Kristensen, A. R. 1993. *Markov Decision Programming Techniques Applied to the Animal Replacement Problem*. Dissertation for the dr. agro. degree. Dina KVL, Department of Animal Science and Animal Health, The Royal Veterinary and Agricultural University, Copenhagen. ISBN 87 7026 332 9.

Chapter XII. Conclusions and outlook. (p 159-166)

XII

Conclusions and outlook

In the introduction, the main purpose of this thesis was defined as the adaptation of Markov decision programming techniques in order to be able to cope with the animal replacement problem in a satisfactory way. The problems were identified as the *dimensionality problem*, the *uniformity problem* and possible *herd restraints*. It is now the time and place to conclude to what extent the problems have been solved.

We can conclude from the preceding chapters that the problems are mutually inter-dependent. As shown in Chapter VII, the solution of the uniformity problem may also in some cases contribute to the solution of the dimensionality problem by state space reduction, and as it appears from Chapter VIII, the introduction of herd restraints makes the dimensionality problem worse because such models inevitable become very large when all animals must be considered simultaneously. Thus a true solution to the herd restraint problem will also in some models contribute to the solution of the dimensionality problem.

The main contribution to the solution of the dimensionality problem is, however, the formulation of the hierarchic Markov process. The computational advantages of the method have been illustrated by theoretical considerations and a numerical example in Chapter II. The major forces of the technique may be summarized as follows:

1) The method is exact.
2) The method is much faster than the value iteration method (i.e. the usual dynamic programming technique) as it appears from Chapter II.
3) The method makes it possible to calculate the consequences of an arbitrary policy directly as it appears from Chapter X. Furthermore it is possible directly to calculate many technical and economic results under a given policy as discussed in several chapters (e.g. annual replacement rate, annual milk yield, average litter size etc.)

Since the method is faster than the usual techniques it *contributes* significantly to the solution of the dimensionality problem, because the optimization of larger models becomes realistic in real time. On the other hand, the dimensionality problem has not been *solved*. The limits of the possible have been raised, but not removed.

As concerns the uniformity problem, the Bayesian updating technique of Chapter VII has been proposed. The force of the Bayesian approach is that it constitutes a framework for dealing with imperfect knowledge. At any level of knowledge it is possible to take an optimal action *under the present circumstances* (with imperfect knowledge). Thus the Bayesian approach seems more to be in accordance with a real life situation. It is expected that the method in particular will be relevant in dealing with categorical effects (such as diseases) as sketched in Chapter VII. However, that perspective has to be tested on real data before any finite conclusion may be drawn. As concerns the application to usual quantitative traits as milk yield or litter size the method is considered to be a significant contribution to the solution of the uniformity problem, because it makes it possible to distinguish the variation caused by different effects and thus explains the very nature of the variation in traits. Furthermore the technique may in some cases reduce the size of the state space without loss of information.

Two different herd restraints have been considered in this thesis. One restraint is a milk quota in dairy cattle, which has been dealt with by the introduction of an alternative criterion of optimality maximizing average net returns per unit of milk produced (Chapters V and VI). The new criterion solves the long term ranking problem of cows in a herd producing under a quota, but it does *not* solve the short term adjustment problem of deciding how many cows to use in the production at any time. To include this feature we will have to turn to the parameter iteration method applied in Chapter VIII to an other herd restraint which was a limited supply of heifers. It has been demonstrated that the technique is superior to the usual single-animal models in a situation with shortage of heifers, but it is not an all-embracing method that may be transformed directly to all kinds of herd restraints. The basic idea is to take advantage of the fact that an optimal solution to the unrestricted problem is known and then consider in what way the restraint influences the total present/relative value of the herd. This *basic* idea may also apply to other restraints, but in each case some hard work is left determining the appropriate functions and parameters involved. Thus the herd restraint has not been *solved*, but the *framework* of an approximate method has been constructed.

A secondary purpose of the thesis was defined as illustration and discussion of the applicational perspectives of the techniques. In Chapter IX the applicational areas of the techniques were identified as *research*, *development of methods to be used in practice* and *direct application in commercial herds*. As illustrated in Chapters VI and X, we may conclude that the techniques are useful tools in research were the conditions and traits that influences the optimal policies may be studied. Furthermore they may be used in comparative studies in the development of operational methods to be used in commercial herds (cf. Chapter XI). As concerns direct application in such herds, we must expect that it will become technically possible, but whether or not it is appropriate will depend on the outcome of such studies, and no final conclusion may be drawn at present.

With regard to the need for future research activities, the solution of the dimensionality problem should be given high priority. This may be done in two different ways. One way is to raise the upper limit concerning the size of state spaces to handle. The day when a herd model as the one described in Chapter VIII may be solved exactly is, however, very far away, unless a real epoch-making discovery is done. Furthermore it is a question whether not the limits of the human mind regarding the ability to grasp such a model will be reached before. Another way to solve the problem would be to consider some kind of state space transformation which will reduce the state space with no (or at least little) loss of information. A further development of the Bayesian techniques might be a way of doing this, but much further research in this area is necessary.

Also the question of how to deal with traits related to the health of the animal need to be studied. Again the Bayesian technique might be a relevant tool. It seems obvious that the question of herd restraints must be a main task in the future, since in the real world animal production is performed in herds. Therefore the idea of a simple comparison of the animal in production with a possible replacement is not valid if all animals compete for the same scarce resource or production quota.

These future research areas are reminders demonstrating that further methodological research remains in order to fulfill the objective of this thesis completely, but it should be noticed that *even* if all methodological problems were solved and, accordingly, the rather technical objective was fulfilled, only part of the job had been done. It seems relevant also to consider the work in a wider perspective. On the long view, it is of course the idea that the developed techniques should support the farmer's decisions on which animals to replace. In other words, the techniques are intended to form the central element of a decision support system.

None of the techniques presented have been implemented in a decision support system, and it is natural to ask why not. The situation is in no way unique. Despite at least two decades of research in optimization and simulation models, very little has reached the farmer in the form of working decision support systems. The 3rd International Congress for Computer Technology in 1990 was devoted to "Successful Practical Applications". Afterwards a participant ironically said that some of the applications presented at the congress were "successful" while others were "practical" and some were just "applications". In other words, successful practical applications seem to be exceptions. The title of the 4th congress in the same series "Farm Computer Technology in Search of Users?" suggests that this is a general feeling.

The lack of successful decision support systems in animal production makes it relevant to consider in general what the success of a decision support system would depend on. In Figure 1 the basis of a decision support system is sketched. The elements of the figure should be interpreted as *necessary* conditions (or bottle-necks) that must be fulfilled. (In some cases they may even not be *sufficient*).

The necessary conditions are divided into 4 groups, depending on whether they are *hardware* related, *software* related, *method* related or *farmer* related. Some of the hardware conditions refer to

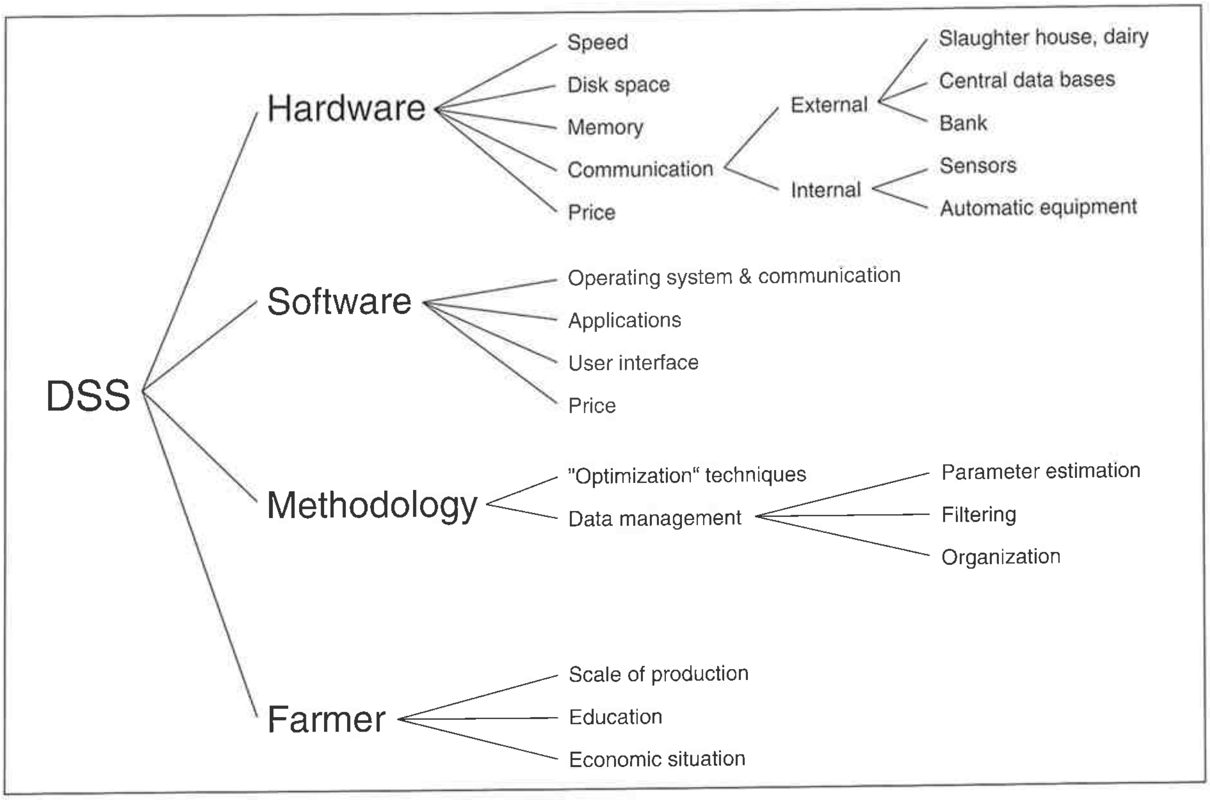

Figure 1. The basis of a decision support system (DSS).

performance characteristics like speed, disk space and internal memory. Some methods require even very powerful computers. In the *short run* the performance of computers may be a bottle-neck in the development of decision support systems, but, as illustrated in Chapter IX, the performance characteristics of computers improve at a very fast rate, so in the *long run* the performance of computers will hardly be a problem. The same applies to communication hardware making the computer able to receive data from external sources like classification of animals and milk from slaughter-house and dairy, or from internal sources (sensors) like temperature and conductivity of milk or weight of animals. It may also be necessary to be able to send data from the computer to automatic equipment like milking robots or automatic concentrate feeding. The last condition mentioned in the figure is the price which has to be sufficiently low to make the investment in hardware profitable.

The *software* conditions refer partially to operating systems and communication software which, however, is commercially developed concurrently with hardware. The development of applications (i.e. computer coding of optimization techniques and data management) with good user interfaces is more important in this context. Especially the user interface has often been overlooked, because most attention has been paid to the coding of the methods developed. Nevertheless, a decision support system with an improper user interface has no chance on the market. The best way to ensure a high level in software development (including user interfaces) is probably to realize that this part of the job should be handed over to specialists in programming (e.g. employed by the advisory service). The researcher, who developed the method, is usually not a programming expert, and furthermore he or she is certainly not impartial in the assessment of the applicational perspectives. On the other hand, a rapid implementation of new relevant methods demands a close cooperation between researchers, advisory service and education. Just as for hardware, the price of the software must be sufficiently low to make the investment profitable.

At least in research, most attention has been paid to *methodology*, in particular "optimization" techniques in a broad sense which in this connection also cover e.g. expert systems and simulation. Several methods and prototypes have been developed and praised by the researchers themselves, but as mentioned before, very little has reached the farm level. Since the utility value of the methods in several cases has been verified, we may conclude that lacking optimization techniques is hardly a bottle-neck in the spread of decision support systems. Just as important, but less studied, is data management. As a result of the technical progress the number of data sources is assumed to increase. Sensors and external communication lines are expected to provide huge amounts of registrations. The transformation of these registrations to data and information demands new methods for filtering, organization of data bases and estimation of parameters on herd level.

Last, but not least, the situation of the *farmer* must be considered. Is the production large enough to justify the purchase of a decision support system, and can he afford it? Even if the answer is yes, the education and lacking computer experience of the farmer may be a problem. This is probably the most limiting factor in the spreading of decision support systems. The lack of computer experience may to some extent be compensated by training and good user interfaces, but it should be recognized that it may take a generation before the average farmer is really familiar with computers and considers them as just as natural tools as pen and notebook. Also the educational level in a wider sense than computer experience is important. For instance, lack of knowledge on statistical theory may be a problem when dealing with stochastic modelling, confidence limits, sensitivity considerations etc.

This short general survey of conditions to be met in order to create a decision support system seems to show that it is not surprising that "successful practical applications" are very few. The main problem is that there has been extensive research in methodology, but the level of software development (in particular the design of user interfaces) and farmer education has not been raised simultaneously.

After these general considerations, focus will be turned back to the specific problem of integrating the methods presented in this thesis in a working decision support system. As all examples of the preceding chapters, this discussion will refer to a commercial dairy herd under Danish conditions.

The methods are very computer intensive, and already this fact creates problems in relation to implementation. If a method is implemented at a central main frame computer, the farmer has to pay for the time spent on optimization, and that will probably be too expensive. If it is implemented on a local personal computer or work station, very high demands on speed and internal memory must be made. These demands necessarily make the computer more expensive to purchase. Furthermore there will be a communication problem, because registrations on individual cow performance are stored in a central data base. Thus a reliable external link to the central data base is necessary (e.g. in the form of a modem). Already these hardware requirements show that *at present* a direct implementation in a decision support system is out of the question. On the other hand, it seems likely that the hardware problems will be solved in the foreseeable future, and that the local implementation probably will be preferred.

At present no software has been developed for direct implementation. The problem of transforming the mathematically expressed methods into effective computer algorithms with low time and space complexity is in no way negligible, but, on the other hand it can be done by a programming expert. The user interface should as always be given high priority, and in Denmark, the introduction of the "Integrated Farm Management System" (*Bedriftsløsningen*) at least provides a common standard. Such a standard is of great value in relation to the training and education of farmers. Thus it is concluded that the software related problems may be solved.

As mentioned, the results of this thesis are a contribution to the development of optimization techniques. The data management problem is only indirectly touched in Chapter VII, where the updating of individual traits is discussed. Until now, the parameters of the models have been estimated once for all, and the only adjustment to the individual conditions is through a herd level of milk yield which may be specified. It should be expected that parameters estimated on individual herd data would be better in the sense of less residual variance and thereby more precise predictions of the future performance of cows. However, the amount of data originating from one herd is usually too small to be used for reliable estimation of parameters.

A solution to this problem might be a more intensive application of Bayesian techniques. When the decision support system is applied the first time, a set of standard parameters are used, but as observations are done in the herd, the prior parameters are updated using Bayes theorem, so that the parameters after a few years will reflect the individual conditions of the herd. This may be regarded as a generalization of the method described in Chapter VII, where only animal specific parameters are updated. A necessary condition of using such an approach is that the problems related to organization and filtering (e.g. for outliers) are solved. A personal point of view is that the introduction of Bayesian techniques to decision support systems and monitoring will become a main issue in the research of the next decade, and if the research is successful it may lead to the breakthrough of decision support systems in animal production.

The conclusion is that an implementation of the techniques in a decision support system is not expected within the next few years. It will only be relevant when (a) the necessary hardware is available at a sufficiently low price, (b) the quality of user interfaces has increased, (c) the data management problems have been solved and (d) the educational level of farmers as concerns the use of computers has been raised. Until these conditions are met the applicational scope of the techniques is in research, as discussed in Chapter IX.