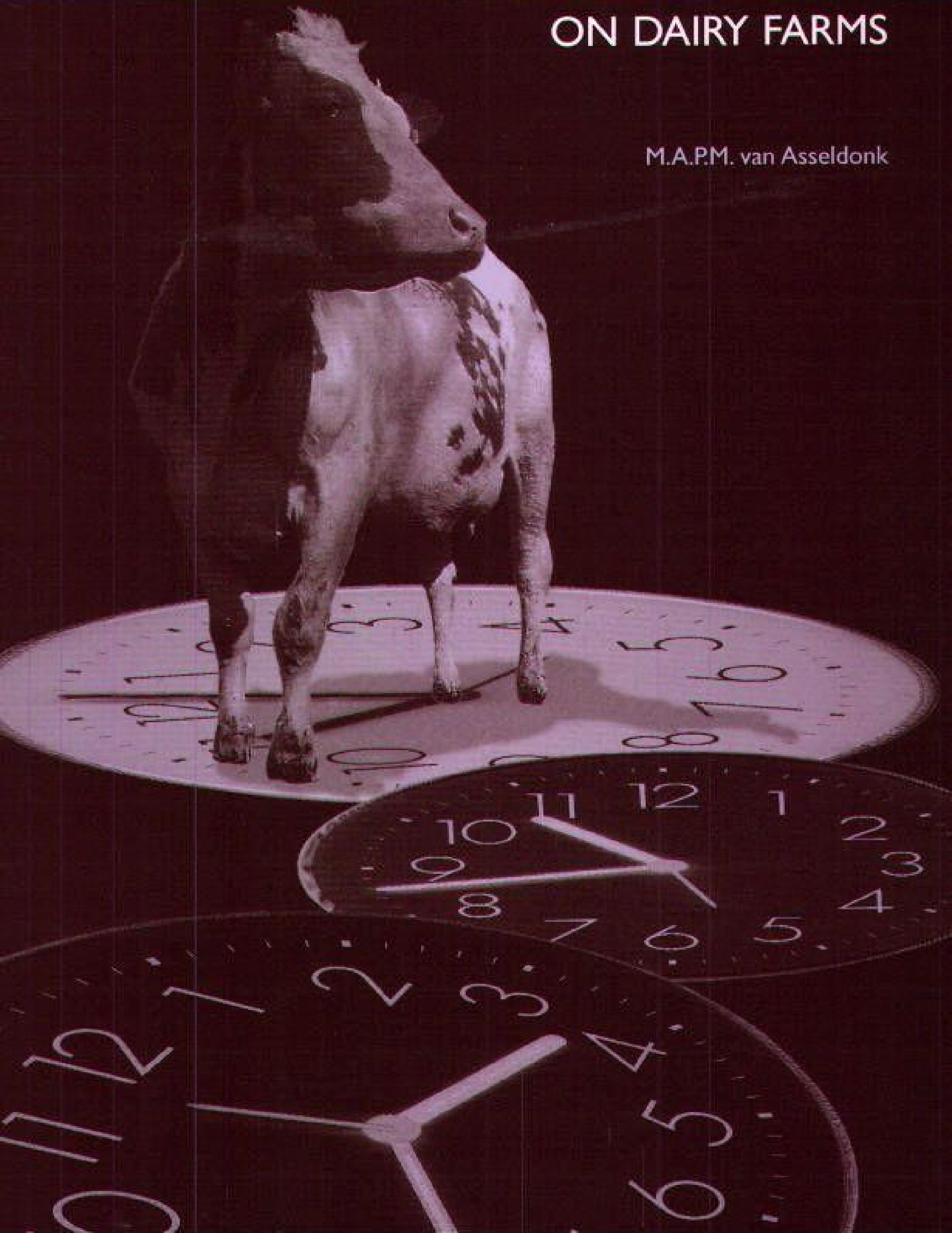
ECONOMIC EVALUATION OF INFORMATION TECHNOLOGY APPLICATIONS ON DAIRY FARMS

M.A.P.M. van Asseldonk



Stellingen

1. Het gebruik van een krachtvoercomputer verhoogt de productie per koe, terwijl aktiviteitsmeting de tussenkalftijd verkort.
   Dit proefschrift

2. Het vergelijken van normatief en empirisch bepaalde technisch-economische effecten van investeringen in informatie-technologie verdient aanbeveling zodat het belang van de gebruiker in het besluitvormingsproces nader wordt aangegeven.
   Dit proefschrift

3. Optimalisatie van investeringsbeslissingen in informatie-technologie is mogelijk met dynamische programmering daar dynamische en discontinue ontwikkelingen ten aanzien van het investeringsbedrag en de technische prestatie eenvoudig meegenomen kunnen worden.
   Dit proefschrift

4. De mate van bedrijfsexpansie bij melkveebedrijven die investeren in informatie- technologie is gelijk aan melkveebedrijven die daar niet in investeren.
   Dit proefschrift

5. The capacity of the human mind for formulating and solving complex problems is very small compared with the size of problems whose solution is required for objectively rational behaviour in the real world, or even for a reasonable approximation to such objective rationality.
   Simon, H.A., 1957, Models of man: social and rational. New York: John Wiley.

6. De impliciete aanname door veel agronomen dat precisie landbouw alleen betrekking heeft op het plaats-specifiek uitvoeren van teeltbewerkingen is een voorbeeld van een éénzijdige visie.

7. Agro-industriële ketens zijn boeiend.

8. Reorganisaties binnen de krijgsmacht verlopen vaak moeizaam vanwege politieke redenen om de slagkracht van deze organisatie te definiëren in termen van manschappen.

9. Handhaving van de overdrachtsbelasting staat haaks op het huidige overheidsbeleid om te streven naar een toename van de arbeidsmobiliteit; een heffing op alleen de eventuele meerwaarde van het onroerend goed is derhalve consistenter.

10. De functionaliteit van routeplanners zal aanzienlijk toenemen indien, rekening houdend met de verwachte files, tevens een kansverdeling van de reistijd wordt verstrekt.

11. Het huidige promovendi-stelsel waarin beursalen, AIO's en toegevoegde onderzoekers met dezelfde inhoudelijke functie maar een verschillende financiële beloning binnen een organisatie zijn aangesteld dient niet gepromoot te worden.

Proefschrift van M.A.P.M. van Asseldonk
Economic evaluation of information technology applications on dairy farms
Wageningen, 5 februari 1999

ECONOMIC EVALUATION OF INFORMATION TECHNOLOGY APPLICATIONS ON DAIRY FARMS

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ECONOMIC EVALUATION OF INFORMATION TECHNOLOGY APPLICATIONS ON DAIRY FARMS

Proefschrift
ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van de Landbouwuniversiteit Wageningen,
dr C.M. Karssen,
in het openbaar te verdedigen
op vrijdag 5 februari 1999
des namiddags te half twee in de Aula

Omslag: Ernst van Cleef
De factor tijd is van belang bij de evaluatie van investeringsbeslissingen in informatie-technologie op melkveebedrijven. Dynamische ontwikkelingen ten aanzien van het investeringsbedrag en de technische prestatie zijn een wezenlijk onderdeel in de beschreven normatieve evaluatie. Tijdreeksen van bedrijfsgegevens vormen de basis voor de empirische evaluatie.
Druk: Grafisch Bedrijf Ponsen & Looijen B.V., Wageningen

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ABSTRACT

Economic evaluation of information technology applications on dairy farms
Economische evaluatie van informatie-technologie toepassingen op melkveebedrijven
Asseldonk, M.A.P.M., van, 1999.

The research described in this thesis focused on the economic evaluation of information technology (IT) applications on dairy farms in order to support investment decisions. The evaluation included a normative (deductive) approach and an empirical (positive) approach. The normative approach predicted potential benefits from a theoretical model of the investment, and investigated how farmers should deal with the applications. The empirical approach observed the actual effects of the investment (realised benefits) and investigated how farmers did deal. Applications were adopted on Dutch dairy farms and were directed towards improvement of management on an individual cow basis. The research was focused on automated concentrate feeding systems, sensors that measure daily physical activity of cows and on-line automated parlour systems for recording of milk production, milk temperature and electrical conductivity of quarter milk. Results obtained from the normative and empirical approach showed that investments in automated concentrate feeders were profitable for a typical Dutch dairy farm. A simultaneous investment in activity measurement was profitable if the level of visual oestrus detection was average. The possible dichotomy between potential and realised benefits of IT applications was examined and discussed. This was focused towards the processes of concentrate feeding, oestrus detection and mastitis detection. In general, similar results were obtained for an application that automated and improved a physical process. However, potential benefits obtained from the normative analysis were more profound than realised benefits obtained from the empirical analysis. This was particularly the case for applications that were heavily depending on time and management skills of the farmer. The methods described were general of nature and could also be used for other applications and species.

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CONTENTS

1 GENERAL INTRODUCTION

1.1 Scope and aim of the thesis

Modern farming imposes increasing demands on farmers' management skills in order to maintain profit and guarantee continuity of the farm. The number of dairy farms decreased in The Netherlands from 50,000 in 1987 to 35,000 in 1997. Milk production per cow increased in that same period from 6,467 kg to 7,907 kg per year. The total number of cows decreased, since dairy farmers were operating under a milk quota system, from 2.1 million to 1.6 million (ACT, 1997). At the same time, availability of tools to support management improved considerably (Huirne, 1990; OTA, 1992; ATC, 1997).

Recent advances in Information Technology (IT) increased the possibilities to support farm management. IT represents a diverse class of applications which include all the hard- and software used by farmers to capture data, to transform data into information, to help in decision making, to establish communication of data/information, internally as well as externally and to perform production tasks. On-line acquisition and processing of data on Dutch dairy farms with IT applications, which enable to perform production tasks and monitor performance on an individual cow-basis, are primarily automated concentrate feeders, milk production meters, activity meters, and milk conductivity meters. By 1997, the number of Dutch dairy farms which adopted these applications were 13,500, 2,800, 700 and 1,200 respectively (ATC, 1997). At the central management computer the actual performance parameters are integrated and compared with the expected or predetermined values of these parameters. As a result, more timely and better information is becoming available. More effective and efficient production is possible due to improved managerial decisions (Silk, 1990).

Although adoption may in itself be an indication of farmers expecting benefits from the investment, it does not provide a quantifiable effect that is attributable to the investment (Verstegen et al., 1995). The characteristics of the farmer, such as schooling and age, are also shown to be important variables for explaining the odds of adoption (Huffman and Mercier, 1991). Through lack of knowledge or through inaccurate perceptions, the individual's evaluation as to whether or not an investment is rational may not agree with the objective rationality. Besides expected profitability also other factors may motivate farmers to adopt a new technology like the desire to gain social status (Rogers, 1995), or interest in the technology. For an evaluation based on objective rationality, the technical impacts of a particular IT investment on the performance parameters and ultimately on economic farm results have to be determined. These effects are, however, difficult to assess and consequently the question whether an investment in a new IT application can be justified is difficult to answer (Dos Santos, 1991). This is even more evident if on-line data is collected by several IT applications to support various farm processes. The aim of this thesis is to evaluate information technology applications on dairy farms in order to support investment decisions. Applications included in the analysis are automated concentrate feeding systems and sensors that measure daily physical activity of cows and on-line automated parlour systems for recording of milk production, milk temperature and electrical conductivity of milk. Because of the assumption of economic rationality other factors explaining investment behaviour in the real world are not evaluated.

Two complementary research methods are used in this thesis to evaluate the IT investments. As the costs of these systems are usually clear, the first step is to investigate the potential benefits of the applications. The economic appraisal of the investment is difficult and inherently complicated because of the dynamic nature of the decision environment. Technical performance and retail price are likely to improve over time. Early investment will generate additional revenues, while late investment will generate higher yearly additional revenues that are deferred due to lower investment costs and improved technical performance. The optimal investment pattern requires a trade-off between the conflicting objectives of minimising invested capital and current payments and maximising receipts. In addition, most research focused on the technical performance of the applications under experimental conditions while the critical aspect of implementation is limited investigated. In order to estimate potential technical performance at farm level this aspect has to be included. In the next step, benefits should be investigated under practical conditions. Quantifying the difference between the benefit what should be obtained and of what appeared to be obtained is valuable to determine the importance of the factor management in relation with the utilisation of new technologies. It can facilitate in formulating actions to improve on-farm use of the technologies.

1.2 Outline of the thesis

In the second chapter the problem of IT evaluation is addressed and the potential benefits are described in general and specific for the applications under research. This is undertaken to restrict the number of processes to be evaluated and to ensure that all important processes are included in a subsequent analysis on investment decisions rather than evaluating all (combinations of) possible processes which may be affected. Reducing the number of farm processes would allow a more in-depth and refined study and enhance the ability to formulate an economic model (Dewey et al., 1992).

The next three chapters describe the normative approach in which the economic benefits are estimated with a theoretical model. Expected benefits of the improvement in biological parameters are based upon a dynamic probabilistic simulation model taking into account farm-specific characteristics (Chapter 3). Simulating a specific farm, with and without the potential effects of one or more IT applications, provides a means to determine the impact of the improvement in biological parameters on farm level. It enables the inclusion of the current status of farm performance (e.g., oestrus detection and average milk production per cow). Since the exact improvements are unclear, simulation models are applied for sensitivity analysis, enabling to gain insight into the potential benefits (Kleijnen, 1984). Incorporated literature was focused on the effectiveness of the applications under experimental conditions while the critical aspect of implementation, and ultimately on farm result, is limited reported in literature. Therefore additional information is obtained from experts to provide a means to interpret the implications of the research results for commercial farms. The method of conjoint analysis is used to elicit the opinions of experts and assesses the potential improvement in biological parameters at farm level (Chapter 4). The results of the previous two chapters are integrated into a dynamic programming framework in order to support farmers' decision making with respect to IT investments (Chapter 5). Dynamic programming is used to determine the investment policy that maximises the net present value over a given planning horizon (Kennedy, 1986; Dixit and Pindyck, 1994; Hardaker et al., 1997). The model determines and quantifies the optimal combination of a stepwise implementation of applications for an individual farm, taking into account price reduction and technical progress over time. Optimal investment patterns are calculated under different assumptions of farm characteristics and farm scale.

In addition to the normative approach, an empirical approach is followed to provide important information on the profitability of the systems in practice. Historically, automation of cow recording systems has been one of the first applications in the adoption sequence of new technologies on dairy farms. More recently, advancements in information technology have made it possible to capture additional on-line cow side data. However, all of these information technology applications incorporate some kind of automated cow recording system, i.e., management information system (MIS). The benefits in Dutch dairy farming of MIS adoption and use (Chapter 6) and additional IT applications (Chapter 7) are estimated with a unique time series data set; i.e., a so-called panel data set (Verstegen et al., 1995). It included cross-sectional data (different variables during the same temporal interval) and time series data (annual periods from 1987 to 1996) of adopters and nonadopters as well as farm results before and after adoption. Differences in performance data before and after adoption of the technology were corrected for trends and biases. Analysis of this kind of data provides a good opportunity to estimate the effect of the adoption of a particular technology on herd performance, eliminating the influence of other effects specific to the group of farms or herd (Mundlak, 1961). In addition, the experimental design allows estimation of technology effects for each year after adoption and showed whether the particular technology applications caused a gradual response over several years or whether the response was immediately apparent at the time of adoption (Lazarus et al., 1990).

In the general discussion (Chapter 8) the techniques used and the results obtained are compared and discussed. Ultimately, the implications of different benefits, obtained from the normative and empirical approach, on the appraisal of the investment are discussed. Furthermore, the importance of the factor management in relation with the utilisation of new technologies is discussed. A summary of the study is provided at the end of this thesis.

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2 INFORMATION NEEDS AND INFORMATION TECHNOLOGY APPLICATIONS ON DAIRY FARMS[1]

Abstract

Investments in Information Technology (IT) enable the farmer to collect and process data at farm and animal level to be used in decision making. In order to evaluate the currently available IT applications it is essential to determine in which way IT will support the information needs. A methodology was presented that was based on system decomposition principles which made a formal analysis possible. When evaluating an automated concentrate feeder, processes related to the function of nutrition are important. In case of activity measurement the evaluation should include at least the function reproduction and in case of electrical conductivity of quarter milk the function health care. Milk temperature measurement supports two functions, namely reproduction and health care, while milk production measurement supports a wide range of processes in the different functions.

2.1 Introduction

In farming, the need for more and better information for decision making is not a new issue. Over the years, however, this issue has become more important for capital-intensive farming systems due to increasing economic pressure. Small differences in production performance result in an increasing difference in profit. As a result, modern farming places stronger demands on farmers' management skills in order to maintain profit and guarantee continuity of the farm. Consequently, utilities that support management are gaining importance (Huirne, 1990).

Recent advances in information technology (IT) have increased the opportunities for effective decision support. Nowadays, several applications are available that can support important farm processes. In order to set priorities amongst the currently available IT applications, the identification of information needs is essential (Rockart, 1979). Investments should be aligned with these information needs; applications that support the needs with the

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[1] Paper by Van Asseldonk, M.A.P.M., Huirne, R.B.M., Dijkhuizen, A.A., Beulens, A.J.M. and Udink ten Cate, A.J., accepted for publication in *Computers and Electronics in Agriculture*.

greatest economic benefit and use the least resources should get the highest priority (Ward, 1990).

The long-term objective of the current study is to develop and evaluate an economic model which determines the optimum IT investment decisions. The current study was undertaken to restrict the number of processes to be evaluated and to ensure that all important processes are included in a subsequent analysis on investment decisions rather than evaluating all (combinations of) possible processes which may be affected. Reducing the number of farm processes would allow a more in-depth and refined study and enhance the ability to formulate an economic model (Dewey et al., 1992).

The identification of information needs and the assignment of priorities can be accomplished by utilising expert opinions (Kleijnen, 1984). In this study, information needs and potential opportunities of investments are systematically evaluated by using a decompositional approach (Martin and Leben, 1989) as a reference framework for an expert panel. Applications included in the analysis are automated concentrate feeding systems (ACF), sensors that measure daily physical activity of cows (AM) and on-line automated parlour systems for recording of milk production (MPM), milk temperature (MTM) and electrical conductivity of milk (ECQM). After describing the concept of system decomposition and the approach followed of eliciting subjective knowledge, the most important processes affected, induced by IT implementation, are presented and discussed.

2.2 Materials and methods

2.2.1 System decomposition

The available information resulting from IT applications on dairy farms are mainly used to support operational management decisions related to livestock and pasture. Therefore, the information needs and potential benefits of IT applications in this research focus exclusively on the operational management decisions. However, the impact of IT developments are difficult to determine and are inherently complicated because not just one but a number of interrelated farm processes may be affected by one and the same IT application, each process to a more or lesser extent. The Dutch information model (De Hoop, 1987) presents an efficient reference framework upon which potential effects can be evaluated (Figure 2.1). It includes functions, processes, information flows and data, which are all considered to be important for the management of the dairy business (Martin and Leben, 1989). The information model has been constructed at the level of the individual dairy farmer, has been well documented and verified by external experts. The development occurred in close co-operation with research and private companies. The project was initiated as the information stimulating plan for the agricultural sector (Doeksen, 1993). The different functions and processes of a farm are deducted from the basic management concepts 'planning', 'implementation/operation' and 'control' (Boehlje and Eidman, 1984; Huirne, 1990). Every function is decomposed into associated processes. Management of a farm is divided into: a strategic planning function (long-term; >1 year), a tactical planning function (medium-term; 1 year), various operational functions (day-to-day activities) and an overall control function. Each function includes a control part in which parameters concerning the status of the processes are calculated, followed by a comparison with target values and analysis of deviations. In case of a dairy farm, operational management includes the functions reproduction, health care, milk production, nutrition, cattle replacement and roughage production. Fixed assets administration and cash administration, also functions in the operational management, are not incorporated in this study. A short description of the processes included is given.

Reproduction includes record keeping in which animal performances and action lists are processed with data recorded in the different operational functions and processes (Figure 2.1). The observation whether or not cows are in heat, together with the strategy of insemination, conception and sire selection, determines the reproduction status of a farm. The function health care includes the observation of the health status by the farmer of a number of processes (clinical and subclinical mastitis, other infections, metabolic disorders and leg/claw disorders). Possible treatment can be based upon examination. Besides the physical process of milking and the different aspects of milk delivery, the function milking includes the additional recording of data such as milk production, milk composition and cell count. The physical process of feeding and recording of actual feed consumption is supported on the basis of feed administration of concentrates and roughage and the interrelated processes of ration composition and feed calculation for an individual cow or a group of cows (milking cows, dry cows and other livestock). The function cattle replacement includes the processes related to the purchase and culling of animals in order to realise a targeted herd size and herd composition. The function which is somewhat independent of livestock production itself includes associated processes related to roughage production.

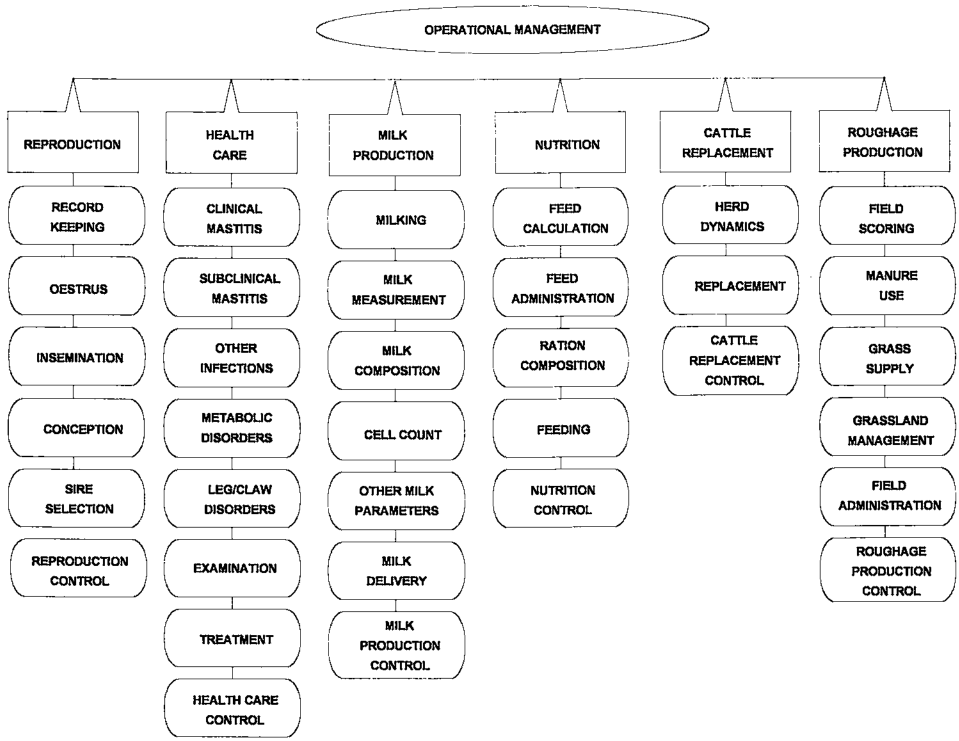

Figure 2.1 System decomposition.

2.2.2 Eliciting subjective knowledge

In the current research Delphi was confined to identifying which information needs can be supported by IT applications. The Delphi technique is an iterative instrument that is used for systematically eliciting and aggregating human judgements when experimental or observational data are not available (Linestone and Turoff, 1975). The procedure was characterised by: 1) the use of a formal questionnaire; 2) anonymous personal answers; 3) determination of a statistical group answer; 4) sharing information of the participants and 5) repetition of the investigation.

In the first part of the questionnaire the experts had to rate 1) the current status of farm performance and 2) the opportunities to improve farm performance within the next 10 years (which is the economic impact as a result of improved technical parameters). An extensive description of an average Dutch reference farm was provided. It was stressed that initially no IT applications were available on the reference farm. The experts had to divide 100 points among the 6 functions incorporated in the information model. With the two assignments the relative importance of each function on the economic results was quantified. Then, a further distinction was made between the associated processes within a function. In total, 2*(1+6)=14 different sets were evaluated by 100 points for each set; 2 time perspectives (current and potential performance); 1 set of functions and 6 sets of associated processes. After the identification of information needs, the experts had to score which processes would be supported by five IT applications. These applications evaluated were: 1) an automated concentrate feeder; 2) activity measurement; 3) milk production measurement; 4) milk temperature measurement and 5) electrical conductivity of quarter milk. The experts had to divide 100 points among the 35 processes per application, representing the relative improvement expressed in economic terms.

2.2.3 Data analysis

In this study, data from an expert panel were obtained through a written two-round Delphi survey. In the first stage, a group of 25 experts working in dairy IT agribusiness were approached to participate, of 19 whom completed the follow-up. The experts were asked to motivate their numerical answers. In the second Delphi round, the participating experts were resurveyed for re-estimating their personal numerical answers with the help of the statistical group values evaluated from the first investigation (means and ranges). Motivations for relatively higher and lower judgements were added to the numerical answers. The second questionnaire was aimed at either achieving a consensus or clarifying those aspects about which there was most dissension.

The analyses were performed on the basis of the original scores as well as ranks. In order to test significant differences between rank sums, Friedman's two-way analysis for block designs was performed for a main-effects analysis of variance. In this test, direct comparisons between experts were not made and no comparisons could be made between processes in different functions. In order to translate the scores of the processes into the results of the information model as a whole, the individual scores of the processes were multiplied by the overall scores of the corresponding functions per expert. The multiplication explicitly assumed linearity of the scores obtained. In addition, the overall scores were adjusted for the expected values. Negative scores occurred if the actual score was lower than expected (which assumed an indifference of the importance of the processes). The Mann-Whitney test (or Wilcoxon test) for unpaired measurements was applied in order to test statistical difference between current and potential performance per process. The evolution of the degree of agreement among the experts, that is the convergence of ratings on the ordinal scales, was measured approximately by the proportions of the ratings within 2.5, 5 and 10 points of the median and the average absolute difference between ratings and medians (Larréché and Montgomery, 1977). A cross-validation was used to investigate the possible impact of the group composition on the results. The sample in the second round was split up into two subsamples of 9 and 10 participating experts in a random fashion. For each subsample, the median ratings were computed and compared with those of the original overall sample.

2.3 Results

2.3.1 Identifying information needs

Some descriptive statistics obtained from the final Delphi questionnaire identifying information needs are summarised in Table 2.1. The importance of the functions included in the information model are described for both time perspectives for the reference farm: potential and current performance. In general, the initial and final ratings were given in multiples of 5 on the 0 to 100 scales. On the scale used from 0 to 100, the absolute ratings ranged from 0 to 70. The interquartile range was considerably narrower with 5 and 30 points. Ranks were computed in a descending order within experts (highest score rank one, second highest score rank two and so on).

Table 2.1 Farm functions evaluated in the information model.

	Potential performance				Current performance			
	Rank sum	Quartiles			Rank sum	Quartiles		
		25%	50%	75%		25%	50%	75%
1 Roughage production	46	20	25	30	68.5	10	17.5	20
2 Nutrition	47	18	20	30	38.5	20	20	25
3 Health care	62	10	20	25	72.5	10	15	20
4 Production	72	10	15	20	55	11	20	30
5 Reproduction	80.5	5	10	15	68.5	10	15	25
6 Cattle replacement	91.5	5	10	12	96	5	10	10
	+ -----				+ -----			
	399				399			

The overall rank sum of the panel (19 experts) was equal to 19*(1+2+...+6)=399 for the functions in each of the two independently evaluated time perspectives. With a rank sum of 46, meaning an average rank per expert of 46/19=2.42, roughage production was considered the function with the highest potential for improvement. The hypothesis of no differences between functions (α=0.05) for both time perspectives was rejected. Subsequently, multiple comparisons were executed for comparing individual functions. Any two functions whose rank sums were more than 15.7 and 15.2 points apart could be considered unequal ($t_{0.95}$), for the ratings of the potential and current performance respectively. According to this test, only nutrition was not significantly different from the function with the lowest rank sum (roughage production) in case of the potential performance. Yet, nutrition and health care were not different from each other. The following combinations were also different: health care with reproduction; health care with cattle replacement and production with cattle replacement. Comparison of the individual rank sums showed that the current performance of nutrition and cattle replacement were significantly different from all functions included. Moreover, health care and production were different from each other. Other differences between functions were not statistically significant.

A main-effects analysis of variance on ranks for the processes included per function rejected the null hypothesis in all cases. This means that the processes within a function were statistically not the same. Similar to the previous analysis it was tested whether the rank sums of processes in different functions could be considered unequal. The overall rank sum for the two independently evaluated time perspectives was equal to 19*(1+2+...+35)=11970. Numerous processes were scored statistically different from each other. Ration composition, oestrus, milking, feeding and clinical mastitis were regarded as most important with respect to the current performance (sum ranks were 140, 148.5, 177.5, 182.5 and 216 respectively). Since this study focused on potential processes, only these components of the information model were analysed further. Grassland management was considered the process with the highest potential for improvement (rank sum 172). Eleven other processes were not statistically different from grassland management. The Mann-Whitney test (two-tailed) for these twelve processes pointed out that the scores in case of potential performance of health care control and nutrition control increased in comparison with the current performance at a significance level of α=0.05.

In the course of the Delphi process, the experts re-evaluated the ratings on the functions and processes in the information model. In the second round the proportion of the ratings that was within the interval [median-2.5, median+2.5] increased by 0.01 (Table 2.3). The trivially increased proportions and declined average absolute difference between ratings and medians indicated that the experts were rather persistent in their opinions. Little agreement was sought among the experts, a better overall consensus was not likely to be achieved by conducting more rounds.

Table 2.2 Farm processes evaluated in the information model.

	Potential performance				Current performance			
	Rank sum	Quartiles			Rank sum	Quartiles		
		25%	50%	75%		25%	50%	75%
1 Grassland management	172	22	142	522	262	-128	55	213
2 Health care control	193	-68	137	242	390.5	-158	-108	-8
Manure application	193	-28	222	472	242.5	-58	52	222
4 Nutrition control	193.5	-33	167	417	352.5	-33	117	267
5 Feed calculation	197	42	117	267	237	-108	67	267
6 Feeding	209	-33	117	417	182.5	-33	117	267
7 Ration composition	218.5	-33	117	467	140	107	242	567
8 Subclinical mastitis	226.5	-58	42	192	310.5	-158	-43	92
9 Milk production control	240.5	-38	62	162	327.5	-88	-38	62
10 Oestrus	241	-153	82	322	148.5	22	222	522
11 Clinical mastitis	248	-158	92	192	216	-58	92	192
12 Field administration	248.5	-78	22	282	325.5	-178	-68	122
13 - 35 Other processes; Total:	9389.5				8835			
	+ ----				+ ----			
	11970				11970			

Table 2.3 Analysis of Delphi round effect.

	Delphi round	
	I	II
Proportion of ratings within 2.5 points of the median	0.31	0.32
Proportion of ratings within 5 points of the median	0.62	0.64
Proportion of ratings within 10 points of the median	0.85	0.86
Average absolute difference between ratings and medians	7.17	6.77

In addition, the absolute median difference was calculated by comparing the subsample medians with the total medians per function, process and time perspective evaluated. The final median ratings would be somewhat different if only a subset of the group of experts had participated (Table 2.4). However, the analysis indicated that these differences are relatively small, as suggested by a high percentage of medians within a narrow range and the low value of the average absolute median difference. Therefore the medians obtained were rather insensitive to the size of the group of experts.

Table 2.4 Analysis of sample size effect.

	Subsample	
	I	II
Percentage of medians within 2.5 points of the corresponding total medians	0.73	0.84
Percentage of medians within 5 points of the corresponding total medians	0.95	0.96
Percentage of medians within 10 points of the corresponding total medians	0.99	1.00
Average absolute median difference	1.81	1.55

2.3.2 Support by information technology

The results of the second part of the questionnaire, identifying the possible support by the IT applications under research, are summarised in Table 2.5 (Delphi I and II). According to the panel, the major benefits of an automated concentrate feeder would be obtained for the processes feeding, nutrition control, ration composition and feed calculation with relative benefits of 31%, 17%, 13% and 12% respectively in Delphi II.

Table 2.5 Relative potential improvements per application on the farm processes for the first (I) and second (II) Delphi round.

	ACF		AM		MPM		MTM		ECQM	
	I	II	I	II	I	II	I	II	I	II
Oestrus	3	4	52	50	5	5	24	23	2	3
Reproduction control	0	0	16	15	3	1	3	3	0	0
Clinical mastitis	1	1	1	1	6	7	22	21	25	30
Subclinical mastitis	0	0	0	0	5	4	7	6	41	35
Other infections	1	1	1	1	5	4	18	17	1	1
Metabolic disorders	4	6	1	3	8	8	4	4	2	1
Leg/claw disorders	2	4	11	11	6	5	2	2	0	0
Health care control	3	5	3	4	6	7	20	23	18	16
Milk production control	3	4	0	0	27	29	0	0	0	0
Feed calculation	11	12	0	0	3	6	0	0	0	0
Ration composition	16	13	0	0	5	7	0	0	0	0
Feeding	31	31	0	0	6	4	0	0	0	0
Nutrition control	21	17	0	0	6	8	0	0	0	0
Other processes; Total:	4	2	15	15	9	5	0	1	11	14
	+ --	+ --	+ --	+ --	+ --	+ --	+ --	+ --	+ --	+ --
	100	100	100	100	100	100	100	100	100	100

Activity measurement is expected to support mainly the processes oestrus, reproduction control and leg/claw disorders. Milk production measurement supports the control of milk production. Milk temperature measurement supports oestrus, health care control and clinical mastitis, while electrical conductivity of quarter milk supports the control of clinical as well as subclinical mastitis and health care. (All above 10% of total expected benefits per application.) These processes were also considered to be processes with a relatively higher importance with respect to the potential benefits (Table 2.2). The difference between the scores in Delphi I and II ranged from 0 to 6 points.

2.4 Discussion and conclusion

In this paper information needs and the way in which these information needs can be supported by IT applications on dairy farms were identified. The results obtained from the expert panel showed that the decompositional approach was effective to elicit subjective knowledge. Although the allocation of associated processes to the functions was to some extent arbitrary and the processes were not completely independent of each other, the methodology could be used to evaluate the expected impact of IT applications on the processes necessary for an economic evaluation. When evaluating an automated concentrate feeder, processes related to the function of nutrition will be important. In case of activity measurement and electrical conductivity of quarter milk the evaluation should include at least the function reproduction and health care. Milk temperature measurement will support two functions, namely reproduction and health care, while milk production measurement supports a wide range of processes in the different functions. In a follow-up study the potential economic benefits as a result of an improvement in the important processes identified will be derived, which is necessary to develop an economic model to optimise investment decisions with respect to IT applications for individual farms.

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3 POTENTIAL ECONOMIC BENEFITS FROM CHANGES IN MANAGEMENT VIA INFORMATION TECHNOLOGY APPLICATIONS ON DUTCH DAIRY FARMS: A SIMULATION STUDY[1]

Abstract

Economic benefits of information technologies were assessed at farm level by means of a dynamic probabilistic simulation model. The model included biological performances with respect to oestrus detection and concentrate feeding. In this way, main benefits of activity meters, automated concentrate feeders and on-line automated parlour systems for recording of milk production and milk temperature could be estimated.

In comparison with the default situation, improvement in oestrus detection from 50% to 90% increased gross margin by Dfl. 1.28 per 100 kg fat and protein corrected milk (FPCM) per year under Dutch production conditions. This equals 8.0% of a farmer's typical net return to labour and management. Using an individual feeding system increased gross margin by Dfl. 0.77 per 100 kg FPCM per year and the net return to labour and management by 4.8%. Feeders increased the frequency of concentrate provision from 2 to 4 times a day. Moreover, a more accurate performance-related concentrate provision was achieved from total daily amount in portions of 1 kg to 0.1 kg. In addition feeders enabled the possibility of overcoming the limited concentrate intake for high-producing animals in the milking parlour in the beginning of the lactation. A more accurate milk production estimation increased gross margin and the net return to labour and management by Dfl. 0.17 per 100 kg FPCM and 1.1% respectively. In the latter case equilibrium feeding was compared with a feeding method in which concentrate supply was based on an standard deviation of 5% in the estimated energy requirements for milk production. The results of this study will be used to evaluate theoretically the economic viability of the investigated IT applications.

3.1 Introduction

Due to a rapid development of sensors, on-line recording and processing of data are becoming practically feasible on dairy farms (Doluschitz, 1990; Dado and Allen, 1993; Spahr, 1993 and

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1 Paper by Van Asseldonk, M.A.P.M., Jalvingh, A.W., Huirne, R.B.M. and Dijkhuizen, A.A., accepted for publication in *Livestock Production Science*.

Tomaszewski, 1993). For example, activity meters, milk temperature meters, milk production meters and automated concentrate feeders, which also enable performing production tasks, monitor performance on an individual cow basis. On the central farm computer the actual performance parameters are integrated and compared with the expected or target values of these parameters as to which corrective action can be undertaken. As a result, more timely and better information is becoming available. More effective and efficient production is possible due to improved managerial decisions (Silk, 1990).

Because of its close relationship with many production activities, the technical impacts of a particular information technology (IT) investment on the performance parameters and eventually on economic farm results are difficult to determine. The question whether an investment in a new IT application can be justified is difficult to assess (Dos Santos, 1991). This is even more evident if on-line data are collected by several IT applications to support various farm processes. As the costs of these systems are usually clear, the first step to solve this problem is to investigate the potential benefits of the systems. If the potential benefits outweigh the costs, then benefits should be investigated under practical conditions.

The objective of this paper was to estimate the potential economic benefits of activity meters, concentrate feeders and on-line automated parlour systems for recording of milk production and milk temperature. In order to obtain benefits resulting from different improved processes, and eventually to determine the differences between the investment alternatives, the analysis included the effects of improved oestrus detection and concentrate feeding. The potential benefits of the IT applications under consideration were based upon an existing dynamic probabilistic simulation model taking into account farm-specific characteristics (Jalvingh et al., 1993). However, for this study the existing model had to be expanded to estimate the potential benefits of automated concentrate feeders and milk production meters. After describing the general benefits of the applications under study and the approach applied to determine the potential benefits, the results are presented and discussed.

3.2 General benefits of IT applications

A low rate of oestrus detection is an important reason for considerable losses of farm income (Dijkhuizen et al., 1987 and Esslemont and Peeler, 1993). Oestrus detection can be supported by a number of IT applications. An increased activity and milk temperature combined with a decreased milk production and concentrate feed intake may all be associated reactions of oestrus (Schlünsen et al., 1987). An average Dutch dairy farm achieves an oestrus detection of 56% with a standard deviation of 7% and a calving interval of 390 days with a standard deviation of 13 days (Rougoor et al., 1997). According to De Mol et al. (1997), oestrus detection can be improved significantly by utilising IT applications, ranging from 83% to 94% depending on the application or combination of applications which were implemented. So, depending on which applications are implemented, oestrus detection may increase from approximately 50%-60% to ultimately 90%.

Implementing an automated concentrate feeder and an on-line milk production measurement accomplishes an automated yield-oriented feeding in which the concentrate intake can be optimised effectively. A suboptimal concentrate supply occurs if concentrates are fed under- or above-equilibrium feeding level (milk production at a constant body weight). An energy deficiency in comparison with the energy requirements to produce the amount of milk achieved at equilibrium feeding will partly be compensated for by mobilisation of body energy. In case of energy intake above the requirement for the equilibrium feeding level, additional energy will be used for additional milk production and for deposition of body tissue (Hulme et al., 1986). However, in both cases the utilisation of energy to produce milk is not as efficient as in case of equilibrium feeding.

An automated concentrate feeder provides a method of equilibrium feeding in which concentrates are supplied more accurately to meet the needs of individual cows, and to enable to increase in the feeding frequency. Traditionally, a system in which cows are fed concentrates in the milking parlour twice daily in portions of 0.5 to 1 kg, commonly resulting in a daily total amount of concentrate supply in multiples of 1 kg, is the most accurate method in The Netherlands. In practice, implementing an automated concentrate feeder enables cows to be fed concentrates in portions of 0.1 kg in approximately 4 (rewarded) portions per day (Rees and Rowlinson, 1985). Concentrate feeding outside the milking parlour enables the farmer to overcome the upper limit of concentrate intake as a result of the limited feeding time in the milking parlour. In the situation with concentrate feeding in the parlour (default situation), the upper limit of average concentrate consumption was 3 kg for heifers and 4 kg for cows per milking (Leaver, 1987).

In order to estimate lactation yields (e.g., necessary for breeding and culling purposes), monthly milk recording schemes are accurate enough, since deviation between estimated and actual lactation yield is approximately 2-3%. However this is not necessarily the case for operational management of concentrate feeding. Milk production has the largest day-to-day variation of traits used for calculating the energy requirements; the prediction of energy requirement for milk production explains almost 92% of the total variation in energy content. In contrast, fat content explains 7% (Svennersten-Sjaunja et al., 1997). Therefore, daily milk production measurement will increase the accuracy of the estimated energy necessary to realise an equilibrium feeding level in comparison with an energy estimation based on a monthly test scheme. Svennersten-Sjaunja et al. (1997) reviewed the day-to-day variation in milk production to be 6-8%. According to Ouweltjes (1997), variability in milk production is higher in the first month of lactation and thereafter gradually declines and is less variable for heifers than for cows. However, if variability was expressed in percentage of milk production, it would be fairly constant among and within lactations. Corrected for time between milking, lactation number and expected average daily production calculated per monthly period, standard deviation in daily production was 6.2% (Ouweltjes, 1997).

3.3 Materials and methods

3.3.1 Dynamic probabilistic simulation

Simulation is an appropriate method to determine potential benefits of IT applications that are related to operational activities. Simulating a specific farm, with and without the potential effects of one or more IT applications, provides a means to determine the impacts of the improvement in biological parameters (Verstegen et al., 1995) taking into account current status of farm performance (e.g., oestrus detection and average milk production per cow). Since the exact improvements achieved at a particular farm are unclear, simulation models can be applied for sensitivity analysis to gain insight into the potential range of benefits (Kleijnen, 1984). A dynamic probabilistic simulation model described by Jalvingh et al. (1993) was used as a basis to determine the technical and economic consequences of various biological variables and management strategies. The default prices and other parameters used are given in Table 3.1. The model was structured according to the Markov Chain technique in which the dynamics of a cow herd were described in terms of: 1) states animals can be in and 2) transitions probabilities between states (Hillier and Lieberman, 1990). Combining the number of animals per state with their performance records in the steady state (equilibrium), which is determined by the insemination and replacement strategy and biological variables (e.g., oestrus detection), enables calculation of technical and economic results for a herd. Transitions were made on a monthly basis and gross margin was defined per 100 kg of fat and protein corrected milk (FPCM) per year under a quota system. Costs of labour and housing were considered to be fixed costs and therefore not included in the model.

Table 3.1 Default price and production parameters used in the model.

Price parameters	
Milk fat (Dfl./kg)	8.00
Milk protein (Dfl./kg)	12.23
Base price of milk (Dfl./100 kg)	-4.00
Grass (Dfl./KVEM[1])	0.22
Roughages (Dfl./KVEM)	0.30
Concentrates (Dfl./KVEM)	0.35
Production parameters	
Oestrus detection (%)	50
Conception rate (%)	40
Milk (kg)	7500
Fat content (%)	4.42
Protein content (%)	3.44
Age at first calving (mo)	24
Mature live weight (kg)	650

1 VEM = Dutch Feed Unit: 1000 VEM = 6.9 MJ NE_L, 1 KVEM = 1000 VEM.

3.3.2 Implementing different levels of oestrus detection

In the dynamic probabilistic simulation model, the level of oestrus detection of the first insemination is incorporated into the variable describing the proportions of first inseminations for heifers and older cows (Van Arendonk, 1985). The proportion of first inseminations were recalculated to account for different oestrus detection levels (Table 3.2).

Besides different levels of oestrus detection, also levels of conception rate and milk production were incorporated into the sensitivity analysis, which estimated the effect of improved oestrus detection on gross margin. The economically optimal insemination decisions were used as insemination strategy for all sensitivity analyses (Jalvingh et al., 1993).

Table 3.2 Proportion of first inseminations for heifers and older cows (month after calving) for different levels of oestrus detection[1].

Oestrus	Month of insemination			
Detection (%)	2	3	4	5
Heifers				
50	31	33	19	17
60	38	38	15	9
70	44	40	12	4
80	50	40	8	2
90	57	39	4	0
Cows				
50	35	31	18	16
60	42	35	14	9
70	49	36	11	4
80	56	35	7	3
90	63	33	3	1

1 Based on Van Arendonk (1985).

3.3.3 Implementing under- and above-equilibrium feeding

The basic model by Jalvingh et al. (1993) was expanded in order to quantify the impacts of different feeding strategies, which differed in accuracy and frequency of concentrate supply. In this way, the potential benefits of an automated concentrate feeder and on-line milk production measurement could be accounted for. The composition of feed intake was on the basis of energy intake requirements, dry-matter intake capacity, feed quality and feeding strategy. Energy intake requirements covered maintenance, milk production, growth, pregnancy and mobilisation and deposition of body tissue. In determining dry-matter intake capacity, size and milk production of the cow and composition and physical form of the diet were considered. The ration was formulated in a way that, depending on the roughage quality which was fed ad libitum, concentrates were supplemented in order to meet the energy requirements, taking into account a substitution effect between roughage and concentrates. Concentrate intake was limited by the roughage requirements: the ration should include at least one third of the dry matter out of roughage. Since energy from concentrates was more expensive than energy from roughage, intake of roughage was maximised under the biological constraints. The ration in summer consisted of grass and concentrates and in winter of grass, silage and concentrates (Jalvingh et al., 1993).

In case of the default feeding strategy, the optimal concentrate and roughage intake was formulated to produce the (genetic) potential milk production at a predetermined course of body weight. Hence, the default feeding strategy was used as a synonym for equilibrium feeding although a body weight decrease was considered, which is common at an equilibrium feeding strategy. The average decrease in body weight was set at 25.0, 37.5 and 50.0 kg for first, second and later parities respectively and at 13.3 kg for each 1000 kg of extra milk above 7750 kg in case of equilibrium feeding. Concentrates were included in the diet by units of 0.1 kg of dry matter per day with a minimum daily intake of 0.5 kg during lactation. The necessary concentrate intake was recalculated at monthly intervals (Jalvingh et al., 1993).

The basic model was expanded in order to quantify the impacts of a second feeding strategy in which concentrates were included in the diet by units of 1.0 kg of dry matter per day, representing the traditional feeding strategy without the use of concentrate feeders. The minimum daily intake was set at 1.0 kg during lactation, at 0.5 kg at each milking representing concentrate feeding in the parlour (Rijpkema et al., 1990). The upper limit of average concentrate consumption was 3 kg for heifers and 4 kg for cows per milking (Leaver, 1987). Daily concentrate supply in units of 1 kg will cause an under- or oversupply of concentrates, while the upper limit of concentrate intake will cause an undersupply for high-producing animals in the beginning of the lactation. As a result of the suboptimal concentrate intake, net energy intake, milk production, milk composition and body weight will change. The extent of these changes are affected by factors such as forage quality, type and level of concentrate input, the level of milk production and milk composition (Leaver, 1987).

In case concentrate supply is below the equilibrium feeding level, the difference between maximum and average body weight reduction could be mobilised during the lactation. The maximum decrease in live weight during lactation has been made dependent on the relative production level, since better producing cows were expected to lose more weight at the beginning of the lactation than low producing cows. Maximum body weight reduction was set at 50 kg at a 7750 kg milk production and at 5.7 kg for each 1000 kg of extra milk (Hijink and Meijer, 1987). The conversion from body tissue into milk energy is considered to be 85%, while energy content per kilogram of weight of heifers and older cows was 2.7 KVEM (Dutch feed unit) and 3 KVEM, resulting in 2.295 KVEM and 2.55 KVEM per kilogram of mobilised body tissue energy respectively (Van Arendonk, 1985). If the maximum energy mobilisation is reached, milk production will be depressed by 2.3 kg per KVEM of lowered energy intake (Groen, 1988). In the model it is assumed that the mobilised energy is compensated for later on in the dry-off period by additional roughage intake, however the requirements for restorage of body energy is 10% higher (Van Es, 1987 and NRC, 1989) (Equation 3.1).

$$\Delta FPCM = -2.3 * (E_e - E_a) \qquad (E_e > E_a \text{ and } E_m = 0) \qquad \textbf{(3.1)}$$

Where: $\Delta FPCM$ = change in fat and protein corrected milk production (kg per day);
E_e = energy intake at equilibrium feeding level (KVEM per day);
E_a = actual energy intake (KVEM per day);
E_m = energy mobilisation of body energy (KVEM per day).

Responses of milk production to incremental increases in energy intake above maintenance are considered not to be constant. According to Hulme et al. (1986), milk production could increase to a maximum of 125% of the genetic potential milk production obtained at equilibrium feeding. In the model by Hijink and Meijer (1987) it was assumed that the first additional energy above-equilibrium feeding was 50% utilised for milk production and linearly declines. According to Broster and Thomas (1981), approximately 30% of the total energy above-equilibrium feeding would be utilised for milk production in the case of feeding

20% above-equilibrium requirements. The assumptions related to the effects on FPCM for the amount of concentrates fed in the current model are presented in Equation 3.2.

$$\Delta FPCM = 2.3 * (E_a - E_e) * (0.1 / (0.1 + 3 * (E_a - E_e) / E_e)) \qquad (E_e < E_a) \qquad \textbf{(3.2)}$$

In the hyperbolic function used, energy intake of, for example, 0%, 5%, 10% and 20% above the necessary energy requirements for milk production at equilibrium would result in 100%, 40%, 25% and 14% of energy to be used for milk production respectively. The extra deposition during the lactation was compensated for in the dry-off period by a similar amount of decreased roughage intake. Associated changes in requirements for maintenance as a result of body weight mobilisation or deposition following from Equations 3.1 and 3.2 are accounted for (Van Es, 1978).

Increasing the amount of concentrates, which are based on more readily fermentable energy sources available to the rumen microbes (Jackson et al., 1991), will increase protein content in relatively high-forage diets. In the experiment by Gordon (1984), a reduction in percentage of roughages from 73% to 65% in the diet increased protein content by 0.07 percentage points. Based on a literature review, De Haan et al. (1995) concluded that protein content increases by 0.005 percentage points, if the percentage of concentrates increases by one percentage point. The latter value was used in the current research (Equation 3.3). Fat content remains constant in relatively high-forage diets but may become depressed in high-concentrate diets (Sutton and Morant, 1989).

$$\Delta PROTEIN = 0.005 * (C_a - C_e) \qquad (E_e <> E_a) \qquad \textbf{(3.3)}$$

Where: ΔPROTEIN = change in protein content;

C_a = percentage of energy from concentrates in actual ration (%);

C_e = percentage of energy from concentrates at equilibrium feeding (%).

3.3.4 Implementing different feeding frequencies

In addition, out-of-parlour automated concentrate feeders enable an increased frequency of concentrate feeding in comparison with a system in which the provision of concentrates is inside the parlour. An increased frequency of concentrates can stabilise rumen fermentation patterns and, ultimately, may result in an improved efficiency of rumen fermentation affecting milk production, milk component, or body condition (Robinson, 1989). Different benefits are reported in the literature; Gibson (1984) reviewed that, on average, frequent feeding proportionately increased milk production by 0.027 and fat content by 0.073 compared with cows fed twice daily and only occurred if fat content was originally depressed. Protein content was unaffected by the frequency of feeding. In the experiment by Rees and Rowlinson (1985), who compared the effect of a concentrate feeder with that of parlour-fed cows, it was concluded that milk production, weight and body condition-score improved, though milk fat concentration decreased. Based on a literature review, De Haan et al. (1995) concluded that an increased feeding frequency from 2 to 6 times per day, fat and protein contents would increase per percentage point of concentrates in the ration by 0.005 and 0.0015 percentage points respectively. In the current model, it was considered that feeding frequency increased from 2 to 4 (rewarded) portions per day (Equations 3.4 and 3.5). Therefore the effect of increased feeding frequency on milk content was assumed to be approximately 50% of the reported effects by De Haan et al. (1995). If energy from concentrates was, for example, 30%, fat and protein contents would increase by 0.075 and 0.0225 percentage points.

$\Delta FAT = 0.0025 * C_a$ (Daily feeding frequency increased from 2 to 4) **(3.4)**

$\Delta PROTEIN = 0.00075 * C_a$ (Daily feeding frequency increased from 2 to 4) **(3.5)**

Where: ΔFAT = change in fat content.

3.4 Results

The simulated scenarios can be split into two major sections, namely improvement in the process of oestrus detection and improvement in feeding practices.

3.4.1 Default situation

Based on the assumptions made in the default situation (i.e., oestrus detection and conception rate of 50% and 40% respectively and equilibrium feeding), the model calculated a gross margin of Dfl. 53.14 per 100 kg FPCM per year (Table 3.3). Expressed per cow per year, gross margin was Dfl. 4028, of which feed costs and milk revenues were the main components with Dfl. 1653 and Dfl. 5670 respectively. In the simulated herd, the yearly corrected milk production was 7580 kg per cow, with fat and protein contents of 4.43% and 3.45% respectively. A concentrate intake of 1351 and roughage intake of 4504 resulted in a total energy intake of 5855 (all expressed in KVEM per cow per year). Furthermore, average calving interval turned out to be 394 days and annual replacement rate was 38.4%. For comparison, an average Dutch dairy farm achieves a yearly milk production of 7658 kg per cow, a calving interval of 390 days and an annual replacement rate of 34.3% (Rougoor et al., 1997).

Table 3.3 Technical and economic results in relation with oestrus detection when default parameters are used in contrast to results for alternative parameters.

	Default	Sensitivity analysis						
OD[1] (%)	50	90	-	90	-	90	-	90
CR[2] (%)	40	-	60	60	-	-	60	60
FPCM (kg)	7500	-	-	-	9000	9000	9000	9000
Gross margin (Dfl./100 kg FPCM)	53.14	54.42	54.24	54.76	53.68	54.70	54.59	55.05
Gross margin (Dfl./cow)	4028	4220	4170	4305	4880	5088	5034	5194
Feed costs (Dfl./cow)	1653	1683	1679	1719	1931	1968	1960	2007
Milk revenues (Dfl./cow)	5670	5775	5736	5882	6801	6929	6880	7060
Milk production (kg FPCM/cow)	7580	7753	7688	7862	9091	9303	9222	9437
Fat content (%)	4.43	4.41	4.42	4.40	4.43	4.41	4.42	4.40
Protein content (%)	3.45	3.43	3.44	3.42	3.45	3.43	3.44	3.42
Feed intake (KVEM/cow)[3]	5855	5966	5949	6031	6653	6780	6750	6855
Concentrate intake (KVEM/cow)	1351	1395	1375	1425	2115	2185	2156	2231
Roughage intake (KVEM/cow)	4504	4570	4574	4606	4538	4594	4593	4624
Calving interval (days)	394	375	383	362	394	375	383	362
Replacement rate (%)	38.4	24.8	25.5	21.4	38.4	24.8	25.5	21.4

1 OD = oestrus detection.
2 CR = conception rate.
3 VEM = Dutch Feed Unit: 1000 VEM = 6.9 MJ NE_L.

3.4.2 Improvement in the process of oestrus detection

If a farm with no IT applications implemented one or more IT applications, gross margin would increase by Dfl 1.28 per 100 kg FPCM (54.42 versus 53.14), under the assumption that oestrus detection improved from 50% to a level of 90%. An equal improvement while conception rate was 60%, resulted in an additional increase of Dfl. 0.52 only. In case of a higher-producing herd (FPCM = 9000 kg) the previously mentioned effects were Dfl. 1.02 and Dfl. 0.46. Additional calculations clearly demonstrated that oestrus detection did not have a linear effect on gross margin (Figure 3.1).

Changes in conception rate (CR) or milk production (FPCM) or both had an important effect on gross margin and the additional benefits resulting from an improved oestrus detection decreased.

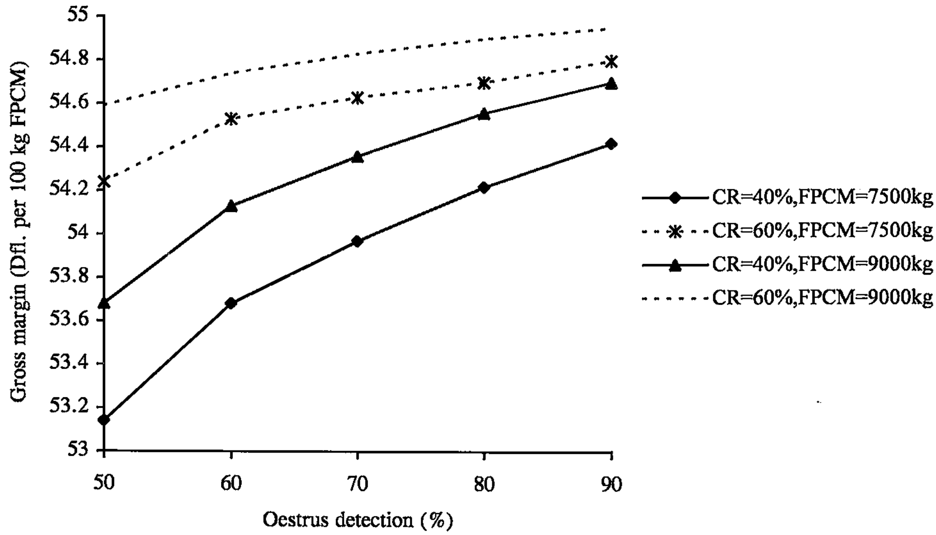

Figure 3.1 Effect of oestrus detection on gross margin.

3.4.3 Improvement in feeding practices

The effect of changing concentrates supply is presented in Table 3.4. A decreased concentrate supply for milk production of 5% resulted in a concentrate intake of 1173 KVEM, which is 13% less than the default situation (equilibrium feeding). As a result of the substitution of concentrates for roughage, roughage intake increased to 4631 KVEM and total feed intake decreased by 41 KVEM (including additional roughage intake in the dry-off period). Total feed intake during lactation decreased by 76 KVEM resulting in a drop in milk production of 173 kg. Gross margin decreased by Dfl. 0.33 per year per 100 kg FPCM. Increasing concentrate supply by 5% for milk production, feed intake increased by 117 KVEM (+178 KVEM concentrates and -61 KVEM roughage). Milk production increased by 116 kg, while gross margin decreased by Dfl. 0.11 per year per 100 kg FPCM. As expected from the assumptions in the model, the relationship between concentrate supply and gross margin was not linear. Gross margin increased in comparison with a changed concentrate feeding accuracy of -5% and 5% by Dfl. 0.46 and Dfl 0.12 respectively for the situation where milk production was 9000 kg.

Table 3.4 Technical and economic results in relation with the accuracy of the estimation of necessary energy for milk production when default parameters are used in contrast to results for alternative parameters.

	Default	Sensitivity analysis								
FPCM (kg)	7500	-	-	-	-	9000	9000	9000	9000	9000
Concentrate feeding accuracy (%)[1]	100	95	90	105	110	100	95	90	105	110
Gross margin (Dfl./100 kg FPCM)	53.14	52.81	51.93	53.03	52.85	53.68	53.22	52.34	53.56	53.37
Gross margin (Dfl./cow)	4028	3912	3702	4081	4077	4880	4710	4469	4909	4892
Feed costs (Dfl./cow)	1653	1625	1610	1700	1731	1931	1903	1891	1974	2008
Milk revenues (Dfl./cow)	5670	5526	5301	5770	5797	6801	6602	6349	6872	6890
Milk production (kg FPCM/cow)	7580	7407	7130	7696	7714	9091	8851	8537	9164	9167
Fat content (%)	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.44
Protein content (%)	3.45	3.43	3.41	3.46	3.47	3.45	3.43	3.41	3.46	3.47
Feed intake (KVEM/cow)[2]	5855	5804	5808	5972	6027	6653	6618	6646	6742	6800
Concentrate intake (KVEM/cow)	1351	1173	993	1529	1709	2115	1897	1680	2333	2549
Roughage intake (KVEM/cow)	4504	4631	4815	4443	4318	4538	4721	4966	4410	4251

1 Concentrate feeding accuracy = percentage of necessary energy for milk production in percent of equilibrium feeding level.
2 VEM = Dutch Feed Unit: 1000 VEM = 6.9 MJ NE_L.

To determine the effect of feeding method and feeding frequency, different alternatives were simulated. The results (Table 3.5) show that a more frequent feeding of concentrates improved fat and protein contents and ultimately gross margin considerably. A deviation in concentrate provision in comparison with the equilibrium feeding level had a limited effect (daily amount in portions of 0.1 kg versus 1 kg of concentrates). Concentrate feeding below the equilibrium was partly compensated for by less expensive roughages and above-equilibrium feeding resulted in an increased protein content. However, concentrate intake decreased, in particular in the higher-producing herd, because the upper limit of concentrate intake for heifers and dairy cows was set at 6 and 8 kg respectively. In total, a more frequent and accurate performance-related concentrate provision by means of an individual feeding system increased gross margin per 100 kg of milk from Dfl. 53.12 (total amount of concentrate is supplied in multiples of 1 kg) to Dfl. 53.89 for cows with an average milk production of 7500 kg. In case of a higher-producing herd this was from Dfl. 53.23 to Dfl. 54.70 per 100 kg of milk.

Table 3.5 Technical and economic results in relation with feeding method and feeding frequency when default parameters are used in contrast to results for alternative parameters.

	Default	Sensitivity analysis				
FM (kg)[1]	0.1	1[3]	-	-	1	-
Feeding frequency[2]	2	-	4	-	-	4
FPCM (kg)	7500	-	-	9000	9000	9000
Gross margin (Dfl./100 kg FPCM)	53.14	53.12	53.89	53.68	53.23	54.70
Gross margin (Dfl./cow)	4028	4027	4085	4880	4724	4973
Feed costs (Dfl./cow)	1653	1653	1653	1931	1913	1931
Milk revenues (Dfl./cow)	5670	5670	5727	6801	6626	6893
Milk production (kg FPCM/cow)	7580	7581	7580	9091	8875	9091
Fat content (%)	4.43	4.43	4.50	4.43	4.44	4.52
Protein content (%)	3.45	3.44	3.46	3.45	3.43	3.47
Feed intake (KVEM/cow)[4]	5855	5853	5855	6653	6677	6653
Concentrate intake (KVEM/cow)	1351	1338	1351	2115	1888	2115
Roughage intake (KVEM/cow)	4504	4514	4504	4538	4789	4538

1 FM = feeding method: portions of 0.1 or 1 kg concentrates.
2 Feeding frequency of concentrates: 2 or 4 times per day.
3 Representing traditional feeding with daily upper limit of concentrate intake for heifers and dairy cows of 6 and 8 kg respectively.
4 VEM = Dutch Feed Unit: 1000 VEM = 6.9 MJ NE_L.

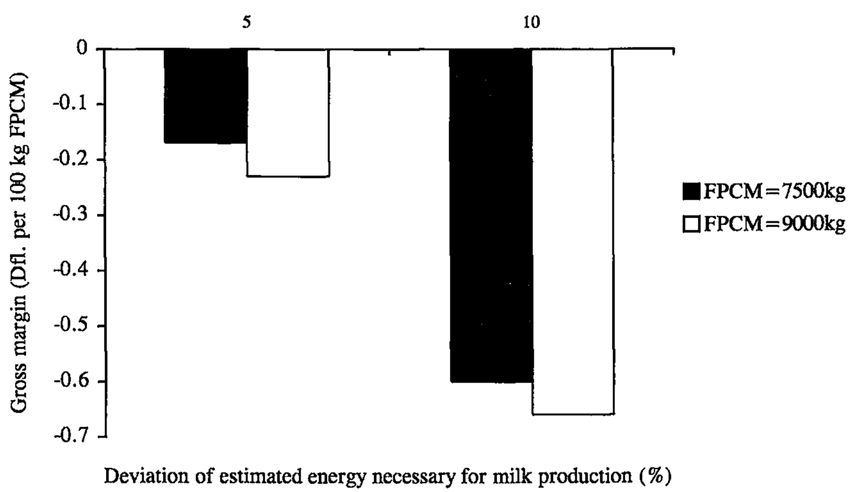

Figure 3.2 Effect of deviation in the estimated energy for production on gross margin.

Under the assumption of normality of daily deviations in milk production (Svennersten-Sjaunja et al., 1997), the effect of an increased milk recording frequency was estimated. The average deviations as a result of inaccurate monthly milk recording in comparison with a daily recording are depicted in Figure 3.2. In case of a standard deviation of 5%, the effect of improved milk production measurement will be Dfl. 0.17 per 100 kg FPCM.

3.5 Discussion and conclusion

Determining benefits of IT applications which improve specific biological parameters by simulation models enables a flexible evaluation with regard to the expected effect of the implemented IT applications and status of current farm performance. In this study the potential benefits of activity measurement, automated concentrate feeding systems and on-line automated parlour systems for recording of milk production and milk temperature were evaluated as to the aspects of oestrus detection and concentrate feeding. Benefits were determined, taking into account farm performance, conception rate and milk production level in case of oestrus detection and milk production level in case of concentrate feeding. In comparison with the default situation, an improvement in oestrus detection of 90% increased gross margin by Dfl. 1.28 per year per 100 kg FPCM. For a typical Dutch farm with a net return to labour and management per year per 100 kg FPCM of Dfl 16, improvement equals 8.0%. A more frequent and accurate performance-related concentrate supply by means of an individual and automated concentrate feeder increased gross margin by Dfl. 0.77 per year per 100 kg FPCM and net return by 4.8%. Additionally, a more accurate milk production estimation (equilibrium feeding versus average 5% under- and overestimation of necessary energy for milk production) increased gross margin and net return by Dfl. 0.17 per year per 100 kg FPCM and 1.1% respectively. The estimated effects of improved oestrus detection were obtained under an optimal insemination strategy, while the traditional feeding system considered was already an accurate method. Considering a sub-optimal insemination strategy and a more inaccurate feeding method in the default situation would therefore improve the potential effects of the IT application(s).

The estimated effects were obtained by additional assumptions of the original model (Jalvingh et al., 1993) with respect to 1) the effect of changed energy intake on milk production and composition and 2) the effect of increased feeding frequency on milk production and composition. An under- and overestimation of energy necessary for milk production of 10% resulted in a changed concentrate intake by -26% and 26%, while milk production changed by -6% and 2% in comparison with equilibrium feeding. In the model by De Haan et al. (1995), changes in concentrate intake by -25% and 25% resulted in changes in milk production of -6% and 5%. An additional sensitivity analyses estimated a decreased milk production of 5% if the maximum body weight reduction was increased by 10 kg at 10%

under-equilibrium feeding, while gross margin was Dfl. 52.51. In comparison with the default maximum body weight reduction, the estimated effect of 10% under-equilibrium feeding on gross margin was approximately 50%, emphasising the importance of this variable. The lower milk production increase in the current model in comparison with De Haan et al. (1995) was because of the assumptions relating to the percentage of energy utilised above-equilibrium feeding. However, the estimated effects on gross margin with the default hyperbolic utilisation function were small and therefore an increment of the percentage of energy utilised above-equilibrium feeding for milk production will not affect gross margin dramatically.

It was assumed that in the situation without a concentrate feeder (conventional feeding system) cows were fed concentrates in the milking parlour 2 times per day. An additional feeding period out-of-parlour can be necessary in some cases for high-producing cows in order to meet the requirements. Clearly, the effects of an increased feeding frequency after implementing a concentrate feeder will be smaller for these cases. It is also evident that the effects reported are strongly influenced by the relations between costs and quality of concentrates and roughage. Implementing a concentrate feeder which is equipped to provide two or more types of concentrates will automate the possibility of differentiating in energy and protein content of the concentrate supplied within the stages of the lactation. This will effect price of concentrate used, milk production and milk content and eventually gross margin. Since this is also possible at farms without concentrate feeders the effects were not incorporated into this study.

The accuracy of daily or monthly estimation of energy necessary for milk production are independent (Svennersten-Sjaunja et al., 1997). In this study, the estimated effect of increased accuracy of milk production estimation was obtained by aggregating simulation results of constant under- or overestimation of energy requirements during the whole lactation. The difference between both methods was limited in the current model, which assumed no correlation in the effect of above-equilibrium feeding between lactation month and milk production. The difference between maximum body weight and average body weight reduction was small; under-equilibrium feeding resulted almost directly in a decrease in milk production and gross margin. Calculation of rations was on a monthly basis although a more frequent adjustment can be achieved with on-line milk production measurement. However, frequent adjustments in daily ration (amounts and composition) might cause a daily change in milk production beyond the one due to the normal shape of the lactation curve (Coppock et al, 1981).

Furthermore, generalisation of the estimated effects should be done with care since the simulation model represented an average Dutch dairy farm. Effects will differ in situations without production restrictions (non-quota situation) and in situations with different management strategies, for example larger dairy herd.

The results of this study can be used to evaluate theoretically the economic viability of IT applications and IT combinations. Therefore, investment and operation costs as well as potential improvement in oestrus detection should be added to the economic benefits assessed. According to De Mol et al. (1997), oestrus detection can be improved to approximately 90% by utilising activity measurement. Utilising information from milk production or milk temperature measurement will improve oestrus detection to a lesser extent than activity measurement. Reviewing the annual costs incurred of the investment in IT applications and IT combinations, an investment in automated concentrate feeders or a simultaneous investment in automated concentrate feeders and activity measurement appears to be economically profitable. Empirical research is recommended to quantify technical and economic effects at farm level for the potential applications under research.

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4 QUANTIFYING CHARACTERISTICS OF INFORMATION TECHNOLOGY APPLICATIONS BASED ON EXPERT KNOWLEDGE FOR DETECTION OF OESTRUS AND MASTITIS IN DAIRY COWS[1]

Abstract

Expert opinions were elicited about the characteristics at the commercial farm level of on-line information technology (IT) applications that are able to detect oestrus and mastitis in dairy cows. Since actual data of these characteristics are not available, judgmental data provided an alternative means to interpret the implications of research results for commercial farms. Applications included were activity measurement, milk-production measurement, electrical conductivity of quarter milk, automated concentrate feeders and milk-temperature measurement. Sensitivity and specificity of detection of oestrus (OD), clinical mastitis (CMD) and subclinical mastitis (SCMD) were ascertained. Conjoint analysis was used to assess the effect of each application indirectly by decomposing the evaluated overall detection characteristics of a predefined number of IT combinations.

The individual experts were consistent in evaluating the alternatives, but there was variation in estimates among experts. Estimations of the main effects of the applications and important first-order interactions were incorporated into the detection models. Implementation of all applications under study resulted in overall sensitivities and specificities of 82% and 90%, 73% and 87%, 58% and 82% for OD, CMD and SCMD, respectively. Further research is necessary that should take into account costs and benefits of the different detection systems based on the current status of farm performance (e.g. OD and mastitis incidence) and farm structure (e.g., farm size and parlour layout). Research to do this is currently in progress.

4.1 Introduction

Failures of oestrus detection (OD), clinical mastitis detection (CMD) and subclinical mastitis detection (SCMD) are important reasons for considerable losses of income in dairy farming (Esslemont and Peeler, 1993; Jalvingh et al., 1993; Houben et al., 1994). Recent advances in information technology (IT), such as on-line data from activity meters (AM), milk-production

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measurements (MPM), electrical conductivity of quarter milk (ECQM), automated concentrate feeders (ACF) and milk-temperature measurements (MTM), have increased the opportunities for effective management support. Multi-factorial analysis is becoming feasible, in which several IT applications are implemented at the same time to support OD, CMD and SCMD.

The literature mainly documents the technical impact of a specific IT application on an isolated farm process. Two main research fields of on-line decision support on dairy farms can be identified. On the one hand, it was investigated whether OD could be supported with the help of AM, as reported by Kiddy (1976), Pennington et al. (1986); Peter and Bosu (1986); Liu and Spahr (1993); and Redden et al. (1993) or MTM as reported by Maatje and Rossing (1976) and Fordham et al. (1988). On the other hand, research focused on supporting CMD and SCMD with the help of ECQM; Nielen et al. (1992) provided an extensive review of this aspect. Multi-factorial approaches in order to support OD by two or more IT applications were reported by Maatje et al. (1987); Schlünsen et al. (1987); Schofield et al. (1991); Lehrer et al. (1992); Scholten et al. (1995) and De Mol et al. (1997) and for the case of SCMD and CMD by Maatje et al. (1992); Nielen et al. (1995a, 1995b) and De Mol et al. (1997). In most studies, the detection characteristics were not decomposed into the individual effects in the multi-factorial approach and were obtained from experimental research stations and so do not necessarily reflect possible impacts on a commercial farm. Moreover, due to dynamic developments in sensor research and development and analysis techniques, improvement in detection characteristics is expected (outdating previous research). The necessary field experiments to determine the effects of a multi-factorial approach would be costly and take years to complete and would require continual updating.

If actual data are not available (and, therefore, analysis of objective data is not possible), additional information can be obtained from experts to provide a means to interpret the implications of research results for commercial farms (Figure 4.1). Experts, which have considerable experience with the information technology applications under research conditions, will have a good impression on how these systems will work on commercial farms taking into account management effects (i.e., farm-specific adjustments in the minimum values to signal significant changes and system failures as a result of non-optimal maintenance of the system). The objective of this study was to summarise present knowledge of the individual and combined effects of AM, MPM, ECQM, ACF and MTM on the sensitivities and specificities of OD, CMD and SCMD at the (commercial-) farm level by using an expert panel. The so-called "method of conjoint analysis" was used to elicit the opinions of experts. The concept of conjoint analysis is reviewed briefly and the results are described and discussed.

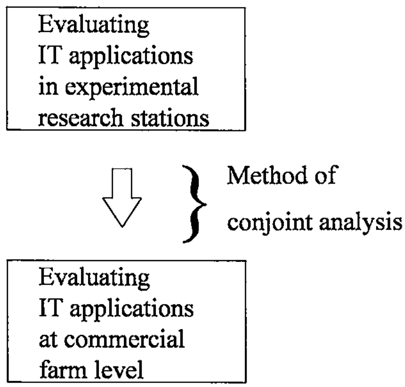

Figure 4.1 Schematic view of the evaluation procedure.

4.2 A conjoint analysis application to the evaluation of detection characteristics

4.2.1 Conjoint analysis design

Conjoint analysis was developed from the theoretical work of mathematical psychologists (Luce and Tukey, 1964) and is commonly used in marketing research (Cattin and Wittink, 1982) for measuring buyers' trade-offs among multi-attributed products and services. The trade-off or importance of each attribute is assessed indirectly by decomposing the overall preferences for several multi-attributed alternatives. The main advantage of the conjoint method is that the predictive performance outperforms the compositional method in which the respondents have to assess the values for the attribute levels directly (Huber et al., 1993).

In our study, conjoint measurement was used to quantify and predict the experts' overall judgement of a particular multi-factorial detection system on the basis of the underlying applications (called "attributes"). The experts' overall judgements on a set of predefined alternative detection systems (called "profiles") were broken down in order to determine the contribution (called "part-worths") of each application within the detection system (Green and Srinivasan, 1978). The two basic assumptions were that 1) the detection system could be described by a set of applications and 2) the overall judgement of the experts on that system were based on the underlying applications.

The applications (i.e., attributes), can be either implemented or not implemented on a farm (i.e., each application has two levels: 0 if not present and 1 if present in the profile). If the full-profile concept is used, all attributes are presented at some level in the description. All applications under study were estimated for the farm processes of OD and CMD which makes a total of $2^5 = 32$ profiles. In the case of SCMD only MPM, ECQM and MTM were studied which makes a total of $2^3 = 8$ profiles. Information related to activity and concentrate consumption was excluded since their additional support to detect subclinical mastitis is limited (Schlünsen et al., 1987). The evaluation of all possible profiles by the experts would be an extensive task, if possible at all. According to Addelmann (1962a) the number of evaluated profiles can be reduced (a fraction of all possible profiles) by using a orthogonal fractorial design in order to estimate a limited number of effects without correlation. The degrees of freedom available for the estimation of the error term is reduced in the fractorial design in comparison with the complete design while there is a minimum loss of accuracy. In Table 4.1 a layout of a segment of the conjoint questionnaire used is depicted in which the overall judgement for 16 profiles consisting of five attributes had to be assessed.

Table 4.1 Specific layout of a conjoint questionnaire. The overall judgements were based on the sensitivity and specificity at commercial farm level.

Profiles	Attributes[1]				
	AM	MPM	ECQM	ACF	MTM
1	0	0	0	0	0
2	0	0	0	1	1
3	0	0	1	0	1
4	0	0	1	1	0
5	0	1	0	0	1
6	0	1	0	1	0
7	0	1	1	0	0
8	0	1	1	1	1
9	1	0	0	0	1
10	1	0	0	1	0
11	1	0	1	0	0
12	1	0	1	1	1
13	1	1	0	0	0
14	1	1	0	1	1
15	1	1	1	0	1
16	1	1	1	1	0

[1] 0/1 = attribute not present (0) or present (1) in the profile.

Inherent to conjoint analysis, possible important interactions should be specified a priori; this is necessary to construct an orthogonal fractorial design in order to estimate the specific interaction. Clearly, interactions between the IT applications are not negligible since the combination of IT effects are smaller than expected based on the separate IT effects. For example, temperature and activity measured separately, detect approximately 70% of the cases of oestrus each (Maatje et al., 1987). If a main effect model comprised MTM and AM as explanatory variables with value of 70% each, a combined implementation would give a value of 140% (1*70 + 1*70). The applications described were used as independent dummy variables in the conjoint model with a value of 1 if the IT application was implemented and a value of 0 if not. However, analysing the two measurements in combination increases detection to approximately 90% (Maatje et al., 1987). Therefore, the basic "compromise design plans" of Addelman (1962b) were used, which permitted the estimation of main effects as well as all two-factor interactions (we assumed that higher-order interactions were negligible).

4.2.2 Experimental design

A computerised conjoint questionnaire was conducted among 18 experts, covering the different on-line sensor research groups in The Netherlands. The panel included respondents working at or associated with the School of Veterinary Medicine (n=5), the Institute for Agricultural and Environmental Engineering (n=3), dairy research station (n=2), experimental farms (n=2), milk equipment companies (n=2) and advisers (n=4) employed by feed or milk processing companies.

The knowledge of the experts of the detection characteristics was elicited per farm process (i.e., oestrus, clinical and subclinical mastitis). Sensitivity (the proportion of true positives that are detected by the system) as well as specificity (the proportion of true negatives that are correctly classified as negative) of the alternative detection systems had to be rated on a scale from 0 to 100. There is an inverse relationship between sensitivity and specificity and both are influenced by the threshold value defining the boundary between healthy and diseased animals (Thrusfield, 1995). The experts had to evaluate sensitivity and specificity in relation to the management actions (and their economics) undertaken after classification. For example, management actions in which treatment of false-positive cases is costly in comparison with the revenues of treatment of positive cases and the costs of non-treatment of false-negative cases, will result in a model with a lower sensitivity and a higher specificity. It was explained to the experts that the detection profiles of oestrus all included visual observation of the farmer, and that cows classified as being in oestrus (with or without on-line decision support) were inseminated. Frequently stripping of the suspected positive quarters of clinical mastitis at least one milking before clinical signs was considered to be the implemented therapy. Treatment with antibiotics during the lactation of cases classified as subclinical was not considered an option.

Following the procedure of Addelman (1962b), 16 profiles were evaluated for OD and CMD in order to estimate five main effects and all ten first-order interactions, and for SCMD a complete factorial design was used in order to estimate three main effects and all three first-order interactions (8 profiles). Visual observation of cows by the farmer was always assumed to be present in addition to IT applications in all profiles evaluated. The first profile, in which the situation without any IT applications was described (Table 4.1), enabled estimation of the visual oestrus detection by the farmer as assumed per expert. The no-IT profile for CMD and SCMD was not incorporated, because the profiles relating to clinical mastitis were evaluated on the detection characteristics of clinical mastitis cases at least one milking before the start of clinical symptoms, and because visual detection of subclinical mastitis is, by definition, impossible.

Three profiles for OD and CMD were added as hold-outs; these profiles were not used to estimate the models (Green and Srinivasan, 1978). The predicted validity of the non-hold-outs and the predictive validity of the hold-outs was quantified by Pearson's product moment correlation coefficient (interval-scaled data) and Kendall's τ rank correlation coefficient (hierarchically ranked data) to check the fit of each individual model (Siegel, 1956). Scores of the hold-out profiles were estimated using the individual's own model, and then compared with the actual scores given in the questionnaire (Horst et al., 1996) to test the predictive ability of the model and the consistency of the respondent (cross-validity). Pearson's correlation is based on actual numbers, while Kendall's correlation measures the order (ranks) of the observations. The differences in part-worths between the respondents was illustrated by the quartiles and two subsamples of the aggregated part-worths. In addition, an external validation was conducted in order to evaluate the differences in detection characteristics obtained from the most recent experimental results and the estimated farm level results obtained from the expert opinions.

Six models were estimated with sensitivity (SE) and specificity (SP) of OD, CMD and SCMD as independent variables (SE_{OD}, SP_{OD}, SE_{CMD}, SP_{CMD}, SE_{SCMD} and SP_{SCMD}). Regression analysis was used as the procedure analysis to estimate the regression coefficients of the constant (C) and the part-worths (β's) of the main effects and first-order interactions per expert (Cattin and Wittink, 1982). Conjoint analysis differs from almost all other regression methods in that it has the ability to be carried out at the individual level (disaggregate); for each respondent separate models were estimated (Hair et al., 1987). The individually estimated constant and part-worths were subsequently aggregated by determining the average of the constant and the part-worths for the group of respondents. Because the expertise was expected to vary among respondents, a question was included in which they could quantify personal impressions about their level of knowledge for each farm process on a scale ranging from 1 (low) to 5 (high). The impact of the knowledge levels was examined by comparing the unweighed results with the weighed results, meaning that in the latter case the result from a respondent with a level of 5 counts five times as much as that from a respondent with an indicated knowledge level of 1 (Horst et al., 1996). Detection characteristics of the individual IT applications can be derived from the models, by adding the corresponding part-worth of the main effect to the constant term. The part-worth of the first-order interaction must be included if a specific combination of IT applications is of interest.

4.3 Results

The fit for each respondent of the additive models which only included main effects, measured by Pearson's r and Kendall's τ was in general considerably lower than that of the interaction models which estimated the part worths of the main effects as well as one or more first-order interactions. On average, the correlation for the additive and complete first-order interactive model fitted with the non-hold-out profiles was 0.85 and 0.95 respectively. When the models were fitted with the forward selection procedure (SAS, 1988), the models incorporated different significant first-order interaction terms. In order to obtain estimated mean part-worths for the expert panel as a whole, identical models should be aggregated. In case of OD the first-order interactions AM*MPM, AM*MTM and MPM*MTM and for CMD and SCMD the interactions of MPM*ECQM, MPM*MTM and ECQM*MTM were included. The detection characteristics of electrical conductivity and concentrate consumption to support OD and the detection characteristics of activity and concentrate consumption to support CMD were incorporated with only main effects. The following final models were used (Equations 4.1 to 4.6):

$$SE_{OD} = C + \beta_1 AM + \beta_2 MPM + \beta_3 ECQM + \beta_4 ACF + \beta_5 MTM + \beta_6 AM{*}MPM + \beta_7 AM{*}MTM + \beta_8 MPM{*}MTM \quad (4.1)$$

$$SP_{OD} = C + \beta_1 AM + \beta_2 MPM + \beta_3 ECQM + \beta_4 ACF + \beta_5 MTM + \beta_6 AM{*}MPM + \beta_7 AM{*}MTM + \beta_8 MPM{*}MTM \quad (4.2)$$

$$SE_{CMD} = C + \beta_1 AM + \beta_2 MPM + \beta_3 ECQM + \beta_4 ACF + \beta_5 MTM + \beta_6 MPM{*}ECQM + \beta_7 MPM{*}MTM + \beta_8 ECQM{*}MTM \quad (4.3)$$

$$SP_{CMD} = C + \beta_1 AM + \beta_2 MPM + \beta_3 ECQM + \beta_4 ACF + \beta_5 MTM + \beta_6 MPM{*}ECQM + \beta_7 MPM{*}MTM + \beta_8 ECQM{*}MTM \quad (4.4)$$

$$SE_{SCMD} = C + \beta_1 MPM + \beta_2 ECQM + \beta_3 MTM + \beta_4 MPM{*}ECQM + \beta_5 MPM{*}MTM + \beta_6 ECQM{*}MTM \quad (4.5)$$

$$SP_{SCMD} = C + \beta_1 MPM + \beta_2 ECQM + \beta_3 MTM + \beta_4 MPM{*}ECQM + \beta_5 MPM{*}MTM + \beta_6 ECQM{*}MTM \quad (4.6)$$

Pearson's r and Kendall's τ obtained for each respondent indicated that the respondents were rather consistent in their evaluation. In Table 4.2 the average correlation is depicted. The predicted validity of the non-hold-outs and the predictive validity of the hold-outs was on average high (ranging from 0.66 to 0.96) and significant. The predictive performance of the specificity models was not as good as that of the sensitivity models.

Table 4.2 Validity of the models which estimated sensitivity (SE) and specificity (SP) at commercial farm level by the average Pearson's r and Kendall's τ.

		Oestrus detection		Clinical mastitis detection		Subclinical mastitis detection	
		SE	SP	SE	SP	SE	SP
non-hold-out profiles							
	Pearson's r	0.98	0.93	0.94	0.89	0.96	1
	Kendall's τ	0.92	0.79	0.80	0.73	0.91	0.95
hold-out profiles							
	Pearson's r	0.99	0.74	0.97	0.90	-	-
	Kendall's τ	0.97	0.66	0.95	0.90	-	-

4.3.1 Oestrus detection

The pooled weighed part-worths, obtained from aggregation of results of the individual respondents, indicated that in case of a single factorial detection system, AM was considered to be the most-important application with respect to the detection of oestrus: SE = 61 (C) + 15 ($ß_1$AM) = 76; SP = 88 followed by MPM and MTM. The estimated first-order interactions in case of a combination of two measurements were small. The dispersion of the estimated part-worths was expressed by the quartile ranges. The dispersion in the constant term, which had to be interpreted as the level of visual detection of oestrus by the farmer, was considerable with quartile ranges of 21% and 11% for sensitivity and specificity respectively. Based on the weighed part-worths of all respondents presented in Table 4.3 a complete multi-factorial implementation resulted in a sensitivity of 82% as calculated in the model: 61 (C) + 15 ($ß_1$AM) + 5 ($ß_2$MPM) + 0 ($ß_3$ECQM) + 1 ($ß_4$ACF) + 5 ($ß_5$MTM) -3 ($ß_6$AM*MPM) -2 ($ß_7$AM*MTM) + 0 ($ß_8$MPM*MTM). Specificity was 90%, the calculation was analogous to the previous one.

In order to illustrate the differences in part-worths between the respondents, the estimated individual part-worths were split into two subsamples. The classification was based on the estimated complete multi-factorial sensitivity (SE_{total} < 82% and $SE_{total} \geq$ 82%). The mean parth-worths were pooled unweighed. Comparison of the subsamples indicated that the level of visual detection of oestrus (C) had to be considered the most-important part-worth in explaining the differences. There was more consensus with respect to the other estimated part-worths of the main effects and first-order interactions. The impact of the knowledge levels was examined by comparing the weighed results of the whole expert panel with the unweighed results of the two subsamples (for example, weighed SE_{total} = 82 versus unweighed SE_{total} = (72*6+88*12)/18=84). The average absolute deviation between weighed and unweighed mean estimates was in general small.

Table 4.3 Estimated mean part-worths and quartiles for the oestrus detection model at commercial farm level with inclusion of the important first-order interactions (SE=sensitivity, SP=specificity).

	Weighed part-worths (N=18)						SE_{total}<82 n=6		SE_{total} ≥82 n=12	
	SE	Quartiles		SP	Quartiles		SE	SP	SE	SP
		Q_1	Q_3		Q_1	Q_3				
Constant	61	51	72	87	84	95	58	89	65	87
AM	15	10	20	1	-3	5	11	-2	16	2
MPM	5	1	8	1	0	1	4	2	5	1
ECQM	0	0	1	0	0	0	0	0	0	0
ACF	1	0	2	0	0	0	0	0	1	0
MTM	5	0	6	1	-1	3	1	0	6	1
AM*MPM	-3	-4	0	0	-1	0	-3	-1	-3	0
AM*MTM	-2	-2	0	0	-1	0	0	0	-3	-1
MPM*MTM	0	-1	1	0	0	1	1	-1	1	1
TOTAL	82			90			72	87	88	91

4.3.2 Clinical and subclinical mastitis detection

The estimated weighed mean part-worths describing the detection characteristics of mastitis indicated that ECQM was evaluated as the most-important application to support CMD (Table 4.4) and SCMD (Table 4.5).

Table 4.4 Estimated weighed mean part-worths and quartiles for the clinical mastitis detection model at commercial farm level with inclusion of the important first-order interactions (SE=sensitivity, SP=specificity).

	Weighed part-worths (N=18)						SE_{total}<73 n=6		SE_{total} ≥73 n=12	
	SE	Quartiles		SP	Quartiles		SE	SP	SE	SP
		Q_1	Q_3		Q_1	Q_3				
Constant	10	2	13	71	44	95	8	59	11	80
AM	5	0	9	1	0	3	4	2	6	1
MPM	16	5	25	4	-1	4	14	4	18	4
ECQM	44	24	66	8	-2	26	29	17	51	0
ACF	2	0	5	1	0	1	2	0	3	1
MTM	16	1	30	1	-2	5	9	3	22	0
MPM*ECQM	-8	-18	0	-1	-2	3	-10	-4	-6	1
MPM*MTM	-5	-11	0	1	-2	2	-3	2	-8	0
ECQM*MTM	-7	-13	0	1	-2	8	-3	-2	-10	4
TOTAL	73			87			50	81	87	91

According to the expert panel a single factorial implementation of ECQM would result in a sensitivity of 54% and 51% and a specificity of 79% and 80%, for CMD and SCMD respectively. The detection characteristics increased to 73% and 58% for sensitivity and 87% and 82% for specificity in case of a complete multi-factorial approach, mainly due to the applications MPM and MTM.

Subsequently, classification was based on the estimated complete multi-factorial sensitivity for both detection systems and the individual part-worths were pooled unweighed. The subsamples indicated that the results were rather heterogeneous with respect to the estimated part-worths. The average absolute deviation between weighed and unweighed mean estimates was for CMD and SCMD of the same magnitude as that for OD.

Table 4.5 Estimated weighed mean part-worths and quartiles for the subclinical mastitis detection model at commercial farm level with inclusion of the important first-order interactions.

	Weighed part-worths (N=18)						SE_{total}<58 n=7		SE_{total} ≥58 n=11	
	SE	Quartiles		SP	Quartiles		SE	SP	SE	SP
		Q_1	Q_3		Q_1	Q_3				
Constant	1	0	2	67	50	95	1	60	2	77
AM	14	4	18	-2	-2	4	12	-10	17	3
MPM	50	24	60	13	0	34	24	16	66	7
ECQM	15	1	20	0	0	5	6	1	25	-2
ACF	-8	-14	0	2	-3	0	-8	8	-10	-2
MTM	-5	-6	0	3	0	5	-2	6	-8	1
ECQM*MTM	- 9	-13	0	-1	-5	2	-3	-4	-15	3
TOTAL	58			82			30	77	77	87

4.3.3 External validation of the detection models

In this study conjoint analysis was used to elicit expert opinions with respect to the multi-factorial detection characteristics of on-line IT applications on dairy farms. With the weighed mean part-worths obtained it was possible to estimate the detection characteristics of all possible multi-factorial approaches. In Table 4.6 an external validation with the most recent results was conducted in order to evaluate the differences in multi-factorial detection characteristics obtained from the experimental results and the estimated farm level results obtained from the expert opinions. The detection characteristics reported were derived from experimental circumstances that will not always reflect the results obtained at farm level (for example exclusion of system errors in experimental circumstances).

The estimated sensitivity and specificity of OD was lower than the levels reported (De Mol et al., 1997 and Maatje and Rossing, 1976). However, in the reported studies cases were based on semi-weekly analysis and not on the basis of each milking. Since Maatje and Rossing (1976) documented the sensitivity of the individual effects of visual observation, MTM and AM, it was possible to compare these effects with the estimated part-worths (visual observation: 77% versus 61%; AM: 15% versus 15%; MTM: 15% versus 5% and AM*MTM: -10 versus -2). Due to an accurate and intensive three-time-daily visual observation 77% percent of the animals in oestrus were detected. According to the expert panel as a whole, this figure was 61% which is more in accordance with the average percentage of oestrus detection (56.4) on Dutch dairy farms (Rougoor et al., 1997). Other studies reported lower detection results for MTM (Fordham et al., 1988). The reported higher main effect MTM increased the interaction term MPM*MTM, since there were (more) non-additive detections to be expected.

The CMD values reported by De Mol et al. (1997) were based on cases at the time of mastitis observation and not on potential clinical mastitis cases at least one milking before clinical signs. A further decomposition than presented in Table 4.6 to validate the individual effects was not possible.

Table 4.6 Comparison of reported (r) experimental results and estimated (e) farm level results for multi-factorial detection characteristics (SE=sensitivity, SP=specificity).

	Information technology applications					SE		SP	
	AM	MPM	ECQM	ACF	MTM	r	e	r	e
Oestrus detection									
Maatje and Rossing, 1976	1[1]	1	0	0	1	98	81	NR[2]	90
De Mol. et al., 1997	1	0	0	0	0	91	76	95	88
De Mol. et al., 1997	1	1	1	1	1	94	82	95	90
Clinical mastitis detection									
Nielen et al., 1995b	0	1	1	0	1	76	66	92	85
De Mol. et al., 1997	0	0	1	0	0	50	54	76	79
De Mol. et al., 1997	1	1	1	1	1	96	73	100	87
Subclinical mastitis detection									
Nielen et al., 1995a	0	1	1	0	0	55	57	90	80
De Mol. et al., 1997	1	1	1	1	1	76	58	98	82

1 0/1 = attribute not present (0) or present (1) in the detection characteristics reported.
2 NR = not reported.

4.4 Discussion and conclusion

Since actual data of detection characteristics at the commercial farm level of on-line information technology (IT) applications are not available, expert opinions provided an alternative means to interpret the implications of research results for commercial farms. The individual experts themselves were consistent in evaluating the different multi-factorial alternatives with conjoint analysis. In general, and as could be expected, detection characteristics at farm level were lower than reported in experimental studies in research conditions. Analogous to empirical studies there was variation among the experts in estimating the detection characteristics. Although in some cases the first-order interactions were low in comparison with the associated main effects, incorporation of the (important) first-order interactions was essential in order to obtain consistent estimates. From the results of the two subgroups per farm process, a positive correlation between sensitivity and specificity could be detected, which indicated a difference in overall expectations. Inclusion of the personal impressions of the expert knowledge level to obtain weighed part-worths did not result in substantial differences in comparison with the unweighed part-worths. Moreover, it can be concluded from the subsamples that in the case of OD the level of visual detection of oestrus was considered to be the most-important factor to explain the differences between experts. Since the experts evaluated the applications for only one level of visual observation of oestrus detection in the current research, it was not possible to test the relation between the effectiveness of the applications and the level of visual observation within experts. Differences between expectations for CMD and SCMD originated from different expectations for several applications.

The potential benefits and the effects of the variation observed resulting from improved detection characteristics can be quantified by using simulation models. Jalvingh et al. (1993) reported that in case of a relative improvement of oestrus detection and conception rate by 10% and a shortening of average interval calving to first insemination by 6 days, gross margin per cow and calving interval would improve by Dfl. 83 and 7 days. The improvement in specificity, resulting in a reduction of false inseminations are limited. Potential benefits resulting from improved detection characteristics of mastitis are more difficult to determine. The expected effects of improved management due to an early detection of potential clinical mastitis cases according to Nielen et al. (1994) could be a reduction of clinical mastitis incidence, a better response rate to treatment, less lactation therapy with antibiotics, less production loss due to clinical cases, less premature culling and a reduction in cow and/or bulk milk tank (BMT) somatic cell count (SCC). According to Houben et al. (1994) total losses caused by clinical mastitis are Dfl. 150 per average cow per year, emphasising the economic impact of mastitis. The break-even point for farm level treatment which reduces mastitis incidence by 25%, on a farm with 10 clinical quarter cases per 10,000 cow days, was estimated to be Dfl. 48.60 per cow per year. Daily monitoring of cows to detect subclinical mastitis could be used to undertake appropriate management actions to decrease the risk of a reduced milk price caused by an increased BMT SCC above the penalty limit.

Detection performance may be improved by implementing IT applications. However, the results of the conjoint analysis showed that the opinion of experts on the improvement in terms of sensitivity and specificity at the farm level for the different IT combinations differed. The economic consequences of this variation, and moreover the economic feasibility of the different possible multi-factorial IT implementations, are still unclear despite current knowledge on detection characteristics. Up to now, an economic evaluation of commercial viability of IT applications, either separate or in combination, has not been undertaken. Therefore, further research is recommended to evaluate the economic impacts of the different investment alternatives in IT applications.

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5 DYNAMIC PROGRAMMING TO DETERMINE OPTIMAL INVESTMENT PATTERNS IN INFORMATION TECHNOLOGY ON DAIRY FARMS[1]

Abstract

The feasibility of integrating the information of a number of information technology (IT) applications on dairy farms is gaining interest because of potential synergy to improve economic results. In this study optimal investment patterns involving five IT applications are evaluated, including 1) automated concentrate feeding systems, 2) measurement of daily physical activity of cows and on-line automated parlour systems for 3) recording of milk production, 4) milk temperature and 5) electrical conductivity of milk. The investment decisions are optimised by dynamic programming taking into account price reduction and technical progress over time. The objective is to determine the pattern that maximises the net present value of (a stepwise) IT investments over a given planning horizon.

Optimal investment patterns are calculated under different assumptions of price reduction and technical progress, farm characteristics and farm scale. In this way it is determined under which conditions the applications under research would be incorporated. Results for a typical Dutch dairy farm show that the optimal investment pattern includes automated concentrate feeders. The incorporated electronic individual cow identification and hardware facilitates the appraisal of other on-line sensor investments like activity measurement of cows.

5.1 Introduction

Recent advances in information technology (IT) enable on-line recording and management support of individual cows, such as automated concentrate feeders (ACF), activity measurement (AM), milk production measurement (MPM), milk temperature measurement (MTM) and measurement of electrical conductivity of quarter milk (ECQM). At present, there is increased interest in information about the feasibility of combining a number of IT applications because of potential synergy to improve economic results. However, economic

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evaluation of these technologies is difficult and inherently complicated because of dynamic nature of the decision environment.

The decision to invest in IT is to a certain extent irreversible. Shortly after the investment, salvage values of hardware and software will be low. These salvage values are usually much lower than the depreciated values of the implemented applications. The discrepancy between the written-down value of an investment and its salvage value, called the sunk cost (Pindyck, 1988), is important in the economic appraisal of the investment. Dis-investment means an extra equity loss and the initial investment can influence the profitability of supplementary investments. As a consequence, the farm firm could be caught in a production path which is not profitable ex post. In many cases, although it is possible to undertake investment immediately, it is also possible to delay the investment decision. Since sunk costs are incurred in making such an investment, the possibility of waiting should be evaluated, and the consequences with respect to path dependency should be recognised (McDonald and Siegel, 1986).

In addition, as with many other farm investments decisions, technical performance and retail price is likely to improve over time. Early investment will generate additional revenues early, while late investment will generate higher yearly additional revenues that are deferred. It is also important to consider re-investment (or replacement) decisions. The optimal investment pattern requires a trade-off to be made between the conflicting objectives of minimising capital and current payments and maximising receipts.

The objective of this study is to contribute towards understanding investment decisions in ACF, AM, MPM, ECQM, MTM on dairy farms. Investments and re-investments decisions in IT applications are characterised by a time-dependency; investment in one year lead to returns in subsequent years and influences the prices and returns of other IT investments in the subsequent years. In addition, improvements in technology performances and prices are likely to occur. In order to evaluate the applications under study, and ultimately to determine the effects of the different investment patterns, a dynamic programming model has been developed optimising the multi-period investment decision (Kennedy, 1986). The inherent sequence of re-investment cycles make these investment decisions dynamic and recursive, enabling to formalise and solve the problem with dynamic programming. Benefits from use of the technologies are based on improved oestrus detection, mastitis detection and more appropriate rates of concentrate feeding. Correlations between the additional benefits are assumed to be absent. For example, a more appropriate rate of concentrate feeding under consideration will not influence the reproductive status nor the health status. In this paper, the model structure and the variables included are described. The results obtained are presented and discussed for a default situation and for different assumptions about prices and performance, farm characteristics (e.g. oestrus detection, average milk production per cow per year and mastitis incidence) and farm scale (e.g. farm size and number of parlour units).

5.2 Model structure

5.2.1 Description of the investment model

The principle of dynamic programming enables the optimal investment pattern in multi-period decision problems to be determined. It is often used in traditional farm machinery replacement decisions (Doluschitz, 1987) and animal replacement decisions, for example in dairy cows (Van Arendonk, 1984 and Kristensen, 1988). Dynamic programming has the advantage of determining optimal decisions without requiring exhaustive enumeration of all sequences of transition possibilities. Computation usually starts at the final stage in the planning horizon (T) and proceeds backwards in time, stage by stage until the initial stage is reached (Bellman, 1957).

The deterministic dynamic programming approach is used to optimise the investment pattern of IT applications. At the beginning of the planning horizon, the model starts with a farm without any IT applications. The decision vector within the model consists of two possible decisions per application at each stage and state: 1) not to invest; or 2) to invest. The expected net present value of the consequences of a particular sequence of investments (investment pattern) is determined by discounting the net cash flows (Brealey and Myers, 1996) found as the marginal receipts (additional positive cash flows) minus the marginal payments (additional negative cash flows).

The relationship in the model between price and performance is accounted for by three factors: 1) corrected investment price; 2) price reduction over time; and 3) technical progress incorporated by additional receipts depending on when the equipment is installed. The first two factors are based on initial catalogue price. Formally, given the initial state X_t of the farm at the beginning of stage t, the maximum present value of expected net receipts during the remainder of the planning horizon, can be calculated using the Equations 5.1 and 5.2.

$$V_t(X_t) = S(X_t) \qquad (t=T) \qquad \textbf{(5.1)}$$

$$V_t(X_t) = MAX_{\alpha_t} \{ (R_t (X_t, \alpha_t) * (1 + IP) - E_t (\alpha_t) * RP * (1 - A)^t - M(X_t) + \varrho * V_{t+1} (\tau (X_t, \alpha_t)) \} \qquad (0 \leq t \leq T-1) \qquad \textbf{(5.2)}$$

where:

X_t = vector representing the state of the farm at stage t in terms of investments made and their years in use;

$V_t(X_t)$ = the maximum present value of expected net receipts during the remainder of the planning horizon of the optimal investment pattern given the initial state of the farm at the beginning of stage t;

$S(X_t)$ = salvage receipts of the implemented applications with status X_t at stage T, is on basis of a linear depreciation of the actual discounted investment;

$R_t(X_t, \alpha_t)$ = receipts of the implemented applications for a farm with status X_t and investment decision α_t taken at stage t;

IP = improvement in performance over years depending on when equipment is installed, is a factor multiplied with the additional receipts (for example 0.05), see text and example for further understanding;

$E_t(\alpha_t)$= additional investment for the decision taken at stage t, α_t, is the initial catalogue price;

RP = corrected retail price, is a proportion between zero and one of initial catalogue price (for example 0.75);

A = autonomous price reduction over years of equipment installed at stage t (for example 0.05);

$M(X_t)$ = additional maintenance payments for a farm with status X_t;

ϱ = discount factor;

$\tau(X_t, \alpha_t)$ = stage transformation function, τ, defining the state of the system at time t+1, given the previous state, X_t, and the decision taken at stage t, α_t.

Technology of concentrate feeding is assumed to be stationary with respect to time and, hence, re-investment always occurs with feeders of similar type. With this kind of applications the actual physical process of concentrate feeding is automated and improved (more accurate and more frequent). Improvements over time in functionality of hardware and software will be limited since this application is on the market for more than two decades. Possible improvements in the diagnostic area as a results of refined algorithms including for example concentrate leftovers are limited. Default is the situation in which the possible implemented concentrate feeders either needs replacing, or requires a major modernisation. Salvage receipts (in this context terminal values) are only accounted for at the end of the planning horizon (stage T). Terminal values for finite-stage horizons are often based on market values of the salvage equipment (Kennedy, 1986). Terminal values in this study are on basis of a linear depreciation of the actual discounted investment. However, if the planning horizon is long the effect of the terminal value is limited due to the discount factor and a stationary optimal decision vector for the first years is obtained.

Consider the investment in an IT application in the fourth year (transition from t=4 to t=5) of a ten-year planning horizon. Suppose catalogue price of this investment is Dfl. 10,000 (Dutch guilders), while corrected retail price is 80% and autonomous price reduction over time is 5% per year of the catalogue price. Operation time of the applications is as long as the planning horizon, namely ten years and maintenance payments for this fictitious system is Dfl. 500 per year. Initial annual receipts are Dfl. 2000 and improvement in performance is 5% per year. In this example for simplicity the discount factor is zero. The net present value of the investment in the planning period is based upon: 1) investment expenditures at year four of Dfl. 10,000*0.8*$(1\text{-}0.05)^4$=Dfl. 6,516; 2) annual maintenance payments in years four to ten of Dfl. 500; 3) salvage receipts at year ten of (Dfl. 6,516/10)*4=Dfl. 2,606; and 4) annual receipts in years four to ten of Dfl. 2,000*(1+0.05*4)=Dfl. 2,400. Additional characteristic elements in the model are described in the next sections in more detail.

5.2.2 Stage and state variables

Investment decisions are made on a yearly basis and the maximum (technical) operation time of the applications is considered to be ten years (Figure 5.1).

Stage (t):	0	1	2	9	10	20
States (X_t):	(0,0,0,0,0)	(0,0,0,0,0) (.............) (1,1,1,1,1)	(0,0,0,0,0) (.............) (.............) (2,2,2,2,2)	(0,0,0,0,0) (.............) (.............) (.............) (9,9,9,9,9)	(0,0,0,0,0) (.............) (.............) (.............) (.............) (10,10,10,10,10)	(0,0,0,0,0) (.............) (.............) (.............) (.............) (10,10,10,10,10)
Number of States:	1	32	243	100,000	161,051	161,051

Figure 5.1 Decision process of investments in information technology.

The investment decision is optimised for a finite time horizon of 20 years, so all possible states per applications (11) are accessible at the end of the planning horizon (notation: 0 if not implemented and 1 to 10 if implemented and describing the consecutive years in operation). In the final stage the farm is described by 161,051 possible states since five applications were incorporated (ACF, AM, MPM, ECQM, MTM). However, not all states are accessible at each stage: year one only 2^5=32, year two 3^5=243,...., year ten 11^5=161,051. The state-vector X_5: (3,3,0,0,0) at stage 5 means that the first two applications in this 5 dimensional array are 3 years in use and the last three applications are not implemented. Starting from this state only the following transitions are possible to stage 6: (4,4,0,0,0), (4,4,1,0,0) up to (4,4,1,1,1); (1,4,0,0,0), (1,4,1,0,0) up to (1,4,1,1,1); (4,1,0,0,0), (4,1,1,0,0) up to (4,1,1,1,1) and finally (1,1,0,0,0), (1,1,1,0,0) up to (1,1,1,1,1). Scrapping without replacing was not considered to be a feasible option (transition to 0). In this case one or two implemented applications can be replaced, and one or more new applications can be implemented.

5.2.3 Investment

A key element of the investment is individual cow identification. In the model the catalogue price of this component is Dfl. 85 per cow, while an activity sensor integrated with the cow identification adds up to Dfl. 150 (Table 5.1). In all investment patterns a process computer and personal computer with accessory software are necessary. Software prices are based upon the different packages. The antenna(s) are necessary for recording individual cow data of AM, MPM, MTM and ECQM. Depending on the layout of the milking parlour, one or more antennas have to be placed at the entrance of the parlour. If only activity is measured, it is also possible to place the antenna at another place, for example at the exit of the parlour. The costs of the different types of sensors in the parlour are associated with the number of milking units. Since calculations consider only additional receipts and payments, the investment excludes the milk jars in which MPM sensors are placed. The (corrected) retail price is in most cases lower than the reported catalogue prices, depending, for example, on the level of additional investments (i.e., renovation complete milking parlour). Time preference for payments and receipts is accounted for by discounting the net cash flows using a discount rate of 5%. An assumption in the model is that sufficient capital is available to finance any time pattern of investment decisions.

The period over which these systems will perform influences the annual costs of the systems considerably. The maximum operation time of the systems is considered to be ten years. Expenditures to maintain the initial state of performance for the applications MPM, MTM and ECQM were considered to be Dfl. 250, 50 and 50 per milking unit per year, respectively. In this way payments for the replacement of worn out parts of the equipment and for re-calibration were accounted for.

Table 5.1 Typical Dutch catalogue prices of the components.

Components	Prices[1] Dfl.
Identification, per cow	85
Identification and collar activity measurement, per cow	150
Personal computer	3000
Process computer	4250
Concentrate feeder, per 25 cows	3500
Antenna, per piece	1900
Panel, per milking place	600
MPM sensor + print cart, per milking unit[2]	1785
ECQM sensor + print cart, per milking unit[3]	2200
MTM sensor + print cart, per milking unit[3]	1030
Software: ACF	600
Software: ACF+AM	1550
Software: ACF+MPM	1550
Software: ACF+MPM+AM	2500
Software: ACF+MPM+MTM+ECQM	2050
Software: ACF+AM+MTM+ECQM	2550
Software: ACF+AM+MPM+MTM+ECQM	3000

[1] Excluding 17.5% V.A.T.

[2] Milking jar not included.

[3] Milking claw not included.

5.2.4 Benefits from improved feeding

Automated concentrate feeders provide a method of feeding in which concentrates are provided in amounts that more accurate match the needs of individual cows. It also enables an increased feeding frequency in comparison with traditional concentrate feeding in the milking parlour and that the upper limit of concentrate intake as a result of the limited feeding time in the milking parlour can be overcome. On-line milk production measurement increases the accuracy of estimation of the energy necessary to realise a more accurate feeding level in comparison with monthly measurement. In a simulation study based on the model described by Jalvingh et al. (1993), in which some modifications were applied to include effects of differences in concentrate supply, Van Asseldonk et al. quantified the benefits of ACF and MPM. Additional receipts and net present value were estimated per 100 kg fat and protein corrected milk (FPCM) per year under a quota system. A more frequent and accurate performance-related concentrate feeding increased gross margin by Dfl. 0.77 per year per 100 kg FPCM (Table 5.2). The losses as a result of inaccurate monthly milk recording in comparison with on-line recording were estimated to be Dfl. 0.17 per year per 100 kg FPCM. Both figures were applicable to a herd with an average milk production of 7500 kg per year.

Table 5.2 Default assumptions regarding to the annual additional receipts per 100 kg milk in Dfl.

Process	IT-combinations	Additional receipts			
Feeding		7500 kg		9000 kg	
	ACF	0.77		1.47	
	ACF+MPM	0.17		0.21	
Oestrus detection		default 60%		default 70%	
		7500 kg	9000 kg	7500 kg	9000 kg
	AM	0.50	0.36	0.14	0.09
	MPM	0.23	0.16	0	0
	MTM	0.23	0.16	0	0
	AM+MPM	0.57	0.39	0.19	0.12
	AM+MTM	0.60	0.41	0.22	0.14
	MPM+MTM	0.38	0.29	0.02	0.01
	AM+MTM+MPM	0.62	0.42	0.24	0.15
Clinical mastitis detection		Relative rate of mastitis=1		Relative rate of mastitis=2	
	ECQM	0.28		0.75	
	MPM	0.14		0.36	
	MTM	0.14		0.36	
	ECQM+MPM	0.32		0.86	
	ECQM+MTM	0.33		0.88	
	MPM+MTM	0.19		0.51	
	ECQM+MPM+MTM	0.37		0.99	

5.2.5 Benefits from improved oestrus detection

Increased activity and milk temperature as well as a decreased milk production may be associated reactions of oestrus (Schlünsen et al., 1987). Utilising this information can improve the level of oestrus detection considerably. The method of conjoint analysis was used to elicit the opinions of experts to summarise the present knowledge of the individual and combined effects of AM, MPM, ECQM, ACF and MTM on oestrus detection at the farm level (Van Asseldonk et al., 1998). Experts, who had considerable experience with the IT applications in research stations should be able to assess how these systems will work on commercial farms taking into account management effects. The panel results were used as input in the simulation model described by Jalvingh et al. (1993) to determine the economic consequences of the various levels of oestrus detection. Changes in average milk production per cow and the default level of oestrus detection (without additional support) had an important effect on gross margin. Gross margin improved by Dfl 0.62 per year per 100 kg FPCM if all applications were implemented on a farm with a visual oestrus detection of 60% and an average milk production of 7500 kg per cow per year (Table 5.2).

5.2.6 Benefits from early clinical mastitis detection

Increased electrical conductivity of milk, milk temperature and decreased milk production may be early signs of mastitis (Schlünsen et al., 1987). Treatment based on the signals of a detection system can consist of antibiotic therapy or frequently stripping of the suspected quarters. The effects of the different therapy systems and strategies remain to be shown. One of the first attempts reported that mastitis-causing bacteria were successfully eradicate with antibiotics in 97% of cases following early detection while the usual clear-up rate was 60%. In addition, the antibiotic dose decreased by 15-20% and cows recuperated in eight instead of 16 days (Coghlan, 1996). However, with current detection systems immediate antibiotic treatment will not be an option. The relatively high number of false positive signals would result in excessive costs of antibiotic doses and discarded milk (Nielen, 1994). Frequently stripping of suspected quarters is considered to be a more appropriate therapy. Benefits of early detection combined with such therapy might arise from a reduction in costs of antibiotics, lower mastitis incidence, less involuntary culling and reduced production losses. In addition, a detection system will in some cases facilitate earlier antibiotic treatment of true positive cases since the first appearance of clinical mastitis may not always be noticed by a farmer (Milner et al., 1996).

The advantages from an early diagnosis of clinical mastitis followed by stripping of suspect quarters are as yet unclear. We have assumed that frequently stripping of true positive cases before the start of clinical symptoms would result in a decrease of the relative rate of mastitis by 25%. The results of the optimisation model of Houben et al. (1994) were used to estimate the potential benefits of a decreased relative rate of mastitis with associated increased costs for antibiotics and loss of production. Other possible benefits were excluded as a result of model limitations but have a minor impact. Monitoring cows daily to detect subclinical mastitis could be used to undertake appropriate management actions to decrease the risk of a reduced milk price caused by an increased bulk milk tank somatic cell count (BMT SCC) above the penalty limit set by the milk processing industry. However this effect is not accounted for in the current model. In the model no distinctions were made between mastitis pathogens involved. Severity of mastitis was based on a herd with a pathogen occurrence as described by Houben et al. (1993). Benefits of a detection system would be enhanced if appropriate treatments are based on on-line pathogen diagnosis.

The relative rate of mastitis had a major effect on the farm results. Doubling the assumed rate of mastitis in comparison with the average rate decreased gross margin by Dfl. 2.70 per year per 100 kg FPCM, while a 50% reduction increased it by Dfl. 1.05 per year per 100 kg FPCM. The modelling results were combined with the elicited sensitivity of clinical mastitis detection as a result of implementing MPM, ECQM and MTM (Van Asseldonk et al., 1998). In this way insight could be gained into the possible benefits given a certain mastitis incidence (Table 5.2).

5.3 Results

5.3.1 Default situation

The optimal investment pattern was determined under different situations that can be split into three major sections, namely price in combination with performance, farm characteristics and farm scale. Default values describing price and performance were as follows: initial retail price is equal to catalogue price (RP=1) and no autonomous price reduction (A=0) and technical progress over time (IP=0). Default values of the farm characteristic variables milk production per cow, oestrus detection and relative rate of mastitis were 7500 kg, 60% and one, respectively. Default values for farm scale variables of herd size and the number of milking units were set at 50 cows and eight units. With these assumptions the optimisation model calculated an additional net present value of Dfl. 0.20 per year per 100 kg milk. Annual net present value at the farm level was Dfl. 735. In the first stage ACF and AM were implemented and kept for their maximum operation time of ten years (transition from t=0 to t=1). Total initial investment was approximately Dfl. 28,000. The corresponding benefit-cost ratio was 1.27 under the objective of an optimised net present value. In the following sections the effects of changed conditions in some default values were investigated.

Table 5.3 Alternative price /performance and their influences on the optimal investment pattern (stage of investment), net present value per year per 100 kg milk and benefit-cost ratio.

Retail price (RP)	Autonomous price reduction (A)	Performance improvement (IP)	Pattern[1]	Net Present Value	Benefit-Cost Ratio
1	0	0	ACF(1,11)/AM(1,11)	0.20	1.27
1	0.05	0.05	ACF(1,11)/AM(1,11,18)/ MTM(18)/ECQM(11)	0.50	1.64
0.75	0	0	ACF(1,11)/AM(1,11)	0.35	1.61
0.75	0.05	0.05	ACF(1,11)/AM(1,11,18)/ MTM(11)/ECQM(10,19)	0.60	1.92

[1] Stage of investment made in particular IT application.

5.3.2 Effect of price and performance

Characteristic of the types of investment under consideration is the dynamic development of the systems, resulting in an improved price and performance over time. One method of deriving forecasts about improvements of price and performance is by extrapolation of historic data. However, the condition of obtaining representative data are hard to satisfy. Another popular method is using judgmental forecasts. In this study a third option of sensitivity analysis was used to determine the impact of the price and performance variables on the optimal investment pattern.

The sensitivity analyses of the price and performance part was carried out by varying retail price and technical progress as outlined in Table 5.3 with substantial improvements. An autonomous price reduction and performance improvement of 5% each, with or without a reduction in retail price, increased net present value and changed the investment pattern. In this optimal pattern ACF and AM were purchased in stage one, while other investments were made later in the investment horizon. Re-investment of activity sensors and software occurred under the assumption that other parts of the hardware of the system implemented initially did not break down and were compatible with the new items.

5.3.3 Effect of farm characteristics

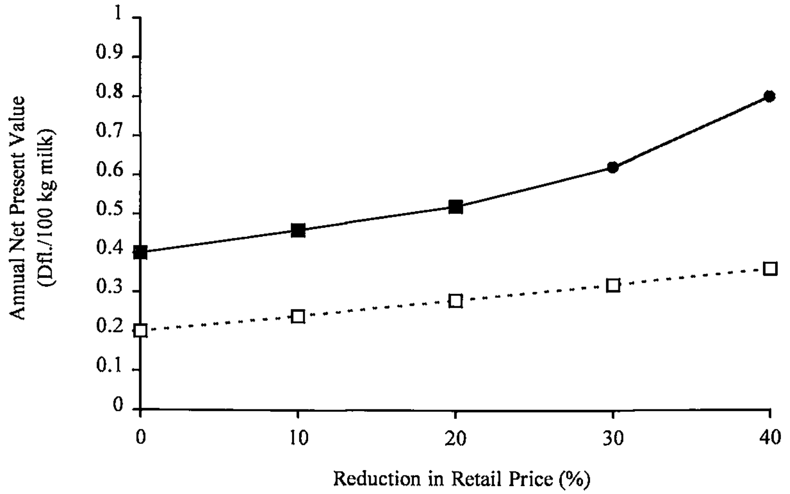
Potential benefits of IT applications were based on an average Dutch levels of milk production per cow per year, oestrus detection and mastitis incidence. Considerable deviations with respect to these variables exists among farms. An average farm produces 7658 kg milk per cow with a standard deviation of 687 kg and achieves an oestrus detection of 56% with a standard deviation of 7% (Rougoor et al., 1997). About 12.7% of the farms have more than twice the average risk of contracting clinical mastitis (Houben et al., 1994). Different levels of these farm characteristics on the optimal investment pattern were studied (Table 5.4). Two sets of price and performance variables were incorporated in the sensitivity analysis. The default (stationary) situation was compared with a set which considered a discount in retail price and price reduction and performance improvement over time, hence called the dynamic price/perfomance set.

Table 5.4 Alternative farm characteristics and their influences on the optimal investment pattern (stage of investment), net present value per year per 100 kg milk and benefit-cost ratio.

Milk Production (kg)	Oestrus Detection (%)	Relative Rate of mastitis	Pattern[1]	Net Present Value	Benefit-Cost Ratio
RP=1, A=0, IP=0					
7500	60	1	ACF(1,11)/AM(1,11)	0.20	1.27
7500	70	2	ACF(1,11)	0.11	1.33
9000	60	1	ACF(1,11)/AM(1,11)	0.67	2.26
9000	70	2	ACF(1,11)	0.28	1.59
RP=0.75, A=0.05, IP=0.05					
7500	60	1	ACF(1,11)/AM(1,11,18)/ MTM(11)/ECQM(10,19)	0.60	1.92
7500	70	2	ACF(1,11)/AM(1,11,18)/MPM(18)/ MTM(11,18)/ECQM(1,11)	0.58	1.64
9000	60	1	ACF(1,11)/AM(1,11,18)/ MTM(18)/ECQM(9,19)	1.01	2.11
9000	70	2	ACF(1,11)/AM(9,19)/MPM(18)/ MTM(9,19)/ECQM(1,11)	1.12	2.65

[1] Stage of investment made in particular IT application.

An improved initial oestrus detection of 10% points and a doubled risk in contracting mastitis resulted in an investment in only ACF given the stationary assumptions. Identical results were obtained if the two variables were changed one-by-one. Apparently the additional improvement as a result of implementing AM did not outweigh the additional costs. Parlour automation was again not incorporated in the optimal patterns. Increments in production per cow resulted in higher net present values due to expected benefits and increased farm scale; fixed and variable costs were supported by a larger milk quota. Investments and re-investments in AM and parlour automation were found to be optimal under the dynamic price/performance assumptions.



❑ = ACF;
■ = ACF+AM;
● = ACF+AM+ECQM;
-------- = oestrus detection 70%, relative rate of mastitis 1;
——— = oestrus detection 60%, relative rate of mastitis 2.

Figure 5.2 Effect of retail price in the optimal situation on investment decision in the first year for alternative farm characteristics (Ten year planning horizon).

In Figure 5.2 the effect of retail price on investment decisions for two alternative sets of farm characteristics is depicted. An inferior performance with respect to oestrus detection and mastitis incidence was compared with a superior combination of these farm characteristics. Improvements over time were considered to be absent and, therefore, potential investments always occurred at the first decision moment. Net present value increased if retail prices of the technology were reduced. Investment decisions did not change up to a 30% discount in retail price given the inferior farm characteristics; ACF and AM were incorporated in the optimal investment pattern. At a price reduction of 30% the optimal investment decision included in addition ECQM. Only ACF was incorporated given the improved farm characteristics.

5.3.4 Effect of farm scale

The costs of parlour automation are influenced by herd size and the number of milking units. In 1997, the distribution of Dutch dairy farms with herd sizes smaller than 30 cows, 30-50, 50-70, 70-100 and more than 100 cows was as follows: 29%, 31%, 23%, 12% and 5%, respectively (ATC, 1997). In the data base of the NRS (Royal Dutch Cattle Syndicate, Arnhem, The Netherlands), the number of parlour units on each of the 2500 farms using on-line MPM at the time of installation is recorded. In Figure 5.3 the number of parlour units for different herd sizes in The Netherlands in 1996 is depicted. The effects of herd size and number of parlour units on the optimal investment pattern is summarised in Table 5.5 for the previously mentioned two sets of price and performance variables.

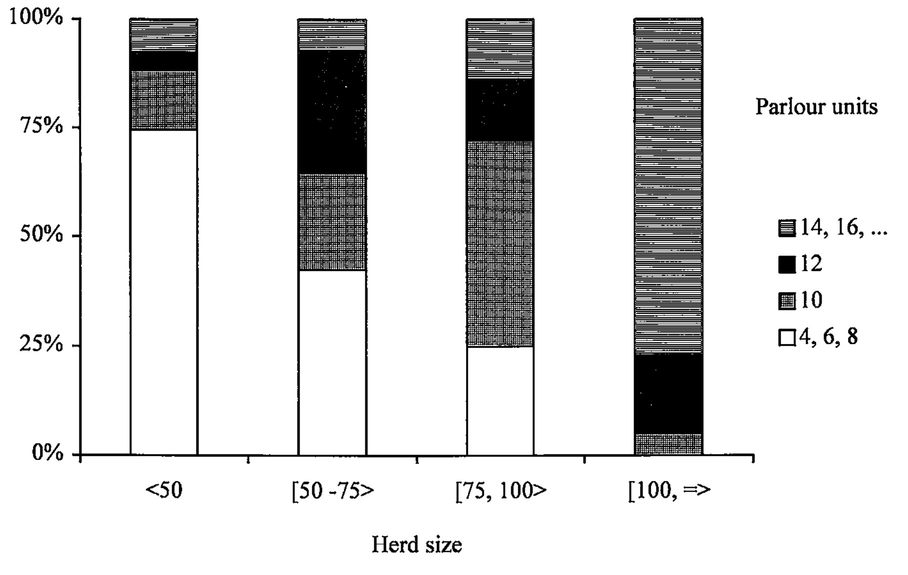


Figure 5.3 Number of parlour units for different herd sizes in The Netherlands in 1996.

The typical relation between number of cows and milking units was estimated to be 25/6, 50/8, 100/10 and 200/16, respectively. The optimal investment decision included ACF and

AM for the stationary assumptions. Increments in herd size resulted in higher net present values since fixed costs were supported by a larger milk quota. Parlour automation would become more rapidly economic with more intensive use of the parlour units.

Table 5.5 Alternative farm scale and their influences on the optimal investment pattern (stage of investment), net present value per year per 100 kg milk and benefit-cost ratio.

Herd size	Milking units	Pattern[1]	Net Present Value	Benefit-Cost Ratio
RP=1, A=0, IP=0				
25	6	ACF(1,11)/AM(1,11)	0.10	1.09
50	8	ACF(1,11)/AM(1,11)	0.20	1.27
100	10	ACF(1,11)/AM(1,11)	0.33	1.54
200	16	ACF(1,11)/AM(1,11)	0.40	1.74
RP=0.75, A=0.05, IP=0.05				
25	6	ACF(1,11)/AM(1,11)	0.45	1.28
50	8	ACF(1,11)/AM(1,11,18)/ MTM(11)/ECQM(10,19)	0.60	1.92
100	10	ACF(1,11)/AM(1,11,18)/MPM(18)/ MTM(11)/ECQM(9,19)	0.75	2.40
200	16	ACF(1,11)/AM(1,11,18)/ MPM(18)/ MTM(6,16)/ECQM(6,16)	0.81	2.48

[1] Stage of investment made in particular IT application.

5.4 Discussion and conclusion

Dynamic programming has proved to be an effective method in traditional farm machinery replacement decisions. This article showed that the method is also applicable to farm IT investment decisions that are characterised by price reduction and technical progress over time. Results for a typical Dutch dairy farm showed that the optimal investment included an automated concentrate feeder. If the default oestrus detection was average, additional investment in activity measurement was incorporated at the same time. Activity measurement was not optimal in case of above average prior rates of oestrus detection. The optimisation model was used for sensitivity analysis, enabling an economic evaluation and a break-even analysis to be done (Kleijnen, 1984 and Dijkhuizen et al., 1997). The analysis with respect to the variables describing price/performance, farm characteristics and farm scale showed the conditions when on-line milk measurement, temperature measurement and electrical conductivity measurement would be incorporated in the optimal investment pattern. Since detection improvements and their effects on biological and subsequently on economic parameters were to a certain extent unclear, a break-even analysis was particularly interesting in case of applications that supported early mastitis detection. Till now, the effects of therapy of early diagnosed clinical mastitis quarters are unclear and the break-analysis showed the maximal costs of the system to justify the investment. In the model salvage values were based on a linear depreciation because data on market values for used systems were limited. Omitting salvage values did not change the optimal investment pattern given the default values. In the optimal investment pattern, concentrate feeders and activity measurement were implemented in the first year and used up to their final possible ten years of operation. Investments were not made, for example, after the first year in a ten-year planning horizon for all calculations in the sensitivity analyses when salvage values were based on market values.

Incorporation of labour requirements in the default situation cases will have an important effect on the achieved net present value but not on the optimal investment pattern. Reduction in labour costs are considered to be important for implementation of an automated concentrate feeder since they perform production tasks. On-line oestrus detection support included always visual observation by the farmer, but such visual observation can be focused on suspect cows using information from the technologies, therefore being less time consuming. On the other hand, early diagnosis of clinical mastitis followed by the moderate therapy of stripping will increase labour use. Treatment of both true-positive and false-positive cases has to be considered. In general, if the effect on labour costs were to be included, net present values would increase since most patterns included feeders.

The possible presence of feeders before the start of the planning period may influence the investment pattern. At the present time, approximately 50% of the Dutch farms with a free-stall barn have adopted feeders, and the need for renovation is likely to be the main reason why a farmer will switch to an automated system in future. If new feeders have been recently installed, the model assumptions leading to the conclusion that investments in activity measurement are optimal would be invalid. The conventional identification is worthless and needs to be replaced with an embedded collar activity and identification system. If investments have already been made, sunk costs of the identification system are not accounted for; the model is based on actual cash flows. But additional receipts of investment in feeding are not accounted for if the maximum years in operation of possible implemented feeders is not yet reached (partial budgeting). The investment in activity measurement is not postponed if the initial implemented concentrate feeder is compatible with the new system. However, the additional is postponed if parts of the hardware such as process computer of the initial implemented system need to be replaced.

The investment decision making is based on the expected payments and receipts of alternative investments, and is therefore subject to a certain degree of uncertainty (Kennedy, 1986). An important issue to consider is that learning and use of the system will require time. Skill in using a particular technology will improve over several years after adoption. A gradual investment may in this case have advantages over above an impatient investment pattern. Learning with a rather simple and less expensive system can prevent sub-optimal utilisation of advanced systems. In the current dynamic programming model stochastic formulations and learning effects were ignored. Emphasis was on the investment pattern especially the first years, which were rather stable in the sensitivity analyses and only included a limited number of applications. Inclusion of only deterministic and constant learning effects therefore appear to be adequate.

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6 DETERMINING FARM EFFECTS ATTRIBUTABLE TO THE INTRODUCTION AND USE OF A DAIRY MANAGEMENT INFORMATION SYSTEM IN THE NETHERLANDS[1]

Abstract

Yearly production and reproduction data on dairy farms in The Netherlands were obtained to determine whether management information systems significantly improved herd performance variables. The analysis included 357 adopters of a management information system (MIS) and 357 herds were used as controls. The data comprised years 1987 through 1996, and included for the adopters both the "before" and "after" period. Adoption and use of a management information system resulted in a significant annual increase in rolling herd average milk (carrier) and protein production of 62 kg and 2.36 kg per cow respectively. Calving interval was shortened by 5 days. The pay-back period was approximately five years of the system (including the hardware), which is acceptable for this kind of applications, and therefore, MIS appears to be economically profitable.

6.1 Introduction

Historically, automation of the cow recording system has been one of the first applications in the adoption sequence of new technologies on dairy farms. Dutch dairy farmers have continued to adopt management information systems (MIS). Recent data indicate that approximately 4800 farms, i.e., 15% of the Dutch dairy farms, now have some type of MIS (ATC, 1997). Automation of the cow recording system offers the ability to improve utilisation of individual cow production records in order to support managerial activities and decision making. More recently, advancements in information technology have made it possible to capture additional on-line cow side data, for example, concentrate left-overs recorded by automated concentrate feeders, milk weight and cow activity. However, all of these information technology applications incorporate some kind of automated cow recording system (Schlünsen et al., 1987 and Spahr, 1993).

Although MIS adoption may in itself be an indication of farmers expecting benefits from MIS, it does not provide a quantifiable effect that is attributable to the system

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1 Paper by Tomaszewski, M.A.,Van Asseldonk, M.A.P.M., Dijkhuizen, A.A. and Huirne, R.B.M., submitted for publication to *Agricultural Economics.*

(Verstegen et al., 1995b). Several attempts have been made to quantify effects attributable to an MIS on dairy farms. The study by Hayes et al. (1997) covered one complete year and indicated that users achieved an improvement in daily milk production (carrier), fat and protein of 1.2, 0.08, and 0.07 kg respectively. In addition, a higher percentage (+8.4%) of cows calved during the desired period, which is critical in New Zealand seasonal calving herds, and a higher percentage of cows (+9.7%) mated at the optimal time to achieve a concentrated calving period in the following year. Introduction and use of an MIS was not associated with improved heat detection efficiency, first service non-return rate and pregnancy rate. Losinger and Heinrichs (1996) estimated that dairy operations with an MIS had a significantly higher yearly milk production of 207 kg per cow than non-MIS users. However, adjustments in the statistical model to overcome bias associated with MIS use is hard with this kind of research data (cross-sectional study) and, therefore, both effects should be interpreted with care (Verstegen et al., 1995a). Lazarus et al. (1990) and Tomaszewski et al. (1997) used time series to quantify MIS benefits, comprising yearly accounting data and milk recording data of 51 and 33 farms which invested in an MIS during the time period respectively. The study by Lazarus et al. (1990) estimated a net farm income rise of $ 85 per cow in the first year of computer use. Tomaszewski et al. (1997) estimated an increased milk production (carrier) of 421 kg, but none of the investigated reproduction variables were significantly affected. Both studies concerned farms operating in the US, i.e., without restrictions on milk production and with relatively large dairy herds. The reported MIS effects may not necessarily be obtained in a situation when an MIS is used in relative small dairy herds such as in The Netherlands under production restrictions (milk quotas). In 1992, Overbeek concluded by means of a cross-sectional research design no effect on gross margins of Dutch dairy farms. As with all cross-sectional studies, this study failed to compare "before adoption" results with "after adoption" results within farms, and could therefore not fully account for the fact that (early) MIS adopters are not a random sample of the population. The purpose of this study is to quantify the benefits of MIS adoption and use in Dutch dairy farming with a unique time series data set; i.e., a so-called panel data set.

6.2 Materials and methods

Empirical methods to evaluate MIS have been explained by Lazarus et al. (1990) and Verstegen et al. (1995b). For this study, we used panel data which included production and reproduction variables in the same temporal interval (cross-sectional data) and annual data from 1987 to 1996 (time series data). Analysing this kind of data makes it possible to compare at the same time "before and after" and "with and without" and hence provides an opportunity to estimate the effect of an MIS adoption on herd performances, eliminating the influence of trends and herd-specific effects. In addition, panel data design makes it possible to estimate technology effects for each year after adoption, clarifying whether the particular technology utilisation acts like a trend over several years or occurs as an instant jump at the time of adoption (Mundlack, 1961).

6.2.1 Study population

The Royal Dutch Cattle Syndicate (NRS) provides herd recording services for Dutch dairy farmers and maintains a historical database on production and other herd specific variables. Yearly production and specific herd data were obtained for all herds in the NRS data set from 1987 through 1996 in order to construct a panel data set. Unique herd numbers of 2,607 MIS users and date of initial MIS purchase were identified by four Dutch software developers, together serving almost the entire MIS market in the Dutch dairy sector. In order to obtain a random sample of these herds, the herds were sorted according to purchase date within each software developer. Every fifth herd was selected as an MIS herd to be included in the analysis. These procedures ensured that all developers were proportionally represented within the sample in relation to the number of programs they had sold, as well as the time of introduction of the program. An additional restriction required that herds had to have purchased the MIS in the time period analysed and had to have data as to the entire range of the study. Of the 521 MIS herds selected, 382 met this requirement.

For the MIS selected herds, the developers provided the unique herd identification number that allowed identification of the herds in the NRS data set. Since other NRS herds could be using some other management software program, which was not known by the NRS, a procedure was developed for selecting control herds that eliminated as many potential MIS users as possible from the NRS database before selecting control herds. Some producers who utilise other data collection programs subscribe to an NRS service that provides a file of their monthly herd recording results, which they then load into their own farm database. Herds that were enrolled on this service were termed EDI (Electronic Data Interchange) herds. It was assumed that these 4,283 EDI herds were potential MIS users. Additionally, we were able to identify 485 herds of the 2,607 MIS herds that had not been included in the EDI herd list. These 4,768 herds were eliminated as potential control herds from the NRS yearly data set, which contains in total about 27,000 herds.

The inclusion of controls in the research design would improve the accuracy of estimation through additional possibilities of correcting for trends not caused by technology use. Since farm size, operator age and education level are important determinants of MIS adoption (Putler and Zilberman, 1988 and Batte et al., 1990), MIS herds might not be seen as a random sample but represent bigger farms with above average management levels. To ensure that the control herds were initially similar to the MIS herds, a control herd was selected for each MIS herd according to the following criteria: 1) the herd's major breed had to be the same and the percentage of the breed within the control herd had to be within 5% of the MIS herd; 2) the number of cows in the control herd had to be within 5% of the MIS herd; 3) the differences between the MIS and control herds for milk, fat, and protein production were calculated and weighted by 1, 3 and 3, respectively, thereby creating an index, in which milk content is extra emphasised because of its economic value. The control herd that had the most similar index was taken as the control herd for the MIS herd. Three MIS herds that failed to match with 1 and 2 were deleted from the analysis. The 379 control herds were reduced to 357 control herds due to the additional requirement that data should be available ten consecutive years. The MIS herds that did not have controls were also eliminated resulting in a data set of 357 MIS and 357 control herds. Structuring the data set in this manner ensured that control and MIS herds were similar at the start of the study and ensured that herds had observations before and after MIS adoption. This procedure avoided, to a certain extent, problems of distinguishing between production (i.e., management level) and MIS effects.

6.2.2 Statistical analysis

Although the NRS data set contained many variables to support management, the average annual amount of milk, fat and protein produced per cow were taken as economic indicators of production. Average annual calving interval was used as an economic indicator of reproductive performance. Heat detection percentage, interval calving to first insemination and non-return percentage at 56 days after insemination were taken as indicators to explain possible effects on calving interval.

Simple descriptive statistics in terms of means and standard deviations were used to explore the differences in herd size and average milk production per cow between adopters and non-adopters. For each period, the category of herds enrolled in an MIS in that year was compared with other herd categories, including: 0) non-MIS herds in the whole period 1987-

1996; 1) MIS herds that had not installed the system yet; 2) MIS enrolment in the current year and 3) having used MIS for more than one year.

The effect of MIS on the response variables is estimated using a whole period mixed effects model. Though *p*-values are reported, it should be kept in mind that these only give some rough indication of significance; the data are non-experimental and consist of several simultaneous time series for which it is almost impossible to model joint stochastic behaviour. A model for the whole period 1987-1996 was developed and analysed using PROC MIXED of SAS (1996) to quantify the effects on milk, protein and fat production. The following regression model was used (Equation 6.1):

```
PROC MIXED; CLASS herd YR correc;
 MODEL y = year herd correc HF FH herd_size MIS05;                    (6.1)
 RANDOM yr(correc) MIS05*herd;
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The regression model estimates Y for each herd in each year with the following independent main variables: YEAR (year of particular observation), HERD (unique herd code), HF (percentage of breed Holstein Friesian), FH (percentage of breed Friesian Holland), HERD_SIZE (number of cows), CORREC (e.g. CORREC = 0, if observation is of year < 1992; otherwise CORREC = 1), MIS05 (e.g. MIS05 = 0 if herd did not use MIS in that particular year) and an error term. CORREC was introduced because yearly production records in the NRS data base had been redefined in 1992. Production records before 1992 were on the basis of lactation production, from 1992 onwards records were based on 305 days in production (records with less than 305 days but 200 or more days were incorporated unmodified). The term MIS05*HERD was added to account for differences in MIS05 effect among herds. Notice that YEAR and YR are a linear and class variable respectively, both containing the year. Because the choice to adopt an MIS appears to depend on previous or current herd conditions, we specified HERD as a fixed effect rather than as a random effect. Because the benefits of an MIS could vary from herd to herd, we superimposed a random interaction of MIS05 and HERD on a fixed MIS05 effect. Finally, because graphical examination of residual plots we introduced a random interaction of YR and CORREC. Estimators of the variance components were obtained with restricted maximum likelihood (REML) and maximum likelihood. The methods produced almost identical estimates from the MIS and associated standard errors; therefore, only REML results are presented (SAS, 1996). Since the reproductive variables were maintained and defined across the entire data range, the adjustment variable CORREC was redundant in the models which estimated the effect on reproduction variables.

The effect of MIS use for a given herd on the economic indicators is assumed to be constant for each year after the switch. However, the process of MIS installation, data entry, learning and utilising MIS information depend on many factors. It is difficult to exactly state at which point in time a producer starts to effectively utilise an MIS and this benefit could be delayed from the starting date. Ignoring this starting point in the estimation of the MIS effects could lead to an underestimation of the effect (Verstegen et al., 1995b). As a compromise, the shift in the year of switching is assumed to be half the shift in later years. So the MIS effect is introduced as a regression coefficient on a regression variable (MIS05) with values of 0 (for non-MIS herds and for MIS before the switch), 0.5 (MIS in year of switch) and 1 (MIS after switch). Additional dependent variables, i.e., heat detection percentage, interval calving to first insemination and non-return percentage at 56 days after insemination were analysed to explain possible effects on the economic reproduction variable calving interval. Management practices and information use are likely to differ by farm size (Lazarus et al., 1990). In order to obtain results applicable to the different herd sizes, two subsets of the original data were analysed with the base model. Herd sizes in the subsets in 1987 were <50 and ≥50 cows. In addition, MIS effects were tested for each year after adoption, clarifying whether the effects of MIS use occurs as an instant jump at the time of adoption or increases the during the following years after adoption. In the adjusted statistical model, class 0 (none-adopters and herds before adoption) has been compared with three classes: 1 (year of adoption); 2&3 (second and third year after adoption) and > 3 (more than three years after adoption).

6.3 Results

The cases and controls closely matched each other in 1987 with respect to the variables under research. Average milk production per cow and standard deviation for cases were 6581 kg and 698 kg and for controls 6572 kg and 680 kg respectively. Herd size over years for herds enrolled in an MIS and herds not enrolled was similar. Herd size for these two categories in 1996 were 60 versus 59, indicating a randomness in MIS adoption with respect to the autonomous growth of the farms. Faster increasing herds were not more inclined to adopt an MIS than slower increasing herds. The change in rolling herd average milk (Figure 6.1) depicts that categories 2 and 3 are higher than 0 and 1, which indicates that MIS benefits increased over the years after adoption, rather than being an instant jump, since category 3 realises a higher average production than category 2. The instant decrease in milk production in 1992 clearly shows the necessity to incorporate a correction factor into the regression model.

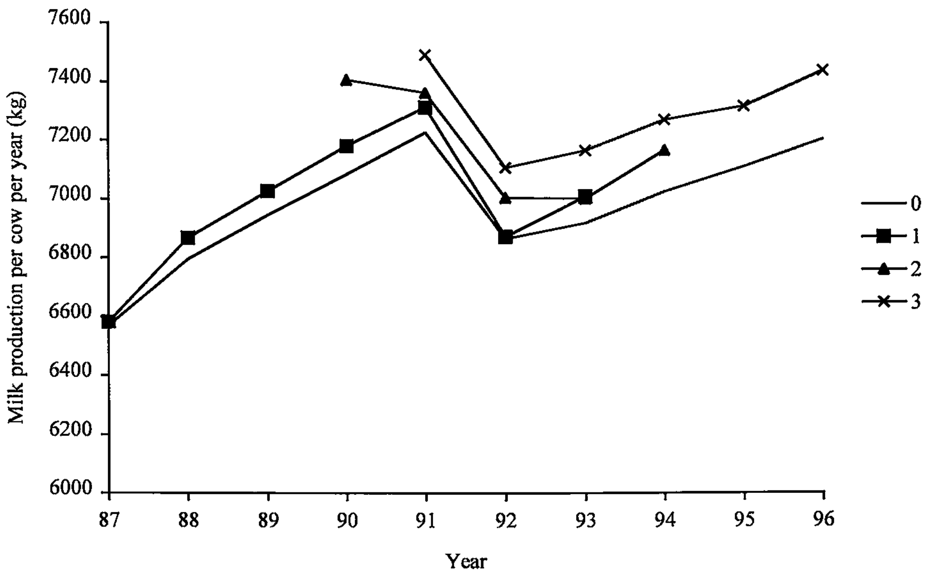

Figure 6.1 Average for milk production according to categories of MIS use, 0=none-MIS adopters, 1=NO MIS use yet, 2=MIS enrolment in current year, 3=MIS use more than one year.

Table 6.1 shows the estimation results of PROC MIXED for milk production. The incorporated effects were significant and all fixed effects, except for the variable HERD, had a degree of freedom of 1. The significant estimate of milk production from the MIS is 62 kg (SD=25), while the estimate of protein production (Table 6.2) from the MIS is 2.36 kg (SD=0.90, significant at p=0.05).

In the second model the variable FH was not significant and excluding this variable from the regression model did not change the effect on MIS05. Estimated effect on fat production from the MIS was not significant. Calving interval shortened by 5 days (SD=0.75, Table 6.3) as a result of MIS use. The goodness of fit measured by the standard deviation of the estimates was for the following models: milk = 329 kg; protein = 12 kg and calving interval =15 days. The additional dependent variables heat detection percentage (1.22%), interval calving to first insemination (-3.20 days) and non-return percentage at 56 days after insemination (-1.67%) were all significantly affected by MIS use (Table 6.4).

Table 6.1 Proc Mixed results of random and fixed effects for milk production.

Random effects		
Covariance parameters	P>|Z|	
YR (CORREC)	0.0675	
MIS05[1] * HERD	0.0001	
Residual	0.0001	
Fixed effects		
Source	NDF	P>F
HERD	713	0.0001
YEAR	1	0.0001
CORREC	1	0.0001
HF	1	0.0001
FH	1	0.0001
HERD_SIZE	1	0.0001
MIS05	1	0.0149
Estimate results		
Parameter	Estimate	P>|T|
MIS05	62	0.0149

[1] MIS05 = 0 for herds that were not enrolled in an MIS and for herds that would be enrolled in an MIS in the future but had not adopted the system yet, MIS05=0.5 for herds that were enrolled in an MIS and had adopted the system in the current year and MIS05=1 for herds that were enrolled in an MIS and had completely adopted the system.

Table 6.2 Proc Mixed results of random and fixed effects for protein production.

Random effects		
Covariance parameters	P>|Z|	
YR (CORREC)	0.0658	
MIS05[1] * HERD	0.0001	
Residual	0.0001	
Fixed effects		
Source	NDF	P>F
HERD	713	0.0001
YEAR	1	0.0001
CORREC	1	0.0001
HF	1	0.0001
FH	1	0.8245
HERD_SIZE	1	0.0001
MIS05	1	0.0086
Estimate results		
Parameter	Estimate	P>|T|
MIS05	2.36	0.0086

[1] MIS05 = 0 for herds that were not enrolled in an MIS and for herds that would be enrolled in an MIS in the future but had not adopted the system yet, MIS05=0.5 for herds that were enrolled in an MIS and had adopted the system in the current year and MIS05=1 for herds that were enrolled in an MIS and had completely adopted the system.

Table 6.3 Proc Mixed results of random and fixed effects for calving interval.

Random effects		
Covariance parameters		P>|Z|
MIS05[1] * HERD		0.0001
Residual		0.0001
Fixed effects		
Source	NDF	P>F
HERD	713	0.0001
YEAR	1	0.0001
HF	1	0.0001
FH	1	0.0001
HERD_SIZE	1	0.0001
MIS05	1	0.0001
Estimate results		
Parameter	Estimate	P>|T|
MIS05	-5.28	0.0001

1 MIS05 = 0 for herds that were not enrolled in an MIS and for herds that would be enrolled in an MIS in the future but had not adopted the system yet, MIS05=0.5 for herds that were enrolled in an MIS and had adopted the system in the current year and MIS05=1 for herds that were enrolled in an MIS and had completely adopted the system.

Table 6.4 Estimated effects of an MIS on reproduction variables in order to explain shortened calving interval.

	Average 1996	Estimate	P>|T|
Heat detection (%)	54	1.22	0.0001
Interval calving - first insemination (days)	81	-3.20	0.0001
None return at 56 days (%)	63	-1.67	0.0008

Analysis of the two subsets in which herd size was in 1987 <50 and ≥50 cows showed substantial differences (Table 6.5). Only the estimated effect on calving interval was significantly affected for the relatively bigger farms in 1987, while milk, protein and calving interval were significantly effected for the relative smaller farms. The relatively bigger farms were characterised in 1996 according to a higher milk production (7458 kg and 7145 kg), protein production (260 kg and 250 kg) and calving interval (397 days and 392 days). In this subset average herd size decreased from 74 in 1987 to 71 cows in 1996. In contrast, herd size increased on relatively smaller farms from 37 in 1987 to 44 cows in 1996.

Table 6.5 Estimated effects and t-values of an MIS for two subsets in which herd size in 1987 was <50 and ≥50 cows.

	Estimate	P>|T|
Milk production (kg)		
- < 50 cows	80	0.0413
- ≥ 50 cows	18	0.5814
Protein (kg)		
- < 50 cows	3.10	0.0265
- ≥ 50 cows	0.48	0.6756
Calving interval (days)		
- < 50 cows	-6.61	0.0001
- ≥ 50 cows	-5.04	0.0001

In Table 6.6 the results are shown in which MIS05 is a class variable as opposed to continuous variable described in the previous sections. Pairwise comparisons of the least squares means between 0 and 1, 0 and 2&3 and 0 and > 3 years after MIS adoption have been tested for statistical significance. Estimates of MIS use showed significant effects on milk (47 kg), protein production (1.93 kg) and calving interval (−3.94 days) in case of none-adopters versus second and third year after adoption. In general, first year performances were lagging behind performances of the following years. Changes in milk, protein and calving interval increased in the following years. So, these effects acted like a trend over several years, rather than an instant jump at the time of adoption.

Table 6.6 Estimated effects of years after adoption versus none-adoption and *p*-values of an MIS. Technology effects are incorporated into the regression model as class variables.

	Estimate	P>|T|
Milk production (kg)		
- None versus 1st year	37	0.1546
- None versus 2nd & 3rd year	47	0.0701
- None versus >3rd year	69	0.0039
Protein (kg)		
- None versus 1st year	1.54	0.0942
- None versus 2nd & 3rd year	1.93	0.0382
- None versus >3rd year	2.58	0.0022
Calving interval (days)		
- None versus 1st year	-2.41	0.0147
- None versus 2nd & 3rd year	-3.94	0.0001
- None versus >3rd year	-6.12	0.0001

6.4 Discussion and conclusion

Farms without MIS adoption, with similar performance records in the base year 1987 in comparison with farms with MIS adoption, were incorporated into the models in order to improve estimations and were constructed in such a way that MIS herds were compared with non-MIS herds with initially similar production and herd size. MIS adoption and use improved annual milk (carrier) production by 62 kg, protein production by 2.36 kg per cow and reduced calving interval by 5 days.

The average herd size and milk production of the total NRS data base were lower than the herds before MIS adoption in 1987. The average NRS herd had 44 cows and had an average milk production of 6,270 kg per cow. The MIS adoption group had 58 cows and 6,581 kg respectively, stressing the importance of inclusion of matching control groups.

The effect of an increased milk production per cow (with the same milk content) on net farm income under Dutch milk quota conditions is approximately Dfl. 0.30 per kg, assuming a good alternative use for idle production factors (labour, capital and buildings) and savings on variable costs (feeding costs for maintenance and AI costs) that come available when the same amount of milk (quota) can be produced with fewer cows (Jalvingh and Dijkhuizen, 1997). The additional protein increase corrected for improved carrier production was approximately 0.19 kg (2.36-62/100*3.5) with a value of Dfl. 13.23 per kg of protein increment. Calving interval was shortened by 5 days, which is estimated to increase net return to labour and management by Dfl. 2.16 per day per cow per year (Jalvingh and Dijkhuizen, 1997). So, net return to labour and management increased by approximately Dfl. 30 per cow per year as a result of MIS adoption and use. For a typical Dutch farm in the sample of 60 cows analysed, increase in income equals Dfl. 1,800 per year. Investment in an MIS included a printer and PC, and Dfl. 2,000 for MIS software and Dfl. 1,000 per year after the first year for service and updates. To break even, the annual costs of investment in an MIS should be at least on a 5-year depreciation period, which is acceptable for this kind of applications with update facilities and therefore appears to be economically profitable.

The panel data analysis has proven to be fruitful to evaluate the benefits of MIS. Therefore, additional information technology adoptions could (and should) be evaluated in a similar empirical manner to clarify whether these technologies increase dairy profitability. For example, automated concentrate feeders, on-line milk production measurement and activity measurement on milk production and reproduction.

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7 EFFECTS OF INFORMATION TECHNOLOGY ON DAIRY FARMS IN THE NETHERLANDS: AN EMPIRICAL ANALYSIS OF MILK PRODUCTION RECORDS[1]

Abstract

This study empirically quantified the effects of the adoption of an automated concentrate feeder, on-line measurement of milk production and activity measurement on milk production and reproduction. Data comprised annual results of Dutch farms operating in a milk quota system from 1987 to 1996. Data included both adopters and nonadopters as well as farm results before and after adoption. Use of an automated concentrate feeder resulted in an improvement of the annual production of milk (carrier), milk protein, and milk fat (102, 4.95, and 5.52 kg per cow, respectively). In contrast, on-line measurement of milk production did not significantly affect milk production records. Calving interval was shortened by 5.7 days after the adoption of an activity measurement system and was not affected by the adoption of an automated concentrate feeder or by the measurement of on-line milk production.

7.1 Introduction

Recent advances in information technology (IT), such as automated concentrate feeders (ACF), on-line measurement of milk production (MPM), and activity measurement (AM) have increased the opportunities for effective management support at the farm level. After a slow adoption rate of ACF in the 1970s, the adoption rate accelerated in the 1980s in the various countries. At the present time, approximately 50% of the Dutch farms with a free-stall barn have adopted ACF, and renovation will likely be the main future reason to buy the system. In the 1980s, MPM was introduced. Although the number of potential buyers was expected to be high, the number of actual adopters was lagging behind these expectations. At the present time, the adoption rate in The Netherlands is approximately 300 farms/year, which equals about 1% of Dutch dairy farms (ATC, 1997). AM is at the current time implemented by innovators (Rogers, 1985). By 1997, the number of Dutch dairy farms that adopted ACF, MPM, and AM were 13,500, 2800, and 700, respectively (ATC, 1997).

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[1] Paper by Van Asseldonk, M.A.P.M., Huirne, R.B.M., Dijkhuizen, A.A., Tomaszewski, M.A. and Harbers, A.G.F., *Journal of Dairy Science,* **81**: 2752-2759.

The use of these new technologies enabled monitoring of production, reproduction, and health and automated concentrate feeding on an individual cow basis. The day-to-day control of those activities is managed as effectively as possible, and the available information resulting from IT applications can be helpful management tools. Increased activity and decreased milk production and concentrate feed intake may be associated reactions of cows in oestrus (Schlünsen et al., 1987). Implementation of ACF orients feeding to yield; concentrates are supplemented to individual cows, and MPM increases the accuracy of determining the equilibrium feeding level of concentrates so that body weight is maintained during milk production. When energy intake is above the requirements of the equilibrium feeding level, the additional energy is used for milk production and deposition of body tissue. An energy deficiency is partly compensated for by mobilisation of body energy. However, in both cases, the utilisation of energy to produce milk is not as efficient as in case of equilibrium feeding. Generally, with ad libitum feeding of roughage, changing concentrate intake affect roughage intake, and the net energy intake, milk yield, milk composition, and live weight change. The extent of these changes are affected by factors such as forage quality, type and level of concentrate input, the level of milk production, and milk composition. In addition, ACF placed out of the milking parlour enable more frequent concentrate feeding compared to a system in which the provision of concentrates is inside the parlour. More frequent concentrates feeding can stabilise rumen fermentation patterns and ultimately may result in an increase in fat and protein contents (Robinson, 1989).

The effects of the different IT applications on the technical and economic results are yet unclear. Previous empirical research has mainly documented the impact of a specific combination of IT applications and did not distinguish among the individual applications. Carmi (1992) analysed the Afimilk system (SAE Afikim, Kibbutz Afikim, Israel) in which milk production, electric conductivity, and activity were recorded on-line. Official yearly records of eight and five user herds in Israel and The Netherlands, respectively, were analysed with respect to change in number of days to first service, the number of open days, milk value, and somatic cell count. The analysis of Gelb (1996) was a follow-up of that research (Carmi, 1992), and studied 66 user herds. Gelb (1996) demonstrated a significant decrease in days open (14.7 days) and an increase in milk yield (275 kg) under Israeli production conditions.

The objective of this study was to quantify the effects on milk production records of ACF, MPM, or AM adoption under Dutch production conditions. Investigated effects were the production of milk (carrier), protein, and fat and length of calving interval.

7.2 Materials and methods

7.2.1 Data analysis

Cross-sectional data (different variables for production and reproduction during the same temporal interval) and time series data (annual periods from 1987 to 1996) of adopters and nonadopters as well as farm results before and after adoption, were used. Differences of data before and after adoption of the technology were corrected for trends and biases (e.g., change of breed type over time within a farm) because time series data of various farms were included. Analysis of this kind of data provides a great opportunity to estimate the effect of the adoption of a particular technology on herd performance, eliminating the influence of other effects specific to the group of farms or herd (Mundlak, 1961). In addition, the experimental design allowed estimation of technology effects for each year after adoption and showed whether the particular technology use caused a gradual response over several years or was immediately apparent at the time of adoption (Lazarus et al., 1990; Verstegen et al., 1995b). The causality of significant relations between technologies and performances, however, cannot fully be proved. The relationships may also partly be the result of exogenous changes other than technology use. For example, if changes on all farms coincide with the start or after technology adoption but are not caused by technology use and do not occur in the group of nonadopters, then the effects will incorrectly be regarded as technology effects (Verstegen et al. 1995a). However, this scenario is not very likely to happen, and, if the bias from changes in adopter group occurs, the change normally increases with time. With the method used, this effect can be identified because the estimations can differentiate among years.

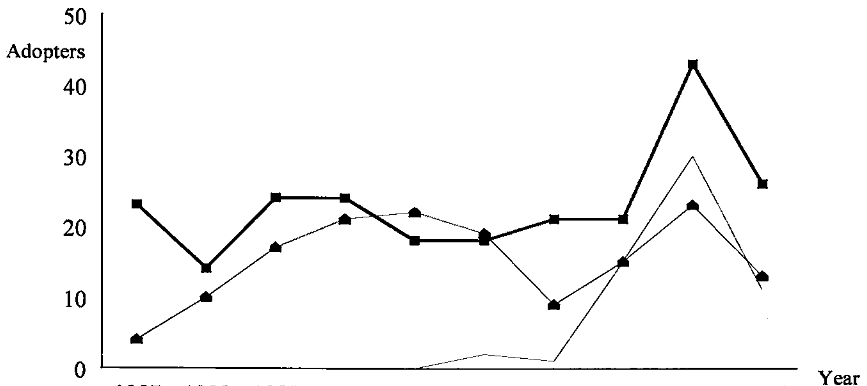
7.2.2 Study population

The study used annual farm data from the NRS (Royal Dutch Cattle Syndicate, Arnhem, The Netherlands) which included mean values for production and performance of the herds. Installation dates by month and year of dairy farms in The Netherlands were included as well. Farms were selected from the database of an IT manufacturer, and only farms with at least ACF were included. The number of ACF implemented on the farm were included if this information was available. In addition, farms could have adopted MPM, AM or both. Also, the type of process computer, which allowed to differentiate between stand alone feeding and the possibility to integrate on-line milk data with ACF, was included if this information was available. The data set of the manufacturer was merged with annual data for production and performance data from the NRS. The NRS also provided a list of installation dates (month and year) of farms with MPM. The installation dates of ACF and AM were obtained from the manufacturer. Data from 295 farms with 10 consecutive yearly records (1987 to 1996) were available. Table 7.1 presents the number of farms in the different classes. The number of farms that adopted MPM and AM was 153 and 59, respectively. The year of ACF adoption was before 1987 for 36 farms and was missing for 27 farms with AM adoption.

Table 7.1 Number of farms with milk production measurement (MPM), and activity measurement (AM)[1].

	AM		
MPM	No use	Use	
No use	113	29	142
Use	123	30	153
	236	59	295

[1] All farms implemented an automated concentrate feeder.



	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
ACF ■	23	14	24	24	18	18	21	21	43	26
MPM ▲	4	10	17	21	22	19	9	15	23	13
AM—	0	0	0	0	0	2	1	15	30	11

Figure 7.1 Number of adopters per year of automated concentrate feeders (ACF), milk production measurement (MPM) and activity measurement (AM).

The yearly number adopters are depicted in Figure 7.1. The number of ACF adopters increased especially in 1995 because the installation coincided with the adoption of MPM or AM or both.

The inclusion of controls in the research design would improve the accuracy of estimation through additional possibilities to correct for trends not caused by technology use (Verstegen et al., 1995b). The fact that all farms adopted ACF indicates that the data might not be a random sample but rather represent bigger farms with above average management, which is generally thought to be the case for technology adopters (Mundlak, 1961). Therefore, in 1987, IT farms (cases) were individually matched with similar herds (controls) from the NRS database. Herd size and the percentage of breed HF (Holstein Friesian) had to be within the range of 5 cows and 5% HF, respectively. From the remaining herds that conciliated these criteria, the control herd that was selected had the least deviation in the produced amounts of milk, fat, and protein compared to that of the case herd. Deviations of milk, fat, and protein were indexed with a weighting factor of 1, 3, and 3, respectively. Control herds did not adopt MPM but could have adopted ACF, AM or both; this information was unknown in the NRS database.

Table 7.2 Characteristics of the analysed data sets for 1987.

	Data A [1]				Data B [2]				Data C [3]			
	Case n = 295		Control n = 295		Case n = 167		Control n = 167		Case n = 68		Control n = 68	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Cows	63	28	63	28	59	26	55	22	72	31	72	31
Milk, kg	6605	683	6604	678	6587	688	6844	737	6651	711	6667	691
Protein, kg	226	23	225	22	226	23	233	25	228	25	227	23
Fat, kg	289	32	281	32	289	25	302	35	291	35	284	32

[1] All farms included.
[2] At least one concentrate feeder per 25 cows.
[3] Integrated milk production measurement and automated concentrate feeder.

Different data sets were analysed to evaluate the effects of ACF, MPM and AM. Data set A included herds that adopted ACF, MPM, and AM and matched control farms, resulting in 5900 yearly herd records. All other data sets were a subset of data set A. Data set B included only herds with a more frequently use of an ACF per cow (at least 1 concentrate feeder per 25 cows at the time of installation), and data set C included only MPM users with an integrated system (individual milking records are stored in a database upon which concentrate feeding strategy can be based). Both data sets obtained controls by the procedure described previously. The cases and controls were closely matched with respect to the variables under research (Table 7.2). User farms with at least 1 concentrate feeder per 25 cows during the year of installation were smaller than user farms of ACF in 1987 (59 vs. 63 cows); farms with an integrated system were larger (72 cows).

7.2.3 Statistical models

Simple descriptive statistics ($\bar{x}$ and SD) were used to explore the differences in herd size and mean milk production per cow. For each time period, the total NRS database, the farms before IT adoption in data set A, and the farms after ACF, MPM, and AM were compared.

The effects of the technology on the production of milk, protein, and fat and on calving interval were quantified with the PROC MIX procedure of SAS (1996), described by Verstegen et al. (1995b) . The following regression model was used (Equation 7.1):

```
PROC MIXED; CLASS herd YR correc;
 MODEL y = year herd correc HF FH herd_size ACF MPM AM;          (7.1)
 RANDOM YR(correc) ACF*herd MPM*herd AM*herd;
```

The regression model estimates Y for each herd in each year with the following independent main variables: year, herd (unique herd code), HF (percentage Holstein Friesian breed), FH (percentage Friesian Holland breed), herd size (number of cows), ACF (e.g., ACF = 0 if herd did not used ACF in that year), MPM (e.g., MPM = 0 if herd did not used MPM in that year), AM (e.g., AM = 0 if herd did not used AM in that year) and an error term. The terms ACF x herd, MM x herd, AM x herd and a nested term YR(correc) were incorporated as random effects because these factors represent only a random sample of the total Dutch farms. The first three interactions were added to account for possible differences in ACF, MM, and AM effect among herds. Correc (e.g., correc = 0, if observation is before 1992; otherwise correc = 1) was introduced because yearly production records were redefined in 1992. Production records before 1992 were on basis of lactation production, and, from 1992 onward, records were based on 305 day lactations (records with < 305 days but ≥ 200 days were unmodified incorporated). Notice that YR is a class variable and year is a linear variable. Estimators of the variance components were obtained with the REML and ML methodology. However, the methods produced almost identical estimates and associated standard errors, therefore, only REML results are presented (SAS, 1996).

Two different models were analysed in which the independent variables ACF and MPM were incorporated as a linear or as a class variable, respectively. In the first model, the variables ACF and MPM have the values of 0 (for nonadopters and for herds before adoption), 0.5 (year of adoption), and 1 (herds after 1st year adoption). Use of the year the application is introduced allows adjustment for the fact that a farmer does not effectively utilise the application at the starting point and the application was not used the entire year. In the second model, class 0 (nonadopters and herds before adoption) has been compared with three classes: 1 (year of adoption); 2 and 3 (year 2 and year 3 after adoption) and > 3 (> 3 year after adoption). The effect of AM was always incorporated as a linear variable because observations of ≥ 4 year after adoption were not available. The majority of AM adoption was well after 1992 when the production variables were recalculated. The AM was estimated with only the observations from 1992 to 1996. In this way, the estimation was not influenced by the correction procedure to overcome the effect of the recalculation. Tests for autocorrelation of the models were quantified with a linear correlation coefficient (Verstegen et al., 1995b).

7.3 Results

Results of the descriptive statistics are presented in Table 7.3. Herd size and milk production of the total NRS database were lower than the selected herds before adoption. For example, in 1987, the mean NRS herd was 44 cows, and mean milk production was 6270 kg. Before adoption, herd size was 60 cows, and mean milk production was 6536 kg. The difference was even more evident for the early adopters of ACF, MPM, and AM. The process of adoption followed a rather typical pattern. The early adopters were relative large farms, and subsequently the majority and late adopters could be characterised as average and small (Rogers, 1985). The 1996 mean values for production in the total NRS database and the after ACF adoption group, respectively, were 7014 and 7411 kg for milk (see Table 7.3), 243 and 258 kg for milk protein and 309 and 327 kg for milk fat. The corresponding calving interval differed 2 days (398 days vs. 396 d). As a result of the sampling procedure, standard deviations decreased for all variables under study.

7.3.1 Estimates with technology use as linear variables

The results of PROC MIXED for milk production are shown in Table 7.4. The incorporated effects were significant and all fixed effects, except for the herd variable, had a degree of freedom of 1. The use of ACF, MPM, and AM is specified with linear (continuous) variables with values of 0, 0.5, and 1, respectively. In data set A (Table 7.5), ACF increased milk production by 55 kg, protein by 2.90 kg, and fat by 2.81 kg ($P < 0.05$). The estimated effect

Table 7.3 Characteristics by year for total NRS database, before IT adoption in data set A (without controls), adopters of a concentrate feeder (ACF), milk production measurement (MPM) and activity measurement (AM). Selected variables are number of farms (#), mean number of cows per farm and mean milk production per cow.

	NRS database			Before IT adoption			After ACF adoption			After MPM adoption			After AM adoption		
Yr	#	Cows $\bar{x}$	Milk $\bar{x}$	#	Cows $\bar{x}$	Milk $\bar{x}$	#	Cows $\bar{x}$	Milk $\bar{x}$	#	Cows $\bar{x}$	Milk $\bar{x}$	#	Cows $\bar{x}$	Milk $\bar{x}$
87	26,811	44	6270	210	60	6536	59	75	6750	4	76	7455			
88	27,028	42	6501	196	56	6790	73	66	7072	14	66	7579			
89	27,176	45	6662	172	57	6968	97	70	7138	31	68	7343			
90	27,291	46	6825	148	58	7132	121	70	7296	52	72	7280			
91	27,381	46	6953	130	58	7230	139	69	7393	74	68	7449			
92	28,254	47	6599	112	61	6849	157	70	7015	93	70	7028	2	88	6640
93	28,364	44	6704	91	56	6927	178	63	7139	102	62	7186	3	83	6708
94	27,702	44	6830	70	54	6951	199	63	7238	117	62	7272	18	75	7057
95	27,230	46	6910	27	60	6979	242	64	7296	140	69	7362	48	71	7253
96	26,812	47	7014				268	65	7411	153	71	7516	59	79	7379

on calving interval was not significant. The effects of MPM on the production of milk and milk protein and on calving interval were not significant. However, milk fat decreased significantly. The goodness of fit measured by the standard deviation of the estimates was for the following models: milk, 291 kg; milk protein, 10 kg; milk fat, 13 kg; and calving interval, 10 days.

Table 7.4 Proc Mixed results of random and fixed effects for milk production (data set A, 5900 observations).

Random effects			
Covariance parameters		Pr > |Z|	
YR (adjusted)		0.0745	
ACF x herd		0.0001	
MPM x herd		0.0023	
Residual		0.0001	
Fixed effects			
Source	NDF		Pr > F
year	1		0.0001
herd	589		0.0001
ACF	1		0.0687
MPM	1		0.5991
HF	1		0.0001
FH	1		0.0190
herd size	1		0.0001
adjusted	1		0.0149

Table 7.5 Estimated effects of an automated concentrate feeder (ACF), milk production measurement (MPM) and activity measurement (AM) for date A [1].

	ACF		MPM		AM[2]	
	Estimate	Pr > |T|	Estimate	Pr > |T|	Estimate	Pr > |T|
Milk production, kg	46	0.0687	-15	0.5991	-35	0.5050
Protein, kg	2.17	0.0184	-1.12	0.2678	-1.81	0.3544
Fat, kg	2.19	0.0669	-3.32	0.0092	-1.43	0.5862
Calving interval, d	-0.58	0.5679	0.54	0.6933	-5.70	0.0012

1) Technology effects are defined as linear effects.
2) Effect of AM is estimated with yearly obsevarions from 1992 to 1996, ACF and MPM are estimated with yearly records from 1987 to 1996.

In all cases $P<0.10$ for the interactions between farm and the different technologies. The hypothesis of possible autocorrelation was rejected. The adoption of AM shortened calving interval by 5.7 days ($P<0.01$ and SD=1.83). In 1996, mean calving interval ± SD for the AM adopters was 395 ± 17 days and for the control herds 398 ± 18 d. Thus, AM adoption occurred on farms with moderate calving intervals and improved the interval beyond the average level. As expected, there were no significant effects on the production variables because these were expressed from 1992 and later in 305 d. If the production variables were expressed, for example, as mean daily production per lactation the effect of lower production at the end of the lactation would quantify the effect of the prolonged calving interval. However, this kind of information was not available.

The results of a selection of the original data set A are presented in Table 7.6. Farmers with at least 1 concentrate feeder per 25 cows at the time of installation increased milk production by 102 kg (SD=30). The amount of produced milk protein and milk fat increased to 4.95 (SD=1.07) and 5.52 (SD=1.37) kg per cow, respectively. Milk and milk protein production for the MPM adopters became positive but were not significant ($P < 0.05$).

Table 7.6 Estimated effects of an automated concentrate feeder (ACF) for data set B and milk production measurement (MPM) for data set C[1].

	Data set B (n= 334, ACF)		Data set C (n=136, MPM)	
	Estimate	Pr > |T|	Estimate	Pr > |T|
Milk production, kg	102	0.0304	58	0.2945
Protein, kg	4.95	0.0030	0.91	0.6516
Fat, kg	5.52	0.0140	-1.40	0.5802
Calving interval, d	1.71	0.3783	-0.58	0.8365

1) Technology effects are defined as linear effects.

7.3.2 Estimates with ACF and MPM as classification variables

Table 7.7 shows the results of PROC MIXED in which ACF and MPM are treated as classification variables. The analysis was performed for the farms with a more intensive use of a concentrate feeder (data set B) and for the farms with an integrated system (data set C). Paired comparisons of the least squares means (0 vs. 1, 0 vs. 2 and 3 and 0 vs. > 3) have been tested for significance. Estimates of ACF use showed significant effects on production of milk (114 kg), milk protein (4.98 kg) and milk fat (5.49 kg) for nonadopters compared with adopters after the 2nd and 3rd yr. The amount of milk fat produced decreased after MPM adoption but not significantly. In general, 1st year performances lagged behind that of the subsequent years. Changes in the production of milk, milk protein, and milk fat increased significantly in the consecutive years of ACF use. Thus, effects increased gradually over several years rather than suddenly at the time of adoption.

Table 7.7 Estimated effects of years after adoption vs. nonadoption of an automated concentrate feeder (ACF) for data set B and milk production measurement (MPM) for data set C[1].

		Data set B (n= 334, ACF)		Data set C (n=136, MPM)	
Variable	Adoption status	Estimate	Pr > |T|	Estimate	Pr > |T|
Milk production, kg					
	none versus 1 y	87	0.0294	-50	0.3930
	none versus 2 & 3 y	114	0.0056	23	0.6936
	none versus 1 > y	176	0.0004	55	0.4502
Protein, kg					
	none versus 1 y	2.79	0.0522	-2.35	0.2615
	none versus 2 & 3 y	4.98	0.0007	0.49	0.8111
	none versus 1 > y	7.19	0.0001	0.20	0.9391
Fat, kg					
	none versus 1 y	4.55	0.0171	-2.12	0.4214
	none versus 2 & 3 y	5.49	0.0050	-2.17	0.4029
	none versus 1 > y	7.04	0.0027	-1.94	0.5513
Calving interval, d					
	none versus 1 y	-1.18	0.4925	-3.14	0.2413
	none versus 2 & 3 y	-1.15	0.5109	-2.63	0.3237
	none versus 1 > y	0.06	0.9786	-5.35	0.8386

1) Technology effects are incorporated in the regression model as class variables.

7.4 Discussion

The effects of a number of IT applications in The Netherlands on milk production and reproduction were quantified empirically. A unique data set comprised annual farm results from 1987 to 1996 for IT adopters and nonadopters as well as farm results before and after adoption of IT. The group of adopters consisted out of 295 farms with ACF of which in addition 153 adopted MPM and 59 AM. Herds with observations only before adoption, only after adoption, or unknown with respect to a certain technology provided, together with a control group, the means to distinguish between effects that were farm-specific and those that constituted a trend. The control group was matched with respect to size, breed, and production results for year 1987 because the technology adopters operated on larger farms with better production results than the average NRS farms. Estimates were derived with a mixed model as used by Verstegen et al., (1995b) in contrast to a traditional regression model used by Lazarus et al. (1990) enabling to incorporate effects which represent only a random sample of a larger set (SAS, 1996).

The use of ACF improved the annual carrier production of milk by 102 kg, milk protein production by 4.95 kg, and milk fat by 5.52 kg per cow (derived from data set B which included ACF adopters with at least 1 concentrate feeder per 25 cows). The effect of increased milk production per cow on net farm income under Dutch milk quota conditions is approximately 0.30 Dfl. kg, assuming a good alternative use for idle production factors (labour, capital, and buildings) as well as savings on variable costs (e.g., feeding for maintenance and AI) available when the same amount of milk (quota) is produced by fewer cows (Jalvingh and Dijkhuizen, 1997). Under the Dutch quota system, which is based on carrier, levy is raised by 1.8% for each 0.1 percent point increase in fat content above the farm-specific reference level. The reference quota resulted in an increase of 83.65 kg of milk and an additional protein increase of 1.40 kg. Net return to labour and management income increased by Dfl. 43.60 (1US$ = Dfl. 2.00) per cow /year as a result of ACF (value of increased protein is Dfl. 13.23 /kg). For a typical Dutch farm of 50 cows, the increase in income equals Dfl. 2180 /yr. The use of AM shortened the calving interval by 5.7 d, which is estimated to increase net return to labour and management by 5.7 x 2.16 = Dfl. 12.31 per cow /year (Jalvingh and Dijkhuizen, 1997). To break even after incurring annual costs of the investment in ACF or AM in case of a simultaneous investment in ACF and AM, the size of a farm should be about 30 and 50 cows, respectively. The obtained results of ACF and MPM represented different manufacturers serving in the Dutch dairy sector, while AM results were obtained from one manufacturer, and, therefore, will not necessarily be representative of activity measurement in general. Furthermore, generalisation of the estimated effects should be done with care since the population under study did not represent an average Dutch dairy farm.

The marginal value of increased milk carrier and content considers additional concentrate costs, but it is unclear whether the ACF users improved milk production with additional concentrates. In this study only variables recorded in the NRS program were available, enabling to estimate the effect on milk production records, and it is unclear to which extent the effects on milk production and milk content are a result of changes in the proportion of concentrates in the ration. Consumption of concentrate may be decreased or remained at the same level by reallocation of concentrates between cows (improved discrimination between high and low producing cows) or within cows (by stage of lactation). In this case, feed costs for the produced milk will be lower, because a ration with more roughage is less expensive. Incorporation of financial data, which cover to a certain extent concentrate and roughage costs, would give insight on the changes occurring in net farm income and profitability of the different applications. Reduction in labour may also be an important economic reason for adoption. Use of ACF enables to automate the physical process of concentrate feeding, while visual observation by the farmer for oestrus detection can be more specific with additional information of the technologies, and therefore less time consuming. However, learning and use of the system will require additional time. In this study we were not able to quantify the effect on labour since actual time used on the different activities were not recorded. Adoption of new technologies may also be explained by reasons other than an enhancement in net return to labour and management (e.g., substitution of capital in place of labour to reduce the physical activities).

Use of MPM did not significantly affect the production performance records. In addition the interaction term MPMxAM was found to be not significant. Additional analyses comprised 479 farms randomly selected from the NRS database containing the 2358 MPM users with complete yearly observations were matched with the equal number of nonusers according to the selection procedure already described. Use of MPM affected the production of milk, milk protein, and milk fat by 25 kg, 0.34 kg and −0.96 kg. Calving interval was shortened by 0.48 d. The nonsignificant effects ($P > 0.10$) of MPM on the investigated variables was confirmed once more.

Farms without IT adoption, with performance records in 1987 similar to those of farms with IT adoption, were incorporated in the models to improve the estimations. The statistical models were also estimated without control time series for the three different data sets. Herds were included only if they had adopted ACF, MPM, or AM in the investigated time period with observations of before and after adoption of at least 1 y (adoption year of a particular technology between 1988 and 1995). In general, the significance of the estimates became poorer; the results, however, still indicated that ACF adoption increased the production of milk, milk protein, and milk fat and that AM adoption decreased calving interval.

7.5 Conclusion

Our analysis, conducted with the unique data set clearly demonstrated significant effects on milk production records occurring during the first years after the adoption of IT, making a differentiation between the different technologies. Adoption of ACF resulted in an annual improvement in the production of milk, milk protein, and milk fat. This effect was for adopters with at least 1 concentrate feeder per 25 cows at the time of installation even more evident. In contrast, MPM did not have a significant effect on the production of milk and milk protein production, and milk fat tended to decrease over time, as was the case for adopters without or with an integration between MPM and ACF. Calving interval was shortened after the adoption of AM but was not affected by adoption of ACF and MPM.

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8 GENERAL DISCUSSION

8.1 Introduction

The objective of this thesis was to design and analyse investment decisions in information technology (IT) applications (Chapter 1). Applications were adopted on Dutch dairy farms and improved management on an individual cow basis. Of interest were automated concentrate feeding systems (ACF), sensors that measure daily physical activity of cows (AM) and on-line automated parlour systems for recording of milk production (MPM), milk temperature (MTM) and electrical conductivity of quarter milk (ECQM).

First, expert knowledge was elicited to restrict the number of processes on which IT applications were evaluated and to ensure that all important processes were included in the subsequent analysis (Chapter 2). Potential IT effects reported in literature on the identified important processes were incorporated into a simulation model (Chapter 3). In addition, expert opinions were elicited and incorporated to provide a means to interpret the implications of research results for commercial dairy farms (Chapter 4). The results obtained from the simulation model and expert panel were used as input to optimise investment decisions by a dynamic programming model (Chapter 5). Second, in the empirical approach, panel data sets were created and analysed to estimate the effects obtained in practice. Data sets included cross-sectional data and time series data of adopters and nonadopters, as well as farm results before and after adoption (Chapter 6 and 7).

In each of the chapters, objectives, methods, limitations and results have been described and discussed. This general discussion focuses on the relations between the subsequent chapters in this thesis.

8.2 Normative versus empirical approach

The research described in this thesis included two parts: 1) a normative (deductive) approach and 2) an empirical (positive) approach. Normative and empirical research approaches are useful and complementary in supporting investment decisions (Dent and Blackie, 1979; Bennett, 1983; Barry, 1984). The normative approach predicts potential IT benefits from constructing a theoretical model of the investment, and determines what the benefits of the applications could be or should be. Many of the relevant effects are, however, to a certain extent unknown. The impact of IT developments are difficult to determine and are inherently complicated because not just one but a number of interrelated farm processes may be affected by one and the same IT application, each process to a more or lesser extent. Use of normative approaches becomes therefore more complicated when an entire information system affecting a wide range of decisions and activities is under study (Kleijnen, 1980). In addition, the utilisation of the additional information available from IT investments are not only dependent on the additional value of the information, but also, or even more, on the subsequent managerial actions undertaken. However, reported IT benefits in literature were often obtained under experimental conditions with the technical performance of the technology as research objective (Nielen, 1994 and De Mol et al., 1997), not adequately capturing the effect of this management component on the overall result. As a result, it is impossible to derive unambiguous IT effects of the investments from the literature. The limitations were partly overcome since technologies under investigation were directed towards specific processes. In addition potential benefits were derived by combining literature and opinions of experts which had considerable experience with the IT applications under research conditions. Their knowledge were elicited on how these systems would work on commercial farms taking into account management effects. In this way potential benefits could be derived.

The empirical approach observed the actual effects of the investment (realised benefits) and determined what the value of the additional information in the operational management appeared to be. This approach is complicated by the fact that many of the relevant variables are difficult, if not impossible, to obtain. In addition, the causality of significant relations between technologies and performances cannot fully be proven with this kind of analyses (Verstegen et al., 1998). However, necessary experimental designs on commercial farms are costly and time-consuming. In this research historical data of milking records were obtained and used to estimate benefits.

The possible dichotomy between potential and realised improvements of IT applications under Dutch production conditions could be examined. Quantifying the difference between the benefits what should be obtained and what appeared to be obtained is valuable to determine the importance of management in relation with the utilisation of new technologies and can facilitate in formulating actions to improve on-farm use of the technologies. The discussion is focused towards the processes of concentrate feeding, oestrus detection and mastitis detection. Ultimately, the implications of different benefits, obtained from the normative and empirical approach, on the appraisal of the investment are discussed.

8.2.1 Automation and accuracy of concentrate feeding

The normative as well as empirical research approach estimated an increment in fat and protein production in case ACF was implemented. The simulation model calculated that a more frequent and accurate performance-related concentrate provision increased annual milk protein and milk fat by 1.48 and 5.26 kg per cow, respectively. In the empirical analysis, all ACF users realised an annual increment in protein and fat by 2.90 and 2.81 kg per cow, respectively. Farms which were utilising ACF more frequently per cow (at least 1 concentrate feeder per 25 cows at the time of installation) improved annual protein and fat production by 4.95 kg and 5.52 kg per cow, respectively. The fact that less intense ACF users did not realise these results, stressed indirectly the importance of the frequency of concentrate feeding. The normative assumption that ACF did not result in milk carrier increase was not in concordance with the empirical results of 102 kg increment per cow per year.

A major problem of the normative analysis was that necessary input about potential benefits was not consistent. The estimated benefits reported in scientific literature applicable for Dutch production conditions were ultimately used as input (Chapter 3). One of the reasons for the fact that empirical effects were profound, even more profound than potential benefits depending from which literature they were obtained, might be the area of automation. With this kind of applications the actual physical process of concentrate feeding is automated and improved (more accurate and more frequent). Management of this kind of applications was rather easy; on average once a month concentrate feeding regimes had to be adjusted, while daily operation and control relied on process-control computers. Another reason may be the fact that under experimental conditions the default situation (without ACF), management with respect to feeding was stringently complied. Possibilities to improve farm results could therefore be more limited in comparison with practical default conditions with possible suboptimal feeding management. Besides an individual concentrate supplemention strategy with ACF also total mixed ration (TMR) feeding has been adopted recently on Dutch dairy farms. This method is gaining interest because of increased herd size and labour costs in dairy production. Moreover, it can make feed rations cheaper and more flexible with respect to by-product concentrates. Results obtained in this research derived of increased frequency of supplemention of concentrates may be expected of the same magnitude with TMR use.

A more accurate milk production estimation and ultimately concentrate feeding, possible with on-line MPM, had a minor impact on gross margin according to the normative model. In the empirical analysis on-line MPM did not have a significant effect on milk production records at all. A considerable part of the MPM users had a stand-alone system, individual milking records were not stored in a historic database upon which concentrate feeding strategy could be based. A stand-alone system did not additionally support management in comparison with a traditional milking jar. Information was lost once a cow had left the milking parlour. Even MPM users which had an integrated system could not improve production results. Apparently the additional information was or could not be utilised by the farmer to improve managerial decisions. Further research is necessary to understand and improve the utilisation of this type of information. It may be the case that the current user-interface of the information systems does not represent the value of the information adequately to the farmer. In addition, devoted time and current management skills to interpret and subsequently deal with the information could be limited. Besides the necessarity to improve the utilisation, enabling to realise benefits, a reduction in retail price of on-line MPM sensors will accelerate the justification of the investment. On-line MPM sensors and milk jars have to be approved by the international committee for animal recording (ICAR). To satisfy the ICAR requirements, deviations between the measured value and the actual (reference) value have to be small. In addition installed sensors have to be checked periodically. Sensors need to be recalibrated/adjusted or replaced if the standard is not met. Accurate milk recording is essential to support daily management, however, adjustments in concentrate feeding level is commonly carried out on a monthly basis using averaged milk production of all milkings of the previous period. A small decline in accuracy will therefore not result in different feeding levels, while retail price and maintenance costs are considered to drop importantly. Improvement of daily management with respect to oestrus detection was not significant even with the small deviations between the measured milk amount and the actual milk amount under research (all systems were ICAR approved). Therefore, a small decline in accuracy will not affect oestrus detection. Further research is necessary to find an optimal trade-off between accuracy and operation costs.

8.2.2 Oestrus detection

Potential improvements in oestrus detection obtained from the normative analysis were more profound than realised in the empirical analysis. The expert panel estimated that AM improved oestrus detection from 61% to 76%. This would result in a reduction of calving interval by approximately 13 days according to the simulation model. In the empirical research, calving interval was reduced by 6 days after adoption of AM, and was not affected by adoption of ACF or on-line MPM.

These values of oestrus detection were low in comparison with the empirical results of De Mol et al. (1997) obtained at research stations. They estimated a level of approximately 90% with support of pedometers. Errors caused by missing or erroneous pedometers, or errors occurring in reading the step counter values were not included in the analysis. This selection procedure is commonly used in experiments. However, under practical management conditions these errors cannot be omitted. Another reason for lower technical performance might be that maintenance of hardware, calibration and maintenance of the software is more stringent complied under experimental conditions than actually done by farmers.

An important issue to consider with respect to IT is how farmers utilise the additional information. As a result of daily monitoring of activity, more timely and better information became available. Ultimately the farmer had to interpret the information and take actions to improve managerial decisions in order to fully utilise the system. This final part is essential and is heavily depending on the management skills of the farmer. The collected data did not describe how farmers managed the additional information. Incorporating this kind of information will enhance the ability to compare and interpret the differences in results among IT-users.

8.2.3 Mastitis detection

The advantages from an early diagnosis of mastitis followed by a particular therapy are yet unclear (Nielen, 1994). We estimated an arbitrary benefit in order to perform a break-even analysis which quantified the maximum costs of the system to justify the additional benefits. Further experimental research is needed to define a suitable therapy and to quantify the improvements in technical results.

No valid data of MTM and ECQM adopters could be obtained and subsequently analysed because the number of adopters were limited and difficult to identify. Adoption of EC(Q)M on Dutch dairy farms increased in the years 1992, 1995, 1997 rapidly from 50, 850 to 1200 respectively, while adoption figures of MTM were low (ATC, 1997). The empirical research method described in this thesis can easily be applied to evaluate the benefits of the EC(Q)M system with respect to the milk records from the NRS (Royal Dutch Cattle Syndicate, Arnhem, The Netherlands). However, milk production records were defined on an aggregated level, not clarifying how these possible significant improvements in milk production were obtained. The potential benefits of improved management due to an early detection and therapy of potential clinical mastitis cases is ultimately lower production losses. Besides this variable, potential benefits could be according to Nielen (1994) a reduction of clinical mastitis incidence, a better response rate to treatment, less lactation therapy with antibiotics, less premature culling and a reduction in cow and/or bulk milk tank (BMT) somatic cell count (SCC). In order to get more insight into which way benefits occur, additional information should be gathered, for example number of clinical mastitis cases, infected quarters, bacteria and treatments (Houben et al., 1993).

8.3 Comparison of empirical results

Automation of the cow recording system with a management information system (MIS) offers the ability to improve utilisation of individual cow production records in order to support managerial activities and decision making. The IT applications evaluated in this thesis captured additional on-line cow side data but at the same time incorporated some kind of automated cow recording system. Therefore it was investigated what the value of the MIS part was. Yearly production and reproduction data of MIS users in The Netherlands were analysed to determine whether MIS significantly improved herd performance variables. Despite the vast possibilities of management automation, the use in current commercial MIS is in the standard version limited to animal production tables, attention lists and working schedules. However, MIS users could have installed additional software, thereby enhancing the functionality of the MIS system.

Adoption and use of an MIS resulted in a significant annual increase in milk (carrier) and protein production of 62 kg and 2.36 kg per cow respectively. Calving interval was shortened by 5 days. To make a more clear comparison between the two Dutch data sets, the MIS data set was analysed with two subsets which differed in herd size. The estimated effect on calving interval was significantly affected on the relatively bigger farms, while milk, protein and calving interval were significantly affected on the relative smaller farms. The relatively bigger farms could be characterised similar to farms which adopted ACF, MPM and AM. Apparently, the automated cow recording component improved calving interval almost as much as a system in which in addition AM was implemented. Further analyses with respect to the underlying reproduction variables was conducted. The additional dependent reproduction variables such as heat detection percentage, interval calving to first insemination and non-return percentage at 56 days after insemination, were all significantly improved by

MIS use. Adoption of AM only resulted in a significant improvement in heat detection percentage. These results clearly demonstrated that AM was more specific supporting heat detection while MIS use supported reproduction in general. The question remains to which extent the additional values of AM was attributable to the MIS part and AM sensor part. If the MIS part was dominant this would also result in significant results for ACF and MPM users since the MIS component in the AM application was basically identical. However ACF and MPM did not significantly affect calving interval, and therefore the MIS part in case of AM adoption is limited utilised.

Generalisation of the estimated effects should be done with care. In the study of Tomaszewski et. al (1997) yearly data of sixty-six herds in Texas from 1983 through 1996 were analysed to determine MIS effects. A significant effect was estimated of 421 kg milk per cow per year. No significant effect of an MIS system could be attributed to the reproductive variables. Further, there was no indication that herds with a rapid milk increase or larger herds were more inclined to switch to an MIS. Management structure can have a large effect on the benefits of MIS or IT applications in general. Cows were milked in the Dutch situation by the farm manager while in Texas farm management and milking were strictly separated. It is plausible that in the latter case the farm manager was more depending on some kind of formal MIS. In addition, time and skills are more restraining when the number of animals and the amount of recorded data increase (Verstegen, 1998). The average herd size in the current study was small in comparison with the Texas herds. In addition, Texas dairy farmers are operating in the absents of production restrictions, enabling to achieve higher benefits in case milk production per cow increases.

A similar system to that studied in this thesis was implemented on Israeli kibbutzim. Benefits were quantified to determine the extent to which the effects were influenced by a different production system. Yearly production and performance data were obtained from the Israeli Holstein Herdbook. The Israeli data set relate to somewhat larger farms than in The Netherlands but which also operate under a milk quota system. The data relate to farms that adopted the AFIMILK system (SAE Afikim, Kibbutz Afikim, Israel) in which MPM, AM and electrical conductivity of milk (ECM) were recorded on-line. The Israeli data set contained 162 kibbutzim with 3 times milking daily of which 74 kibbutz dairies adopted the AFIMILK system. The effects on milk, protein and fat production as well as calving interval were quantified with the model used by Tomaszewski et al. (1997).

The AFIMILK system in Israel resulted in an improvement of the annual milk (carrier) and protein production of 191 kg and 4.52 kg per cow, respectively. The estimated effects on production variables for Israeli kibbutzim were larger than the combined effects of AM and

MPM on Dutch dairy farms. Again, management structure and amount of recorded data on larger farms can be an explanation for the observed differences. Calving interval was reduced by 4 days after adoption. Reproduction improvement was of the same magnitude as under Dutch production conditions. In the empirical analysis of the AFIMILK system, which incorporates conductivity measurement, a significant reduction in somatic cell count was recorded in the first year. This effect was not significant from the second year and onwards.

8.4 Implications of results

Much research is focusing on the effectiveness of the applications under experimental conditions (Nielen, 1994 and De Mol et al., 1997) while the critical aspect of implementation is limited investigated (Anderson, 1993). Implementation involves acquiring the necessary recourses, putting the chosen plan into action, controlling the outcome, and evaluating the outcome which may result in learning (Öhlmér et al., 1998). This lack of knowledge about 'how' may be one of the reasons that management tools are not being used by farmers to the extent expected (Putler and Zilberman, 1988; Davis et al., 1989; Batte et al., 1990). In our research the different estimated benefits, obtained from the normative and empirical approach, varied between the types of technologies. Significant empirical results were estimated for technologies that where directed towards automation of daily operation and were control relied on process-control computers. The discrepancies between normative and empirical effects were considerable for technologies in which the farmer had to interpret the additional information and undertake actions in order to fully utilise the system. So the factor management plays an important role for these applications.

Farmers who benefit potentially most from the use of the new technologies are generally the last to adopt the technology. Farmers who adopt first are likely to be more receptive to innovations, have a better management capacity and more motivation for training. This relationship between innovativeness and the need for benefits is called the innovativeness-needs paradox (Rogers, 1995). However, technologies will not be utilised to the same extent by the farmers in the two groups mentioned. Although potential benefits on farms with moderate production results are theoretically higher, this will not necessarily be the case in practice. The fact that production results before adoption are moderate may indicate that decision-making skills are more limited and this may ultimately limit the benefits of the technology. For example, Verstegen (1998) estimated that the value of a management information system was positively correlated with the management level of the user. Although users with high management levels tended to be better informed than users with low management levels, they derived more added value from a management information system. Management capacity, defined as having the appropriate personal characteristics and skills to deal with the right problems and opportunities in the right moment and in the right way, and willingness to change management are therefore the decisive factors for the utilisation of the application in practice.

An important issue to consider is that learning and use of the system will require time and will improve over time. A gradual investment may in this case have advantages over an impatient investment pattern (Byerlee and Hesse De Polanco, 1986). Learning with a rather simple and less expensive system can prevent sub-optimal utilisation of more advanced systems. To narrow the gap between potential and realised results, more attention has to be paid to the aspect of learning. Manufacturers should train the users at the time of installation and assist them during implementation to ensure that the system is properly utilised. The performance of the chosen day-to-day actions should be monitored continuously during implementation to make sure that management actions formulated are in fact working (Kaplan and Norton, 1996). These procedures should be done on basis of a set of measures that are most critical for the success of implementation. Actions should be undertaken if aspirations are not met. Moreover, comparing the results and experiences with colleagues in peer meetings and, in addition, assistance by farm advisors and veterinarians can improve the utilisation. In general, more research should be undertaken on the implementation of management actions to optimally utilise the additional information. This is especially important for technologies which depend heavily on management skills of the user.

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SUMMARY

Introduction

In farming, the need for more and better information for decision making is not a new issue. Over the years, however, this issue has become more dominant for capital-intensive farming systems due to increasing economic pressure. Small differences in production performance result in an increasing difference in profit. As a result, modern farming places stronger demands on farmers' management skills in order to maintain profit and guarantee continuity of the farm. Consequently, utilities that support management are gaining importance. The economic appraisal of the investment is difficult and inherently complicated because of the dynamic nature of the decision environment. Technical performance and retail price is likely to improve over time and therefore consequences of delaying the investment should be evaluated. The objective of this thesis was to design and analyse investment patterns in information technology (IT) applications in order to support investment decisions. Evaluated applications were adopted on Dutch dairy farms and improved management on an individual cow basis. Of interest were automated concentrate feeding systems (ACF), sensors that measure daily physical activity of cows (AM) and on-line automated parlour systems for recording of milk production (MPM), milk temperature (MTM) and electrical conductivity of quarter milk (ECQM).

Normative approach

As the costs of the systems are usually quite clear, the first step is to investigate the potential benefits of the systems. The normative approach predicts potential IT benefits from a theoretical model of the investment, and determines what the benefits of the applications could be or should be. If the potential benefits outweigh the costs then, subsequently, benefits should be investigated under practical conditions. However, in order to formulate an economic model it is essential to determine in which way IT applications will support management. A methodology based on system decomposition principles (Chapter 1) was used to elicit expert knowledge with this respect. Improvements in oestrus detection, mastitis detection and concentrate feeding were considered to be the most important benefits with respect to operational dairy cow management.

Potential IT effects at research stations on different processes reported in literature were incorporated in a simulation model (Chapter 2). Simulating a specific farm, with and

without the potential effects of the IT applications, provided a mean to determine the aggregated impact at farm level. The improvements in the different processes were calculated for a range of farm-specific characteristics. Implementing ACF enabled a more frequent and accurate performance-related concentrate provision, thereby increasing annual production of milk protein and milk fat per cow (1.48 and 5.26 kg). Gross margin improved by Dfl. 0.77 per 100 kg FPCM per year under Dutch production conditions. Improvement in oestrus detection from 50% to 90%, feasible with AM, reduced calving interval by 19 days and increased gross margin by Dfl. 1.28 per 100 kg FPCM per year. A more accurate milk production estimation with MPM had a minor impact on gross margin.

In addition, expert opinions were elicited and incorporated to provide a means to interpret the implications of research results for commercial farms (Chapter 3). Detection characteristics at farm level were lower than reported in experimental studies under research conditions. For example, it was estimated by the expert panel as a whole, that AM would improve oestrus detection from 61% to 76%, reducing calving interval by 13 days.

The results obtained from the Chapters 2 and 3 were used as input to optimise investment decisions by a dynamic programming model (Chapter 4). The model's objective was to determine the investment pattern that maximised the net present value over a given planning horizon. The model determined and quantified the optimal combination of (a stepwise) IT implementation for a typical Dutch dairy farm. Results for a typical Dutch dairy farm showed that the optimal investment pattern included ACF given the assumed economic input data. Additional investment in AM was incorporated at the same time if the default oestrus detection was average. Break even analysis indicated under which retail price conditions on-line parlour automation (MPM, ECQM and MTM) was incorporated in the optimum investment pattern.

Empirical approach

In the empirical approach two panel data sets were analysed to estimate the realised effects. Cross-sectional data and time series of adopters and non-adopters of IT applications were included in the data sets, as well as farm results before and after adoption (Chapter 5 and 6). Yearly production and performance data were obtained from the Royal Dutch Cattle Syndicate (NRS). Differences between after and before adoption (cases), resulting from technology use, were corrected for trends and biases since time series data of other farms were included in the analysis (controls). In addition, panel data design made it possible to estimate technology effects for each year after adoption, clarifying whether the particular technology utilisation acted like a trend over several years or occured as an instant jump at the time of adoption.

The cases and controls closely matched each other in 1987 with respect to the variables under research. Herd size over years for adopters and nonadopters was similar, indicating a randomness in adoption with respect to the autonomous growth of the farms. Faster increasing herds were not more inclined to adopt than slower increasing control herds.

All of the IT applications incorporated some kind of management information system (MIS) to improve utilisation of individual cow production records in order to support managerial activities and decision making without capturing of additional on-line cow side data. To estimate the benefits of an MIS a Dutch data set comprising 357 farms MIS adopters and an equal number of nonadopters was analysed (Chapter 5). In addition, a second Dutch data set comprising ACF, MPM and AM adopters was analysed (Chapter 6). No valid data of MTM and ECQM adopters could be obtained.

Adoption and use of an MIS resulted in a significant annual increase in milk (carrier) and protein production of 62 kg and 2.36 kg per cow, respectively. Calving interval was shortened by 5 days. An intensely used ACF resulted in an improvement of the annual milk (carrier), protein and fat production of 102 kg, 4.95 kg and 5.52 kg per cow, respectively. In contrast, on-line MPM did not have a significant effect on milk production records. Calving interval was reduced by 6 days after adoption of an AM system, and was not affected by adoption of an ACF or on-line MPM.

Paired comparisons of the least squares means have been tested for significance. Changes in the production of milk, milk protein, and milk fat increased significantly in the consecutive years of a particular technology use. In general, 1st year performances lagged behind that of the subsequent years. For example, estimates for ACF use showed significant effects on production of milk (114 kg), milk protein (4.98 kg) and milk fat (5.49 kg) for nonadopters compared with adopters after the 2nd and 3rd year.

Normative versus empirical results

The discrepancy between realised and simulated effects on calving interval were considerable for AM. Reported effects in literature at research stations about the potential improvements in oestrus detection were high. It was estimated by the expert panel that AM would improve oestrus detection more moderate. This resulted in a reduction of calving interval by approximately 13 days according to the simulation model, while in practice a realised reduction of 6 days was estimated. Apparently farmers could not utilise the information as good as expected by the expert panel and documented research results. The implication of this is that AM would be incorporated in the economic optimum decision under more stringent conditions of e.g. farm size and retail price, while net present value of the combined investment in ACF and AM would be lower. Moreover, an MIS improved calving interval almost as much as a system in which AM was implemented. On-line MPM did not significantly improve realised technical effects. These findings have limited implications on the optimal investment decision since on-line parlour automation were in general not incorporated in the optimal investment pattern. Realised technical effects on milk protein and milk fat by ACF adopters were higher than simulated effects. The simulation model calculated that a more frequent and accurate performance-related concentrate provision by means of ACF would increased milk protein and milk fat per cow by 1.48 and 5.26 kg per cow per year. This was estimated in the empirical analysis to be 4.95 kg and 5.52 kg per cow per year.

Main conclusions

Based on *the results*, the following conclusions can be drawn:

- Results obtained from the normative and empirical approach show that investments in automated concentrate feeders are profitable for a typical Dutch dairy farm. A simultaneous investment in activity measurement was profitable for herds with an average oestrus detection level.
- Use of an automated concentrate feeder resulted in a significant improvement in annual production of milk (carrier), milk protein, and milk fat (102, 4.95, and 5.52 kg per cow, respectively). In contrast, on-line measurement of milk production and cow activity did not significantly affect milk production under the current production conditions. Adoption of a cow activity measurement system shortened calving interval by 6 days.
- The discrepancy between normative and empirical benefits was considerable for technologies in which the user had to interpret the additional information and undertake actions in order to fully utilise the system. This stressed the importance of the human component in the decision-making process.
- The increase of herd size over years for adopters and nonadopters was similar, indicating a randomness in adoption with respect to the growth of the farms. Faster increasing herds were not more inclined to adopt than slower increasing control herds, while estimated technology effects increased gradually over years rather than suddenly at the time of adoption.

Based on this research the following conclusions regarding to the *methodologies used* can be drawn:

- Dynamic programming is a valuable method to determine the optimal investment pattern in information technology since it enables improvement of sensor performance and retail price over time to be included.
- Conjoint analysis provides a worthwhile means to quantify the effectiveness of the technologies on commercial farms on basis of an expert panel representing different on-line sensor research groups.
- Combining cross-sectional data and time series data of adopters and nonadopters as well as farm results before and after adoption provides a good opportunity to estimate technology effects corrected for trends and farm effects. In addition, the design allows estimation of technology effects for each year after adoption and clarifies whether or not use of the particular technology was characterised by a gradual response over several years or was immediately apparent at the time of adoption.

SAMENVATTING

Inleiding

Inkomensmarges op individuele melkveebedrijven staan in toenemende mate onder druk. Kleine verschillen in technische resultaten hebben grote gevolgen wat betreft de bedrijfsinkomens. Verschillen in inkomens worden zowel tussen vergelijkbare bedrijven gesignaleerd als ook binnen bedrijven in de loop van de tijd. Door de onder druk staande economische resultaten is goed management zeer belangrijk om de winstgevendheid en daarmee de continuïteit van het bedrijf te waarborgen. Mogelijkheden om het management te ondersteunen winnen daarmee sterk aan belang. Het in dit proefschrift beschreven onderzoek heeft als doel het ontwikkelen en analyseren van methodieken om investeringsbeslissingen in de informatie-technologie (IT) te ondersteunen. De economische evaluatie van deze investeringen is gecompliceerd vanwege het feit dat de toegevoegde waarde van (individuele) applicaties moeilijk te achterhalen is. Om de toegevoegde waarde te schatten, is derhalve een aantal opeenvolgende en onderling samenhangende methodieken toegepast. De in deze studie onderzochte IT toepassingen waren gericht op de ondersteuning van het individueel diermanagement. Het gaat hierbij om krachtvoercomputers, aktiviteitsmeters en sensoren in de melkstal voor de bepaling van de melkhoeveelheid, melktemperatuur en melkgeleidbaarheid.

Normatieve benadering

In het onderzoek werden een tweetal methodieken toegepast om IT investeringen te evalueren, te weten een normatieve en een empirische. De normatieve benadering voorspelde de potentiële IT opbrengsten met behulp van een ontwikkeld simulatiemodel. Echter om een economisch simulatiemodel te ontwikkelen is het noodzakelijk te achterhalen op welke bedrijfsprocessen de specifieke IT toepassingen invloed uitoefenen. Een methodiek gebaseerd op het "informatiemodel melkveehouderij" werd gebruikt om de kennis van deskundigen hieromtrent in kaart te brengen. Met name krachtvoerverstrekking, oestrusdetectie en mastitisdetectie werden gezien als de belangrijkste bedrijfsprocessen die met behulp van de IT toepassingen ondersteund konden worden ten behoeve van het operationele management (Hoofdstuk 2).

Potentiële IT effecten, gerapporteerd in de wetenschappelijke literatuur, werden opgenomen in een simulatiemodel beschreven in Hoofdstuk 3 van dit proefschrift. Simulatie van een specifiek bedrijf, met en zonder de (potentiële) effecten van de IT toepassingen, maakte het mogelijk het gecombineerde resultaat op bedrijfsniveau te bepalen. De bedrijfsresultaten werden berekend voor een reeks specifieke bedrijven. Als gevolg van een frequenter en nauwkeuriger krachtvoergift met behulp van een krachtvoercomputer stegen de jaarlijkse productie van melkeiwit en melkvet met respectievelijk 1.48 kg en 5.26 kg per koe. Het saldo nam toe met 0.77 gulden per 100 kg melk (FPCM) per jaar. Verbeteringen ten aanzien van oestrusdetectie van 50% tot 90%, bijvoorbeeld mogelijk gemaakt met behulp van aktiviteitsmeting, reduceerden de tussenkalftijd met 19 dagen en verhoogden het saldo met 1.28 gulden per 100 kg FPCM per jaar. Een nauwkeuriger schatting van de melkproductie met behulp van een elektronische melkmeting had slechts een gering effect op het saldo.

De gerapporteerde onderzoeksresultaten werden bijgesteld met behulp van een enquête gebaseerd op conjunct meten (Hoofdstuk 4). De hiermee verkregen gegevens sloten beter aan bij het doel de potentiële bedrijfsresultaten te achterhalen. Detectiekarakteristieken op bedrijfsniveau waren lager dan de literatuurwaarden bepaald in experimentele omstandigheden. De geraadpleegde deskundigen verwachtten bijvoorbeeld dat de oestrusdetectie op een doorsneebedrijf zou stijgen naar 76% met behulp van aktiviteitsmeting, zodat de tussenkalftijd verkort zou worden met 13 dagen.

De resultaten van de hoofdstukken 3 en 4 zijn samen met de bijbehorende kosten van de applicaties gebruikt als invoer om (stapsgewijze) investeringsbeslissingen met een dynamisch programmeringsmodel te optimaliseren (Hoofdstuk 5). Het doel was met behulp van het model de optimale investeringsstrategie over een gegeven planningshorizon van 20 jaar te bepalen. Daarbij werd de netto contante waarde van de cash-flow gemaximaliseerd. Mogelijke gunstige ontwikkelingen ten aanzien van een reductie van het investeringsbedrag en een verbetering van de prestatie buiten beschouwing gelaten, resulteerde de optimale investeringsstrategie in de aanschaf van een krachtvoercomputer. Een gelijktijdige investering in aktiviteitsmeters was zinvol op bedrijven met een gemiddelde visuele oestrusdetectie. Gevoeligheidsanalyses toonden aan onder welke omstandigheden IT toepassingen in de melkstal (meting van melkproductie, geleidbaarheid en melktemperatuur) opgenomen werden in het optimale investeringsstrategie.

Empirische benadering

Het tweede deel van deze studie betrof de empirische benadering van de gerealiseerde opbrengsten in de praktijk. Productiegegevens van 1987 tot en met 1996 van bedrijven die gedurende deze periode investeerden in een of meerdere toepassingen (IT bedrijven) en van bedrijven die niet investeerden (controle bedrijven) zijn geanalyseerd. In de analyse zijn de geschatte technologie-effecten gecorrigeerd voor bedrijfsspecifieke en trendeffecten. Bovendien maakte de gevolgde procedure het mogelijk om de technologie-effecten te schatten voor ieder jaar opvolgend op het investeringsjaar, zodat inzicht werd verkregen in de stabiliteit van de technologie-effecten en in de eventuele toename van de effecten naarmate het systeem langer werd toegepast.

Alle IT toepassingen beschikten over een management informatiesysteem om beter van de individuele productiegegevens te kunnen profiteren. Om het effect van een management informatiesysteem te kunnen bepalen werden gedetailleerde gegevens van 357 bedrijven die deze technologie toepasten en gelijk aantal controle bedrijven geanalyseerd (Hoofdstuk 6). Het tweede databestand bestond uit 295 bedrijven die krachtvoercomputers, elektronische melkmeting en/of aktiviteitsmeting gebruikten (Hoofdstuk 7). Van bedrijven met melktemperatuursensoren en geleidbaarheidsensoren konden geen betrouwbare gegevens worden achterhaald. Productiegegevens in 1987 van (toekomstige) IT bedrijven en controle bedrijven waren gelijkwaardig. Ook de ontwikkeling van de bedrijfsgrootte in de onderzoeksperiode was voor beide groepen gelijk, zodat de investering willekeurig was ten aanzien van de autonome groei van het bedrijf.

De melkproductie en eiwitproductie stegen significant na aanschaf van een management informatiesysteem met gemiddeld 62 kg en 2.36 kg per koe per jaar, terwijl de tussenkalftijd afnam met 5 dagen. Een bedrijf met maximaal 25 koeien per krachtvoercomputer op het moment van installatie, realiseerde een toename van de melkproductie, eiwit en vet met respectievelijk 102 kg, 4.95 kg en 5.52 kg per koe per jaar. Het toepassen van elektronische melkmeting en aktiviteitsmeting had echter geen significant effect op de productie. De tussenkalftijd nam met 6 dagen af op bedrijven met aktiviteitsmeting terwijl de tussenkalftijd niet beïnvloed werd door de installatie van een krachtvoercomputer en elektronische melkmeting. De geschatte technologie-effecten voor ieder jaar na investering toonden aan dat de productie van melk, eiwit en vet verbeterden in de opeenvolgende jaren van technologie-gebruik.

Normatieve versus empirische resultaten

De mogelijke discrepanties tussen de gesimuleerde effecten, bepaald met de normatieve benadering, en de gerealiseerde effecten, bepaald met de empirische benadering, zijn nagegaan per IT toepassing en bedrijfsproces. Gerealiseerde productieverbeteringen van melk, eiwit en vet door krachtvoercomputers waren hoger dan gesimuleerde effecten. Zowel de gesimuleerde als de gerealiseerde verbeteringen waren voldoende hoog om de bijbehorende kosten te dekken, een krachtvoercomputer werd derhalve opgenomen in de optimale investeringsstrategie. De reductie van de tussenkalftijd met behulp van aktiviteitsmeting was aanzienlijk. Gerapporteerde potentiële verbeteringen behaald onder experimentele omstandigheden waren hoog, zij werden door de deskundigen naar beneden bijgesteld. Dit resulteerde in een reductie van de tussenkalftijd met 13 dagen volgens het simulatiemodel, terwijl een reductie van 6 dagen gerealiseerd werd in de praktijk. Het gevolg hiervan is dat aktiviteitsmeting in het optimale investeringspad opgenomen werd onder strengere condities ten aanzien van minimale bedrijfsgrootte en de maximale hoogte van de aanschafprijs. Elektronische melkmeting had bij beide benaderingen een gering (normatief) of zelfs geen significant (empirisch) positief effect op de technische resultaten. Dit verschil heeft slechts beperkte gevolgen voor de gepresenteerde resultaten omdat deze toepassing niet in de optimale investeringsstrategie werd opgenomen. In het algemeen kan worden gesteld dat naarmate de effectiviteit van een technologie meer afhangt van managementcapaciteiten, de gerealiseerde opbrengsten in de praktijk lager uitvallen dan verwacht werd op basis van de inbreng van deskundigen en uit literatuurgegevens. Toekomstig onderzoek zal zich moeten richten op de implementatie (inclusief training) om de toegevoegde waarde van deze systemen beter te benutten.

Belangrijkste conclusies

Met betrekking tot *de resultaten* kunnen de volgende conclusies getrokken worden:

- Bij zowel de normatieve als empirische studie was de investering in krachtvoercomputers op een doorsnee Nederlands melkveebedrijf rendabel terwijl een gelijktijdige investering in aktiviteitsmeting rendabel was voor bedrijven met een gemiddelde oestrusdetectie.
- Na aanschaf van een krachtvoercomputer steeg de jaarlijkse productie van melk, eiwit en vet significant met respectievelijk 102 kg, 4.95 kg en 5.52 kg per koe. Elektronische melkmeting en aktiviteitsmeting resulteerden niet in een toename van de productie. Het gebruik van aktiviteitsmeting verkorte de tussenkalftijd met 6 dagen.
- De discrepanties tussen de normatieve en empirische resultaten zijn aanzienlijk. Met name voor technologieën waarbij de gebruiker de extra informatie moet interpreteren voor het nemen van akties om de toegevoegde waarde volledig tot zijn recht te laten komen. Deze discrepanties benadrukken het belang van de gebruiker in het besluitvormingsproces.
- De toename in bedrijfsgrootte was gelijk voor bedrijven die investeerden in informatietechnologie als voor bedrijven die niet investeerden gedurende de geanalyseerde periode. De geschatte technologie-effecten toonden aan dat de productie van melk, eiwit en vet verbeterde gedurende opeenvolgende jaren van technologie-gebruik.

Met betrekking tot *de toegepaste methodieken* kunnen de volgende conclusies getrokken worden:

- Dynamische programmering is een waardevolle methodiek ter bepaling van het optimale investeringsscenario voor informatie-technologie. Mogelijk gunstige ontwikkelingen ten aanzien van het investeringsbedrag en de prestatie in de tijd kunnen relatief eenvoudig worden opgenomen.
- Experimentele onderzoeksresultaten kunnen, waar nodig, met behulp van een enquête gebaseerd op conjunct meteen worden bijgesteld. De hiermee verkregen gegevens sluiten beter aan bij het doel de potentiële bedrijfsresultaten te achterhalen.
- Het analyseren van bedrijfsgegevens voor en na investering als ook van bedrijfsgegevens van hen die niet investeerden maakt het mogelijk technologie-effecten te schatten waarbij gecorrigeerd kan worden voor bedrijfsspecifieke en trendeffecten. Bovendien maakte de gevolgde procedure het mogelijk om de technologie-effecten te schatten voor ieder jaar na investering zodat inzicht verkregen kon worden of de technologie-effecten stabiel waren of veranderden naarmate het systeem langer werd toegepast.

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CURRICULUM VITAE

Marcel Antonius Petronella Marius van Asseldonk werd op 9 juli 1969 geboren te Veghel. In 1988 behaalde hij aan het Zwijsen college te Veghel het diploma Atheneum. In datzelfde jaar werd een start gemaakt met de studie Zoötechniek aan de Landbouwuniversiteit te Wageningen. Hij rondde zijn studie af in 1994 met als afstudeervakken Veefokkerij, Veehouderij en Agrarische Bedrijfseconomie. Een onderzoeksstage werd uitgevoerd bij P.I.C. Inc., Kentucky. Na zijn afstuderen vervulde hij zijn militaire dienstplicht. Vanaf oktober 1994 tot en met oktober 1998 was hij als Assistent In Opleiding aangesteld bij het departement Economie en Management, leerstoelgroep Agrarische Bedrijfseconomie en het departement Agro-, Milieu- en Systeemtechnologie, leerstoelgroep Toegepaste Informatiekunde van de Landbouwuniversiteit te Wageningen hetgeen heeft geleid tot dit proefschrift. Het onderzoek werd ten dele gefinancierd door Nedap Agri B.V. Ten behoeve van de promotie werd een deel van het onderzoek verricht bij het departement Animal Science, Texas A&M University. Sinds oktober 1998 is hij werkzaam als onderzoeker bij de leerstoelgroep Agrarische Bedrijfseconomie.