ 3 ■ 4 □ 5 □
Importance
1 □ 2 □ 3 □ 4 ■ 5 □

Respect for other people's ideas:
Current status
1 □ 2 □ 3 ■ 4 □ 5 □
Importance
1 □ 2 □ 3 □ 4 ■ 5 □

Commitment to the scientific method:
Current status
1 □ 2 □ 3 □ 4 ■ 5 □
Importance
1 □ 2 □ 3 □ 4 □ 5 ■

Project decisions made from the basis of good science:
Current status
1 □ 2 □ 3 ■ 4 □ 5 □
Importance
1 □ 2 □ 3 □ 4 ■ 5 □

Effective mechanisms and resources to facilitate interaction between and among disciplines:

Current status

1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐

Importance

1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Support for multi-disciplinary approaches to problem solving:

Current status

1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐

Importance

1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Mechanisms, funding and time to collaborate with individuals outside the laboratory:

Current status

1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐

Importance

1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Support for attendance at conferences:

Current status

1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Importance

1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Fair and effective use of peer and advisory committee reviews:

Current status

1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐

Importance

1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Feedback and benefit obtained from review:

Current status

1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐

Importance

1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Laboratory and staff with a history and reputation of producing excellent and relevant research:

Current status

1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐

Importance

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ■

Management that champions the laboratories accomplishments:

Current status

1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐

Importance

1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Attaining to management and internal processes

Criteria for resource allocation is clear, known and considered fair:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Managers willing to make tough decisions:
Current status
1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Managers knowledgeable about staff research:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Management credibility and trustworthiness in making decisions consistent with stated corporate values:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Management decisions based on data rather than personalities:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Management with people skills:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Management with technical knowledge:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Management ability to protect staff from internal politics:
Current status
1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Laboratory emphasis for teamwork and internal collaboration rather than internal competition for resources:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Consistent and effective communication within the laboratory regarding current laboratory activities:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Willingness of people to share information:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Less "overkill" in policies and procedures:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Simplified project approval and reporting requirements:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Competent, efficient and user-friendly laboratory services:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Effective computer support:
Current status
1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ■

Minimal overhead/indirect costs:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Attaining to setting and achieving relevant goals

A "big picture" view of the lab and its future that helps provide context for understanding laboratory-level resource allocation, hiring and other decisions:
Current status
1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

General belief that the laboratory is headed in the right direction:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Belief that one's own research is consistent with the laboratories vision:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Consistent research directions and themes:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Researchers see their projects as part of larger laboratory research themes:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Laboratory with long-term planning horizon having willingness to invest in new projects and future areas of research:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Good and direct relationship with sponsors/customers:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Existence of mechanisms for identifying project opportunities:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Commitment to basic research as a key component of the laboratory's portfolio:
Current status
1 ☐ 2 ☐ 3 ■ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ■

Laboratory portfolio of R&D projects breadth, depth and a high potential to have an impact on mission and national needs:
Current status
1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Project planning and execution:
Current status
1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

Formal laboratory measures of success and rewards that are consistent with doing excellent research:
Current status
1 ☐ 2 ■ 3 ☐ 4 ☐ 5 ☐
Importance
1 ☐ 2 ☐ 3 ☐ 4 ■ 5 ☐

***

Thank you for your time and effort required in completing this questionnaire.

Appendix B

Spreadsheet detailing survey data

	ENTRY																							
	1		2		3		4		5		6		7		8		9		10		11		12	
Question	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.
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	ENTRY																							
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Question	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.
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	ENTRY																								
	1		2		3		4		5		6		7		8		9		10		11		12		
Question	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	
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Attribute																									Linking questions
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2	3	5	2	5	2	4	3	5	2	5	2	5	2	5	3	5	2	4	2	5	3	5	3	5	4
3	3	4	3	5	1	4	3	5	2	5	3	5	3	5	1	5	4	4	2	5	3	5	3	5	5
4	3	3	4	5	5	4	4	4	4	4	1	5	2	5	2	2	2	5	2	5	3	5	3	4	6,7
5	3	5	3	4	3	4	3	5	3	5	4	4	2	5	3	4	3	4	2	5	2	5	3	5	8,9
6	4	5	4	4	3	4	3	5	4	4	3	3	2	5	5	4	2	4	2	4	3	5	3	5	10,11
7	3	4	3	4	1	3	2	5	3	3	2	3	1	5	2	3	1	4	2	4	3	5	3	4	12,13,14
8	3	5	3	4	3	4	3	4	4	4	4	3	2	5	2	4	2	4	1	4	3	5	3	4	15,16
9	4	5	4	5	4	4	3	4	3	4	4	4	3	4	3	2	2	4	1	5	2	5	4	4	17,18,19

	ENTRY																								
	1		2		3		4		5		6		7		8		9		10		11		12		Linking questions
Attribute	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	Cur.	Imp.	
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11	4	5	3	5	3	4	4	4	4	4	4	5	3	5	3	4	3	4	2	5	4	5	4	4	23,24,25
12	5	5	5	5	4	4	5	5	5	5	4	5	3	5	5	5	2	3	2	5	5	5	4	5	26,27
13	3	5	3	5	2	4	2	5	3	4	2	5	1	5	3	4	3	3	2	4	1	5	2	5	28
14	4	5	3	5	3	4	4	5	3	4	3	5	2	5	3	4	4	3	2	4	4	5	4	4	29,30,31,32
15	4	5	3	4	3	4	3	4	3	4	4	4	2	5	2	5	4	4	2	5	4	5	4	5	33,34
16	3	5	4	5	3	4	4	4	4	3	4	4	3	5	4	4	3	4	2	5	4	5	3	5	35,36
17	3	4	3	5	2	4	3	3	1	3	1	2	1	5	1	1	4	4	1	5	4	5	3	4	37,38
18	4	4	3	5	2	4	3	5	3	5	3	5	2	5	3	4	4	4	2	4	3	5	4	5	39,40
19	3	4	3	4	2	3	2	4	2	4	2	4	1	5	4	5	3	3	2	4	4	5	4	4	41
20	4	4	3	4	2	4	2	4	3	4	2	4	1	5	3	4	2	4	2	5	4	5	3	4	42,43
21	3	4	4	5	3	3	2	4	2	4	2	4	2	5	3	5	3	4	2	5	4	5	4	4	44,45
22	4	5	3	4	3	4	3	4	2	4	3	4	1	5	3	3	1	4	1	4	3	5	4	4	46,47,48
23	3	4	3	4	2	4	3	4	2	3	3	3	2	5	2	5	3	3	2	4	4	4	4	5	49
24	4	4	3	4	3	4	4	4	3	4	3	4	3	5	3	5	3	5	1	5	4	5	4	4	50,51
25	4	4	3	5	3	4	4	4	3	3	4	3	2	5	3	3	3	4	3	3	2	5	4	5	52,53
26	4	5	3	5	4	4	3	5	2	4	2	5	1	5	1	5	3	4	2	5	4	5	3	5	54,55
27	3	4	3	4	3	4	3	4	4	4	5	5	1	5	4	5	3	3	1	5	3	5	4	4	56
28	3	4	3	4	3	4	2	4	3	4	2	3	1	5	2	3	3	4	3	3	3	5	3	4	57,58,59
29	4	4	4	4	3	4	2	5	3	3	2	3	2	5	2	3	3	4	2	4	4	5	4	4	60,61
30	3	4	3	4	3	4	2	4	1	4	2	4	2	5	3	3	2	4	2	4	4	5	5	5	62
31	3	5	3	4	3	3	3	4	3	4	4	5	3	5	3	3	2	5	1	5	2	5	3	5	63
32	2	5	3	5	2	3	2	4	3	4	4	4	1	5	4	4	2	4	2	4	1	5	4	4	64
33	2	4	5	5	3	4	4	4	3	4	2	4	1	5	2	5	4	4	2	5	4	5	4	5	65
34	3	4	3	4	2	3	3	3	3	4	3	4	1	5	2	4	2	5	2	4	1	5	4	5	66
35	2	4	4	4	3	3	3	4	3	4	3	4	1	5	1	3	2	4	3	4	1	5	3	4	67
36	2	4	3	4	2	4	2	5	3	3	2	3	1	5	1	4	2	4	1	5	1	5	3	4	68