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Management control of biomedical research and pharmaceutical innovation

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Abstract

This paper investigates management and organization factors which may enhance the effectiveness of biomedical research and pharmaceutical innovation. The study consists of 222 survey questionnaires returned by senior scientific staff of academic hospitals and large health research institutes in the Netherlands and the main R&D laboratories of innovative pharmaceutical companies in Europe, and 47 in-depth interviews with professors, institute directors and R&D directors. The results suggest that pharmaceutical companies are more positively engaged in consistent control than are academic research laboratories, with health research institutes taking up an intermediate position. It is concluded that a well-balanced combination of personnel, administrative and external control is needed to improve effectiveness in universities, institutes and companies alike. © 1997 Elsevier Science Ltd

1. INTRODUCTION

The achievements of today's medicine are impressive. Smallpox, cholera and diphtheria, diseases which devastated populations, are now rare or nonexistent in most parts of the world. The search for 'magic bullets', which kill germs without destroying host cells, has led to a constant stream of antimicrobial medications. However, as their bacterial targets have developed resistance, physicians have entered a never-ending race to stay ahead of adaptation. Physicians are therefore in need of a continuous stream of new and innovative drugs. Increased knowledge of the biochemical and physiological background of diseases has enabled pharmaeutics to provide them with a large spectrum of gradually safer and more effective drugs. Increasingly, research efforts are being put into more complex therapeutic areas for which no easy solution is forthcoming.

A study by Capron (1994), including 135 companies in the chemical, (tele)communication, computer and aviation industries, under which 22 were branded ethical drug firms, revealed the pharmaceutical industry as one of the most technology driven. In the pharmaceutical industry, even more than in other high-tech industries, competitive power is based on innovative capacity. The pharmaceutical R&D process takes more than a decade and is carried out in a number of laboratories located in different countries. It

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includes laborious searching for NCEs (new chemical entities with assumed therapeutic efficacy) in drug discovery, drug targeting and toxicology testing in pharmaceutical development and the succeeding clinical testing on healthy volunteers and patients (Omta *et al.*, 1994*a*,*b*; Omta, 1995). Basic, applied and industrial research into drug discovery and drug design have become increasingly interwoven. Taylor (1994) calculates that the innovative pharmaceutical industry spends on average 10% to 20% of its total R&D budget on sponsorships and collaborative research with universities and institutes.

The present study has been conducted in 71 research laboratories in academic hospitals, health research institutes and innovative pharmaceutical companies. It investigates the management and organization factors which may enhance research effectiveness, and the instruments which should be used to do so.

2. THEORETICAL MODEL

The innovation management model developed in this study is based upon the concept that effectiveness stands, via positive and negative feedback and feedforward loops, in dynamic equilibrium with the quality of management control (control exerted by the research management, the senior scientific staff of the laboratory). Management control in turn is considered to be a function of organizational flexibility and control capacity. Organizational flexibility refers to the ability of the organization to adapt to changing situations. Control capacity refers to the competence of the research management to achieve these adaptations, given the level of organizational flexibility. A highly competent research management may reach a high adaptation level, even if the organization is relatively inflexible, whereas a less competent research management may fail, even if the organization as a whole is highly flexible (see equations 1 and 2).

$$E = f(\mathrm{MC}) + \mu \qquad (1)$$

where E = effectiveness, MC = management control, μ = residual variation;

$$\mathrm{MC} = f(\mathrm{OF}, \mathrm{CC}) + \mu \qquad (2)$$

where MC = management control, OF = organizational flexibility, CC = control capacity and μ = residual variation.

Fisscher (1991) emphasizes that, for management control to be effective, system-technical factors (such as phasing and structuring of research projects, setting of targets in terms of time, money and specifications) and socio-dynamic factors (directed towards enhancement of the motivation of the scientific staff) should be combined. Therefore a control mix of system-technical and socio-dynamic factors is tested in this study.

The study design is based on the concept of 'context comparison'. If, for a certain phenomenon (management control) in one overall context (biomedical research and pharmaceutical innovation) but in three different (sub-) contexts (universities, institutes and company laboratories), consistent relationships with outcome are found, this phenomenon is considered to be fundamental for these relationships and may therefore be generalized to related contexts in other technology fields.

3. OPERATIONALIZATION OF VARIABLES

3.1 Management control

In management practice, control is often narrowly defined, including monitoring and correcting (often used in financial terms to mean budget control). The system-theoretical concept of control, used in this study, originates from a much broader paradigm, namely: *any method of (goal)-directed influence* (de Leeuw, 1990). This broader paradigm enables control to be applied to a variety of forms of organizational processes, such as power processes, organizational learning, and changing of the organizational structure. Management control can be divided further into system, process and external control (see Table 1).

System control refers to control over the personnel and material resources of the laboratory. It is divided into personnel and resources control. Personnel control refers to the 'objective' quality of the reward system (organizational flexibility: number of tangible and intangible incentives, career policy etc.) and the competence of management to react to changing situations (control capacity: e.g. pace and manner of conducting reorganizations). The challenge of research management is to create the conditions conducive to meeting the corporate goals of scientific performance (system-technical performance) as well as the scientists' need for satisfaction and motivation (socio-technical performance). Several examples of effective reward systems for researchers have been reported (Badawy, 1988). In this study the incentives mentioned by Jauch (1976) are used to operationalize personnel control. Resources control refers to the adequacy of the resources (such as laboratory devices, budget and space) to facilitate the conductance of the tasks of the laboratory, and the absence of administrative constraints. It combines organizational flexibility and control capacity at the operational level.

TABLE 1. Operationalization of management control

System control

Personnel control (12 items)
Assessment of the effectiveness of personnel policy; Likert scales, higher values indicate a more positive assessment, e.g.
- cases concerning appointment, promotion and dismissal
- primary and secondary working conditions (salary level, stocks, use of company car etc.)
- good reputation of the organization or the research leader
- career planning within the organization or as a step-up towards other organizations
- recognition, e.g. possibilities for publishing, extra payment for extraordinary research efforts and training facilities
- pace and manner of conducting reorganizations

Adequacy (resources control: 3 items)
Assessment of the ability to conduct the primary tasks of the laboratory; Likert scales:
- adequacy of the research budget and laboratory equipment

Administrative control (resources control: 2 items)
Assessment of the organization's ability to adapt to changing situations; Likert scales:
- speed of reallocation, appointment and procurement procedures

Process control

Planning (2 items)
The perceived importance of short- and middle-range planning by higher management as related to day-to-day research activities

Frequency of research meetings (research process communication, 1 item)
Frequency of communication in research meetings

Attendancy mix (research process communication, 4 items)
Attendance at research meetings: whether only scientific staff or also support staff, scientists from other laboratories, other R&D phases and/or marketing and production; Likert scales

External control

International communication (3 items)
- frequency of contacts with scientists and physicians, and with colleagues at international conference and workshops
- scale and scope of joint research projects with universities, institutes and companies

Contractor communication (2 items)
Frequency of contacts with industrial and government contractors

Process control is divided into planning and research process communication. Planning includes the perceived importance of strategic, tactical and operational planning by the top management for day-to-day research work. It relates to the goal setting/accounting relationship between research management and top management. Research process communication, in contrast, relates to the control capacity of the research management, the gradual transition from 'hands on' to 'hands off' supervision, measured by the frequency of research meetings and the attendancy mix. The latter refers to the level of lateral and cross-functional communication in industry. External control refers to the position of the laboratory in the international scientific network and in universities and institutes, referring also to the network with industrial and government contractors.

3.2 Effectiveness (Table 2)

"Organizational effectiveness relates to the accomplishment of the cooperative purpose ... When a desired end is attained we shall say that the action is effective" (Anthony, 1965, p. 27). In universities and institutes the output of the research units is divided into output directed to the scientific community (research effectiveness) and output directed to industrial and government contractors (user effectiveness). Research effectiveness is measured by the number of scientific papers published per full-time equivalent (fte) scientific staff. It is considered as a quantitative indicator of the ability to conduct basic research. This is combined with the indicator for the apparent use of the research results by the scientific community (effective output according to Hazeu and Spangenberg (1991)), the citation score.[2] User effectiveness is

TABLE 2. Operationalization of effectiveness

Research effectiveness (universities and institutes)
The average number of papers published annually by scientists of the research unit, in international scientific journals per scientist from 1988 to 1991

User effectiveness (universities and institutes)
The average number of reports published annually per scientist of the research unit for industrial or governmental contractors from 1988 to 1991

Citation score (universities and institutes)
The average number of citations per scientific paper, published from 1985 to 1987, in the three years following publication. Self-citations and citations by research unit members are omitted. The number of citations is divided by the average number of citations of all papers published in that period in the same journals (journal weighed) and in the same (sub-)disciplines (weighed for discipline)

Number of patents (industry: innovative effectiveness)
The average annual number of patents for new chemical compounds, submitted worldwide with first priority date from 1985 to 1991 (Pharmdoc Section of the World Patents Index Database of Derwent Publications; process and formulation patents have not been considered) per US$10 million R&D expenditure in discovery

Length of development (industry: innovative effectiveness)
The average time span between patenting of the lead compound and launch of the registered drug on the prescription drug market (years^{-1})[1]

Operating profit margin (industry: industrial effectiveness)
Operating result/revenues. Operating result: result after deduction of normal operating charges and before financial income and expenses, taxes etc. Revenues: net turnover including other operating revenues, change in stocks and capitalized costs

[1]Estimation of research directors of the time-span between patenting and launch of anti-hypertensive and anti-ulcer drugs. These drugs were chosen because the development process is neither relatively short (antibiotics) nor very long (anti-psychotics). In five companies the reported length was checked for ten drugs which were launched after 1987. In all cases the findings proved to agree.

[2] Extensive literature exists about the shortcomings of citation analysis (Moed *et al.*, 1992). The main points of criticism concern the differences in the kinds of journal published and the differences across (sub-)disciplines in the number of researchers, the number of references per paper and the time lag between publishing and the citation optimum. In addition, self- and peer group citation are notable problems. An attempt was made to solve these problems by excluding self-citations and by weighing for the average number of citations of the papers in the journals in which they were published and for the average

measured by the number of reports published annually per scientist for industrial and government contractors. It is considered to reflect the ability of the research unit to conduct applied research.

In industry, effectiveness is measured at the level of the research process itself (innovative effectiveness) and at the company level (industrial effectiveness). Innovative effectiveness relates primarily to the control capacity of the research management, whereas industrial effectiveness is primarily related to the top management level and thus to organizational flexibility. To assess innovative effectiveness two measures are used. The number of patents per annual R&D expenditure in discovery is used as an indicator of the effectiveness of the discovery phase.[3] The length of the development process is used as an indicator of the effectiveness in the development phase, because time-to-market is one of the most important factors determining the profitability of a pharmaceutical company (Redwood, 1987; Taggart, 1993; de Wolf, 1987).

Innovation, although essential, is not enough to reach the ultimate goal of attaining long-term profitability for a company. It is obvious that without an adequate marketing and sales force an innovative drug will never reach its full profit potential. Vos (1989) analyses two companies which jointly developed a drug. The successive marketing effort was done separately. The firm with the best R&D–marketing interface clearly got the highest return on R&D investment. Therefore, the operating profit margin is used as an indicator of industrial effectiveness (see Table 2).

4. HYPOTHESES

4.1 Comparison of the strata

Two important sources of differences between the strata of universities, institutes and companies can be distinguished, influencing the level of management control. Firstly, the goals of the organizations are different. Generally speaking, the primary goal of a university is to perform basic research, that of an institute is to perform applied research, and that of a pharmaceutical company is to maintain long-term profitability by conducting R&D superior to its competitors. In the sequence basic research, applied research and R&D, environmental and task uncertainty is assumed to decrease (see, for example, Cohen and March, 1974; Zeldenrust, 1989). Research activities are thought to be rather uncertain in the sense that task outcomes are not repetitive or predictable. To reduce the level of uncertainty, researchers must keep in constant communication with colleagues in order to keep up with the state-of-the-art in their research field. It is hypothesized that international communication and research process communication will be more intensive in universities and institutes than in company laboratories. Regarding international communication, the differences might be slight, because in a 'science-based industry' such as pharmaceutics the building of an international scientific network is essential (see, for example, Gambardella, 1992; Taylor, 1994). Contacts with outside contractors will be very intensive in both universities and institutes, because of the increased importance of external funding due to budget retrenchments.

Secondly, there are important differences originating from the profit or not-for-profit background of the research organizations. All universities and most institutes are part of the public sector, and therefore subject to state (e.g. personnel, purchasing and construction) regulations and budget management restrictions. The personnel complement is largely fixed through tenure and contractual provisions. Lifetime appointment, combined with a strong legal status, limits the possibilities of decisive intervention in situations of conflict. Also, reallocation and job rotation are more difficult to implement. Furthermore, in profit organizations the feedback on a reduction in results is very direct. The operating profit margin is very compelling, because of the permanent threat of being overtaken by a competitor. In companies, administration and R&D staff have corresponding interests: maintaining the profitability and thereby the competitive position of the company. Therefore, it is expected that the scientific staff in pharmaceutical companies will set higher value upon system control and planning than the staff in universities and institutes. Table 3 summarizes these predictions.

4.2 Comparing high and low performers

The basic idea behind this paper is that management control is fundamental for success in biomedical research and pharmaceutical innovation. The main hypothesis is that for a number of management control variables the above-average performers will show

number of citations of the papers in the (sub)-discipline(s) involved in the time-span of publishing.

[3] There are a number of problems involved in the use of patent statistics; for instance, the possible difference in patenting policy (timing and scope) between companies (Basberg, 1987; Pavitt, 1988), the difference between leading (real innovative), defensive and follow on (me-too) patenting, as well as the increased importance of in- and out-licensing in order to attain a complete patent portfolio (see, for example, Fitzgerald, 1992; Gambardella, 1992). In a previous paper of the authors these problems are discussed in more detail (Omta *et al.*, 1994).

TABLE 3. Hypothesized relative strength of management control in the three strata

	Universities	Institutes	Companies
System control	−	±	+
Process control			
planning	−	±	+
frequency/attendancy mix	+	+	−
External control			
international communication	+	+	±
contractor communication	+	+	*

+ Comparatively highest strength of the management control variable at issue.
± Moderate strength.
− Lowest strength.
* Not measured.

higher scores than the below-average performers (median split). It is expected that robust and consistent relations between management control and effectiveness will be found for the effectiveness indicators, which reflect the primary goals, and weak and inconsistent relations for those indicators which reflect the secondary goals of the organizations. Not all management control variables are equally important, of course. One of the main objectives of this paper is to indicate which are the most critical for success in biomedical research and pharmaceutical innovation.

5. METHODS OF DATA COLLECTION AND DATA ANALYSIS

Semi-structured interviews were held with professors, institute directors and R&D directors (mostly members of the Board of Directors). In the interviews information was obtained about research management in general, and issues to be included in the survey questionnaires were collected. The interviews were taped and the protocols were sent to the interviewees for approval.

Standardized survey questionnaires, consisting of 126 precoded questions based on Likert 5-point scales, were sent to the research staff of the participating laboratories. They combined factual information (such as number of staff, research budget and output) with views and judgements about different aspects of management control (such as systems of remuneration, the flexibility of the organization to react to changing situations and the intensity of internal and external (network) communication; see Table 1). Before the data collection started, the questionnaires were tested on a sample of twelve biomedical researchers from the Faculty of Science, and four retired staff members from the pharmaceutical and chemical industry. Their comments were incorporated into the questionnaires. After data collection, all scales were recalculated in such a way that a higher number indicates a more positive assessment of the item concerned. Cronbach's α was calculated for the individual subscales to find out whether they corresponded with the variables defined, and to check for the internal consistency of the items supposed to measure a single concept. In all cases Cronbach's α was sufficiently high (>0.62) to warrant confidence in the internal consistency.

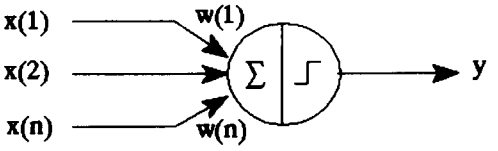
6. DATA COLLECTION

In order to warrant objectivity, the effectiveness indicators were obtained by use of bibliometric measures and checked by the research management concerned. Different statistical methods were used to relate the management control variables to the effectiveness indicators. Substantive conclusions were supported by all statistical techniques. The multivariate associations were assessed by 4Thought, a multilayer feedforward neural network which uses an exponential sum formula based upon series expansion to calculate the node's output value (Box 1). Neural network models are based on pattern recognition and therefore produce non-parametric models. This enables the multi-variate comparison of variables operationalized at different measurement levels.

The empirical study was conducted in 40 biomedical research units in eight academic hospitals and in 17 research units in five health research institutes in the Netherlands. This was combined with a European survey of 14 large pharmaceutical companies with discovery and/or pharmaceutical development laboratories in Great Britain, Germany, France, Belgium and the Netherlands. Nine companies are among the top 20 companies ranked according to the 1991 world-wide branded ethical drug sales. The other five are among the top 50 pharmaceutical companies. Patent analysis revealed that from 1985 to 1991 3874 licensees in total submitted pharmaceutical patents to

Box 1

Artificial neural networks are used in quite different areas such as design support, process management, (medical) diagnostics, marketing (data base mining), speech and visual memory and predicting of exchange rates, and prices of shares and options. Neural networks are based upon the functioning of the human brain. The basic element of the neural network is the artificial neuron (called a node), which can be considered a functional abstraction of the biological neuron. The human central nervous system consists of more than 100 billion of interconnected neurons. The information of one neuron is passed through to thousands of others, which in turn spread it further. Learning in the human brain consists of a continuous readjustment of the relative strength of the signals sent between the different neurons.



In analogy to this, an artificial neural network consists of different layers of neurons working in parallel. Inside a node the weighted (w_{1-n}) input signals (x_{1-n}) are summed (Σ), and an algorithm is used to calculate the node's output signal (y) to the next layer in the network. In the neural network 4-Thought, which was used in this study, the algorithm is an exponential sum formula based upon series expansion (Hoptroff *et al.*, 1991). The neural network uses the independent variables to build a model of the dependent variable(s).

The actual 'learning process' consists of continuously readjusting the weighing factors in the network. In every step of the learning process a neural network compares a pair of input and output values, which differ in a constant factor from each other (in 4-Thought a factor of 1.05). For the next step, that model is chosen in which the sum-of-squares error between the current and the desired mapping performance is most rapidly reduced. At the end of the learning process the model with the highest overall explained variance is selected. There is a threat of 'over-fitting'. An 'over-fit' model fits too perfectly to the data set, ignoring the natural variability ('noise') in the data. To avoid this problem, a neural network divides the data into two groups, a 'training' set and a 'test' set. In 4-Thought the training set consists of 80% and the test set the remaining 20% of the data. The neural network builds a model on the training set data and tests this model on the data of the test set.

The 'learning' process is only allowed to proceed as long as the errors in the training set and the test set are both dropping. Initially, both the errors for the training and the test set fall. When the noise in the data begins to dominate the learning process, the error for the test set starts to rise again, while the error in the training set continues to fall. At this point the learning process is stopped and the resulting model is presented. Statistically, it means the selection of a biased fit to the training set data based on the optimum fit to the test set data (Hoptroff *et al.*, 1991).

A neural network in which the information flows in one direction only (such as 4-Thought) is called a feedforward neural network. In a recurrent network, connections within one layer and with the neurons in the preceding layers of the network occur as well.

the European authorities.[4] The strong innovative capacity was illustrated by the fact that the 14 companies together submitted 25% of all the pharmaceutical patents in this period. In total, 278 questionnaires were sent to the research management in universities, 72 in institutes and 59 in industrial laboratories. Of these questionnaires, 142 were returned from universities, 44 from institutes and 38 from industrial laboratories, a response rate of 51%, 61% and 64%, respectively. Structured interviews were held with 16 professors, nine institute directors and 22 R&D directors.

7. RESULTS

Table 4 shows that the average sales volume of branded ethical drugs amounted to $3.4 billion in 1991, with an operating profit margin of 24%. As could be expected of a science-based industry, the average R&D expenditure is high, about 15% of the total sales volume. About 25% of the total R&D expenditure was spent on discovery, which resulted in about five patents per $10 million annually. The development phase has a long duration: it took the companies on average more than nine years to bring an NCE to the market.

TABLE 4. Descriptive statistics of pharmaceutical companies (n = 14)

	Mean	Standard deviation
Annual sales of ethical drugs ($m)	3372	1913
R&D expenditure ($m)	540	248
discovery ($m)	126	70
development ($m)	390	209
Number of patents (per $10m)	5.3	2.6
Length of development (years)	9.3	2.1
Operating profit margin (%)	23.6	11.2

Table 5 shows that about 20 staff members work in a laboratory. The running costs in biomedical research, being part of 'big science' (Spiegel-Rösing and de Solla Price, 1977), are rather high. The material costs per researcher amount from more than US$10 000 in universities to nearly US$20 000 in institutes. The percentage external funding of the research laboratories in this study doubled from around 20% in 1986 to nearly 40% in 1991. It has

[4] The number of licensees is actually less, because most companies use different licensee names and addresses.

TABLE 5. Descriptive statistics of research units in universities ($n = 40$) and institutes ($n = 17$; mean and F-value)

	Universities	Institutes	F-value
Staff (fte)	19.9	19.5	0.01
Material resources (US$/fte)	11330	19630	2.53
External funding (%)	39	37	0.14
Research effectiveness (sc papers/fte)	1.22	0.87	6.25***
User effectiveness (reports/fte)	0.30	0.65	3.37**
Citation score	1.16	1.59	7.96***

$F_{\text{oneway ANOVA}}$: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

often been argued that if more than one-third of the resources of a laboratory stemmed from external funding the (programmatic) continuity would be at risk. For most of the laboratories this is already the normal situation.

As expected, the research effectiveness is higher in universities, whereas the user effectiveness is twice as high in institutes. The scientists publish (and supervise) more than one scientific paper per year. Calculated per PhD student, this is approximately 2 to 2.5 papers. According to citation measures, Dutch biomedical research scores above the world average. In both universities and institutes the number of citations per paper scores above the world average for the (sub)-discipline(s) involved. It is interesting to note that the number of papers per scientist is higher, but the number of citations per paper is fewer, in universities as compared to institutes. The scientific papers of the more experienced researchers in institutes are apparently more penetrating than those of young PhD students, which are written under huge 'publish or perish' pressure in the limited time-span for graduation.

Table 6 shows that clear differences are found in the level of management control in universities, institutes and companies. The scientific staff members in companies are, on average, more positive about the effectiveness of personnel policy than their colleagues in universities and institutes. Although large differences could be established between scientists in the different companies, their average judgement of remuneration, career possibilities and recognition was clearly more positive. In universities especially, the average assessment of the personnel policy situation and the adequacy of resources is judged negatively (the average assessment is below 3 on the Likert 5-point scale).

The other variables of system control—adequacy of resources and administrative control—are also judged more positively in companies. The estimated pace of the administrative procedures is nearly twice as high as in universities. Monitoring of the scientific network is also more intensive and participation in international conferences is significantly higher. Researchers in institutes take up an intermediate position between universities and companies on all the variables of system and external control. In contrast to this, research process control is significantly more intensive in universities and institutes than in companies, and the frequency of research meetings and the attendancy mix are significantly higher.

Table 7 shows the multivariate associations of management control and effectiveness. Concerning universities and institutes, the best models are found for research effectiveness in universities and user effectiveness in institutes, with a total explained variance of 37% and 63%, respectively. In both cases personnel control, administrative control and international communication count for the total of the explained variance. No model was found for user effectiveness in universities and only a weak one for research effectiveness in institutes. It is interesting to note that the same three variables of management

TABLE 6. Comparison of management control in universities, institutes and pharmaceutical companies (mean and F-value)

Management control	Universities $n = 142$	Institutes $n = 44$	Companies $n = 38$	F-value
System control				
personnel control	2.52	3.09	3.33	6.96***
adequacy	2.54	2.89	3.56	3.65**
administrative control	2.00	2.41	3.48	8.96***
Process control				
planning	3.62	3.64	3.78	0.06
frequency	4.25	4.49	3.07	10.50***
attendancy mix	2.81	2.80	2.37	3.37**
External control				
international communication	2.54	3.06	3.46	3.64**
contractor communication	2.84	2.59	na	0.09

na = not applicable; $F_{\text{oneway ANOVA}}$: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

TABLE 7. Percentage explained variance of effectiveness by management control

	Universities $n = 40$			Institutes $n = 17$			Companies $n = 10$		
	re	ue	cs	re	ue	cs	pn	dl	opm
	%	%	%	%	%	%	%	%	%
System control									
personnel control	10	–	4	13	22	3	32	9	30
adequacy	–	–	4(–)	–	–	–	–	–	–
administrative control	8	–	7	–	16	–	–	–	19
Process control									
planning	–	–	–	–	–	–	–	4	–
frequency	–	–	–	–	–	–	25	–	–
attendancy mix	–	–	–	–	–	–	–	10	–
External control									
International communication	4	–	–	–	11	–	–	–	18
Contractor communication	15	–	5	–	14	13	na	na	na
Total	37	–	20	13	63	16	57	23	67

re = research effectiveness; ue = user effectiveness; cs = citation score; pn = patent number; dl = development length; opm = operating profit margin; – variable does not associate significantly with the effectiveness indicator at issue; (–) variable associates negatively with the effectiveness indicator at issue; na = not applicable.

control also explain (in a strictly statistical sense) most of the variance of the industrial effectiveness measure, the operating profit margin. The fact that process control does not add explained variance to all the effectiveness measures in universities and institutes or to the industrial effectiveness measure in industry is also worth mentioning.

The model of the citation score in universities, and to a lesser extent in institutes, shows a similar pattern to that for research effectiveness in universities; but both models are weaker, with a total of explained variance of 16% and 20%, respectively. The neural network models of the innovative effectiveness indicators show that the frequency of project team meetings is higher in the case of high effectiveness in the discovery phase. A shorter development phase is positively associated with the adequacy of resources, the importance of short-term, middle-term and long-term planning and the attendancy mix, indicating a high level of lateral and cross-functional communication.

8. DISCUSSION AND CONCLUSIONS

8.1 Comparison of the strata

Table 6 has shown that great differences occur in the average assessment of the different variables of management control between the strata. In most cases the research units in universities are found at one end of the scale and the industrial laboratories at the other end, with the institutes taking up an intermediate position.

Table 8 shows that most of the hypotheses concerning the differences between strata are confirmed by the data. In accordance with the hypothesis of the profit or not-for-profit background of the research organizations, the staff in companies are clearly more positive about the factors of system control than their colleagues in universities and institutes. The average assessment of personnel control and the adequacy of the personnel and material resources in industry are about 0.8 point higher on a Likert 5-point scale than in universities, and 0.2 and 0.6 points higher than in institutes. The difference in the assessment of administrative control is even larger, about 1.5 points between industry and universities and more than 1 point between industry and institutes. For instance, according to the scientific staff of more than 50% of the university laboratories, it would take more than a year to reallocate a major part of the resources to a new research line, while in industrial laboratories the average estimation is six months or less. This substantial difference in the assessment of the variables of system control may indicate that, despite the recent policy to improve market orientation, fundamental differences between profit and not-for-profit organizations still exist.

In accordance with the hypothesis of higher task uncertainty, the variables of research process communication (frequently of research meetings and the attendancy mix) are assessed significantly higher in universities and institutes than in industrial laboratories. It must be considered, however, that at least part of this difference must be attributed to the much larger size of the R&D process in industry.

TABLE 8. The determined strength of management control compared with the hypotheses

	Universities	Institutes	Companies	Hypothesis
System control	−	±	+	confirmed
Process control				
planning	±	±	±	not confirmed
frequency/attendancy mix	+	+	−	confirmed
External control				
international communication	−	±	+	not confirmed
contractor communication	+	+	*	confirmed

+ comparatively highest strength of the management control variable at issue; ± moderate strength; − lowest strength; * not measured.

In accordance with the expectation, the assessed importance of planning by higher management is the highest in industry, but the differences are far from significant. For universities especially, this result was unexpected. Apparently colleague control is more accepted than is assumed in literature (Weick, 1979). In contrast to expectations, international communication turned out to be more intensive in industry than in universities and institutes. This contradictory finding may be explained by the large difference in the available travelling budget.

An alarming result is the negative judgement of the system control situation in universities and, though to a lower extent, in institutes (see Table 6). For the correct interpretation of this result one should remember that in a professional bureaucracy, such as a medical faculty, there is always a certain tension between professionals and administration (Mintzberg, 1983). This may have resulted in unjustified negative judgement of the organizational flexibility. Nevertheless, it might be an indication of a gradual decrease of organizational flexibility of Dutch research organizations due to budget retrenchments. These have forced research units to acquire additional external funding to such an extent that the programmatic continuity may become at risk.

8.2 Comparing high and low performers

One of the most striking results of this study is that the high performers clearly differed from their low performing competitors on a number of socio-dynamic and system-technical features, regarding both organizational flexibility and control capacity.

Table 9 shows that the management control variables—personnel control, administrative control and external control—together explain the variance of research effectiveness in universities and that of user effectiveness in institutes. In constrast to this, the management control variables explain no variance of user effectiveness in universities, and only personnel control explains some of the variance of research effectiveness in institutes. Research effectiveness is considered to reflect the ability to conduct basic research, the primary goal of universities, whereas user effectiveness is considered to reflect the ability to conduct applied research, the primary goal of institutes. Therefore, these results provide confirming evidence for the hypothesis that robust and consistent associations would be found between management control and those effectiveness indicators which reflect the primary goals, and weak and inconsistent associations with those indicators which reflect secondary management goals of the research organizations.

The above findings are, to some extent, supported by the neural network models of the citation score. This indicator is considered to reflect the use of the results by scientific colleagues and physicians. Both in universities and institutes, personnel control and contractor communication explain some of the variance of research and user effectiveness, whereas administrative control also explains some variance of research effectiveness in universities. But the resulting models are relatively weak, probably due to the inevitable time-lag between publishing and citation measurement.

Interestingly, personnel control, administrative control and external control separate the above-average from the below-average performers for the indicator of industrial effectiveness, the operating profit margin. In the companies with the greatest operating profit margins, the perceived quality of personnel policy is much better than in the average companies. In addition, the average duration of administrative procedures is clearly shorter, and international communication with scientists and physicians at congresses and workshops is more intense. It can be argued, however, that the causality may be the opposite to that which has been suggested. The more effective companies are also the most profitable and can therefore afford to spend more on elaborate laboratory equipment, to

TABLE 9. Explained variance of effectiveness by management control for effectiveness indicators which reflect primary or secondary management goals

Effectiveness indicator	Primary goals			Secondary goals		
	University Research	Institute User	Company Industrial	University User	Institute Research	Company Innovative
System control						
personnel control	+	+	+	–	+	+
adequacy	–	–	–	–	–	–
administrative control	+	+	+	–	–	–
Process control	–	–	–	–	–	+
External control	+	+	+	–	–	–

+ part of the variance of the effectiveness indicator is explained by the management control variable at issue; – no variance explained.

have more frequent international contacts and can have quicker procurement and appointment procedures. The R&D staff in the better companies are also likely to respond more positively to such studies than their colleagues in the less performing companies. However, because of the large size of the companies at issue it may be expected that spending budgets will not be so much of a bottleneck for procurement, appointment and international travelling. Possibly, the operating profits not only reflect the ultimate company goal of maintaining profitability, but also, at least to a certain extent, the contribution of the R&D function in attaining this goal. This would be in accordance with the conclusion drawn by van Engelen (1989) for the marketing function.

If this assumption is correct, in all three strata the same management control variables, personnel, administrative and external control, are closely associated with effectiveness. This would provide confirming evidence for the main hypothesis, that there is a fundamental association between management control and effectiveness, dividing the above-average from the below-average performers, regardless of the organizational setting. It consists of the following factors:

- the perceived effectiveness of personnel policy, a socio-dynamic factor of organizational flexibility and control capacity combined;
- the average duration of the administrative procedures, a system-technical factor of organizational flexibility. For example, it took the best performing research laboratories on average 3 to 12 months less to reallocate a major part of their resources to a new research area;
- the communication with contractors and international communication at conferences and workshops; a socio-dynamic factor combining elements of organizational flexibility (e.g. available travelling budget) and the control capacity of the research management.

Another interesting observation which derives from Table 9 is that process control is relatively unimportant in discriminating between high and low performers in universities and institutes. Although large differences were established in the way and manner in which research is supervised, these differences are not found in the neural network analysis. For none of the effectiveness indicators is variance explained by the variables of process control. Apparently, organizational flexibility is more prominent in the control mix than the control capacity of the research management.

Tables 7 and 9 show that the operating profit margin is not closely related to process control. This is not astonishing. The operating profits of a pharmaceutical company may depend on only one or two major products, but also on a variety of products. Thus a direct relationship between profit performance and R&D organization is very unlikely. In contrast to this, the innovative effectiveness indicators were expected to relate more closely to process control (see Section 3). Table 7 shows this to be true. It shows that part of the variance of the effectiveness indicator for the discovery phase, the patent number, is explained by the frequency of project team communication. In the structured interviews it became apparent that the best performing companies shift their attention from the screening of thousands of chemical compounds to the understanding of the biochemical and physiological background of diseases. The screening process itself its becoming increasingly automated. According to theory, the growing task uncertainty, which derives from this shift from systematic screening to fundamental research, will lead to a higher informational need (see Section 4) which is met by a high frequency of project team meetings. More intensive international communication did not add explained variance; this is probably due to the danger of leakage of confidential information.

In the relatively certain development phase, a positive correlation is found of shorter development

length with the assessed importance of strategic, tactical and operational planning by top management, and the attendancy mix. It indicates the prominent role that concurrent engineering (parallel development with intensive lateral and cross-functional communication in project teams) takes in modern development. Reducing time-to-market is essential. As one of the research directors put it: "Each day a successful drug reaches the market earlier earns $200 000 for the company". With this figure in mind, it is obvious how great the benefits are for companies that are able to shorten the development phase. Concurrent engineering practices have so fundamentally changed the pharmaceutical R&D process that the current R&D process in the most innovative pharmaceutical companies can best be described as a chain of integrated learning loops (Janszen, 1994). All pharmaceutical firms make use of concurrent engineering. The structured interviews learned that in the above-average performers the fine tuning was more precise, and the lateral and cross-functional communication more intense. Interestingly, close monitoring of the development process did not go hand-in-hand with a high frequency of project team meetings. Most of the pharmaceutical companies in this study are multinationals with laboratories in different countries. A high frequency of meetings would mean a lot of travelling. Mutual adjustment was therefore attained mainly by telecommunication (e-mail and video conferences). In cases of very frequent project team meetings, a tendency towards ineffectiveness was observed.

9. MANAGEMENT IMPLICATIONS

For the correct interpretation of the results presented, it should be remembered that all relations are of a two-sided causality, because reinforcement loops such as doing excellent research, getting interesting results, attaining more attention of the outside world, getting more international contacts, developing more innovative ideas etc., are at work here. Therefore, the list of features of a high performing research laboratory, presented in Table 10, is not meant as a blueprint but mainly as a reminder of what is important in research management.

The most important management control variable turned out to be personnel control, which explains part of the variance of all but one of the effectiveness indicators. This is clear confirmation for a central thesis in socio-dynamic literature. Stimulating and rewarding environments, which enhance the motivation of the scientific personnel, are needed for high effectiveness. Probably just as interesting is the observation that process control did not come out as an important factor discriminating between high and low performers in universities and institutes. Both ways of supervision (tight control, with strict planning of every step of the research process, or loose control, leaving the individual researcher room for manoeuvre) may lead to high effectiveness. There are many ways for good research managers to reach their goals, but what they cannot change is the inflexibility of the organization. Research management and management consultants may profit from this knowledge by concentrating their efforts on organizational flexibility.

TABLE 10. Features of high performing research organizations

Personnel control
- pay much attention to human resource management and staff motivation
- use career systems which lead to an inspiring work environment
- provide many opportunities for attaining recognition
- try hard to meet the specific needs of the scientific staff

Adminstrative control
- are flexible in adapting to changing situations
- protect their staff against 'red tape'
- create operating systems which avoid bureaucracy
- reallocation, appointment and procurement procedures are carried out quickly

External control
- scan the environment for new ideas, opportunities and financial resources
- pay much attention to building and maintaining an international R&D network

Numerous researchers have stressed the importance of stimulating and rewarding environments to enhance innovative effectiveness. The importance of a flexible organization to proactively react to changing situations, and the importance of maintaining an extensive R&D network, are also stressed in many studies. However, until now only limited evidence has been presented to prove these statements in the real world of management practice. Taking into account the large contextual variation, the comparison has shown reasonably consistent results. Consequently, the findings of this study may be generalized to management of innovation and technology management at large.

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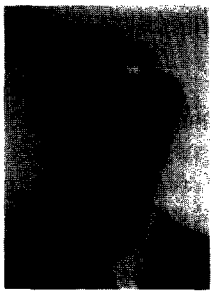

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Translations of abstracts

Management control of biomedical research and pharmaceutical innovation

S.W.F. Omta, L.M. Bouter and J.M.L. van Engelen

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Contrôle de gestion en recherche biomédicale et dans l'innovation pharmaceutique

Résumé

Ce papier fait le point sur les facteurs de gestion et d'organisation qui peuvent améliorer l'efficacité de la recherche biomédicale et de l'innovation pharmaceutique. L'étude consiste en 222 questionnaires renvoyés par l'encadrement supérieur scientifique des hôpitaux universitaires et des grands instituts de recherche médicale aux Pays Bas, ainsi que des principaux laboratoires de R&D des sociétés pharmaceutiques innovantes en Europe, et en 47 interviews approfondies avec des professeurs, des directeurs d'instituts et des directeurs de R&D. Les résultats suggèrent que les entreprises pharmaceutiques sont engagées de façon plus positive dans un contrôle continu que les laboratoires de recherche. Les instituts de recherche sur la santé, quant à eux, ont une position intermédiaire. On conclut qu'une combinaison bien équilibrée des contrôles relatifs aux personnels, à l'administration et aux échanges externes est nécessaire pour améliorer l'efficacité des universités, des instituts et des entreprises, au même titre. © 1997 Elsevier Science Ltd

Managementkontrolle von biomedizinischer Forschung und pharmazeutischer Innovation

Abriss

In dieser Arbeit untersuchen wir Management- und Organisationsfaktoren, die die Effektivität von biomedizinischer Forschung und pharmazeutischer Innovation vergrößern könnten. Die Studie besteht aus 222 Fragebögen, die vom leitenden wissenschaftlichen Personal der Universitätskliniken und der großen Gesundheitsforschungsinstitute in den Niederlanden und von den wesentlichen F&Es Labors der innovativen pharmazeutischen Konzerne in Europa beantwortet wurden, und aus 47 umfassenden Interviews mit Professoren, Institutsdirektoren und F&Es Direktoren. Die Ergebnisse deuten an, daß sich pharmazeutische Konzerne positiver in konsequenter Kontrolle engagieren als akademische Forschungslabors, wobei die Gesundheitsforschungsinstitute eine Zwischenposition einnehmen. Es wird geschlußfolgert, daß eine gut ausgewogene Kombination von Personal, Verwaltungs- und externer Kontrolle notwendig ist, um die Effektivität an Universitäten, Instituten und Konzernen gleichermaßen zu verbessern. © 1997 Elsevier Science Ltd

El control de la administración de las empresas de la investigación biomédica y de la innovación farmacéutica

Resumen

Se investiga en este documento los factores de la administración y de la organización que pueden aumentar la efectividad de la investigación biomédica y la innovación farmacéutica. El estudio consiste de un sondeo de 222 cuestionarios rellenados por el personal científico de alto nivel de los hospitales universitarios y de los grandes institutos de investigación médica en los Países Bajos, a la vez que en los laboratorios de I&D de las empresas de innovación farmacéutica de Europa y 47 entrevistas detallados con profesores, directores de institutos y gerentes encargados de la investigación. Los resultados indican que las empresas farmacéuticas están involucradas más positivamente en el control contínuo que los laboratorios de investigación académicos, y que las instituciones de investigación de la salud toman una posición entremedias. Se considera que una combinación bien equilibrada de control de personal, control administrativo y control externo es necesario para mejorar la efectividad, tanto en las universidades como en los institutos y en las empresas. © 1997 Elsevier Science Ltd

Principle of Manufacturing: a proposed new concept

Akira Kobayashi

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