Application of Mathematical Programming Models for Strategic Direction Setting.

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ABSTRACT

Strategic planning is increasingly being adopted by agricultural research, development and extension organisations. Strategic decisions require an assessment of the future and, in particular, the likelihood of growth in industries. Normally this is conducted descriptively with little quantitative analysis and often without involvement from economists. There are many tools available which help to provide information about the future, mathematical programming (MP) being one of them. This paper demonstrates the use of MP to analyse scenarios. Expert groups estimated scenarios for prices and productivity changes which they considered plausible over the next 10 years. The MP model, MIDAS, was used to generate the optimal mix of enterprises and levels of crop and livestock production consistent with these scenarios for typical broadacre crop/livestock farms in different regions of Western Australia. Results are presented and the strengths and weaknesses of this approach are discussed.

Introduction.

Strategic planning is essential for the long term survival of any organisation. Strategy is derived from the Greek word *strategos* which means generalship, or more broadly, leadership. When applied in the context of planning, the word strategic implies planning which is long term in nature and deals with achieving specified end results (Migliore *et al.*, 1995). In other words, strategic planning can be defined as 'the process by which the guiding members of an organisation envision its future and develop the necessary procedures and operations to achieve that future' (Goodstein *et al.*, 1993).

In order to make strategic decisions about the future, information about the future is necessary. This paper will use an example of a study initiated by The Grain Pool of WA (referred to as The Grain Pool from here on) into the future production of grain crops in Western Australia. In order to take maximum advantage of market opportunities, and to provide lead time for market development, marketing organisations need to know the type, quantity and quality of grain to be produced. They also require this information in order to detect if production is out of line with market needs, in which case they need to provide signals back to growers to influence the pattern of production to maximise benefits for the industry as a whole. It was intended that the study would enable The Grain Pool to make strategic decisions with regards to marketing grain in view of the expected future production and diversity of cropping in the state. Information gained from the study was expected to help not only The Grain Pool, but also assist in the medium- to long-term planning of agricultural related activities within Western Australia across all sectors of the industry. For example, transport companies could benefit in planning transport routes, and grain handling and storage bodies could benefit in planning the number of storage bins required and their locations. This paper is a description and discussion of the process The Grain Pool adopted to carry out the study into the future production of grain crops in Western Australia.

There are many tools available to assist in making assessments of the future. Most of these are forecasting techniques which make use of currently available information in order to estimate values for variables of interest for the future (Blyth and Young, 1994a). These tools range from sophisticated quantitative models to simple exercises of judgment. Blyth and Young (1994a) outline the various techniques, both quantitative and qualitative which may be used to make forecasts. They briefly outline the advantages and disadvantages of these techniques and make reference to Jones and Twiss (1978) and Freebairn (1975) for more depth about the actual processes and their advantages and disadvantages.

Scenario analysis is one of these methods which may be used to gain insight into the future, which rather than relying on forecasts, aims to understand the factors that drive the system. Thus, a scenario is not a prediction or forecast of the future, but rather it binds together forecasts and plots, to construct a coherent story about how the future may unfold from identifiable events and trends in the present (Blyth and Young, 1994b). According to Blyth and Young (1994b) scenarios for the future are preferred over forecasts when making strategic decisions because they improve the decision maker's understanding and thinking of the future, as the decision makers are involved in the scenario planning.

In the project proposed by The Grain Pool, the strategic planning process involved holding a series of workshops with experts in order to decide on a scenario for the future production of grain crops in WA. As the farming system involves so many interactions, even if one had a complete grasp of all relevant information, the problem of combining it and appropriately evaluating and analysing it would be beyond the capacity of any single human mind (Pannell, 1996). As a person's mind cannot account for all the different interactions simultaneously, there may be internal inconsistencies in the scenario. The ideal solution to this is to be able to quantitatively assess the scenario with a model which can account for all the interactions and complexities which occur in a farming system. A method by which this could be carried out is by using a mathematical programming model of the farming system.

Ten years ago, a project was carried out to develop an econometric forecasting model for areas planted to wheat in the Cooperative Bulk Handling shipping zone of Geraldton in WA (Lloyd-Smith, 1985). Forecasting using econometric models consists of constructing a statistical model of an economic system in an attempt to analyse and measure cause and effect relationships between the variables in the system (Rodgers, 1974). The project carried out by Lloyd-Smith was only concerned with wheat production. However this study is concerned with total grain production including all other grain crops (eg. barley, oats, canola, lupins, field peas, chick peas, faba beans).

The mathematical programming model MIDAS (Model of an Integrated Dryland Agricultural System) has been used in the past very successfully as an influential tool for things such as research prioritisation, extension, and education (Pannell, 1996). In the case of this project, MIDAS is used to carry out a quantitative analysis of the scenario proposed by experts at workshops. The aim is to aid with strategic decision making and direction setting of an organisation.

What is MIDAS?

MIDAS (Model of an Integrated Dryland Agricultural System) is a mathematical programming model which represents both the biological and economic characteristics of a farming system. The characteristics of the farm can be changed by altering the production parameters in the model. Some examples of these parameters are areas of different soil types, availability of finance, machinery capacity, crop yields and sheep/wool production parameters.

The optimisation process of MIDAS selects a set of activities which maximise farm profits subject to resource constraints of the farm, while taking into account the various positive and negative interactions which occur between activities. For instance, MIDAS will select a profit maximising mix of crops in rotations which may also include sheep and pasture on the various soil types of the farm. It does so by accounting for not just costs and returns of each enterprise but also the interactions such as nitrogen fixation and disease-break benefits from legume crops and pastures to cereals. In optimising the farm profit, MIDAS selects a cropping level which meets the seeding capacity and operating finance limits of the farm. A more thorough description of MIDAS can be found in Kingwell and Pannell (1987).

The key strength of MIDAS is that it can handle changes to several parameters at once and choose a farm plan which maximises profit for the new scenario. This means that optimal farm plans for different scenarios may be analysed and compared, to aid with strategic decision making. However, the general equilibrium nature of MIDAS allows us to look at different scenarios, but not at how the farm manager may change his or her management and resources to get from one scenario to the other. This limitation of the model is not an important factor in the present study which is concerned with equilibrium levels of production, rather than transitional phases.

Case Study: Future production of grain crops in WA.

The study involved the use of MIDAS as a tool to quantitatively analyse scenarios for the future in order to gain a picture of how farms may be managed in 10 years time. This would give The Grain Pool consistent information about the future production of grain crops in WA, and thus facilitate their strategic decision making and direction setting.

The Grain Pool received funding from a range of agriculture related organisations for the study. A private consulting firm, ACIL Economics and Policy Pty Ltd (referred to as ACIL Economics from here on) was contracted to carry out the project. The first step in the process involved workshops organised by ACIL Economics at which a scenario for the future was defined. The workshops involved experts in areas of cropping, such as plant breeders, agronomists and senior extension officers. At these workshops, future yields were discussed and hence state average yields for the various grain crops were estimated for the year 2005. Production estimates were also made for 2005, however these estimates were made with no quantitative connection to price projections. It was concluded that only 6.25 million hectares of the approximately 15 million hectares of arable land in WA would be sown to crop.

ACIL Economics then held a workshop with marketing experts from the Australian Wheat Board (AWB) and The Grain Pool, to decide on future prices for the various grain crops. On the basis of all these workshops, ACIL Economics defined a future scenario which they felt to be plausible for the year 2005.

The next step in the process was to analyse the scenario with all of the currently operational MIDAS models: the Eastern Wheatbelt model (EWM), the Great Southern model (GSM), and the two Northern Wheatbelt models (the low rainfall LRNWM, and medium rainfall MRNWM). By using MIDAS to analyse the scenario, quantitative connections are made between grain yields and prices, as well as all the other interactions of the farming system, thus adding value to the scenario. The results generated by MIDAS were then discussed with farmers at a series of farmer workshops held throughout the agricultural areas of the State. The aim of these workshops was to use the MIDAS results to generate discussion with farmers.

Finally a workshop was conducted, again with cropping experts, at which the MIDAS results were discussed along with the feedback from farmers. The original scenario was then amended to give the final scenario for future grain production in WA.

Hurdles encountered during the process.

MIDAS is not well understood by many people. It is very large and complex and, given the size of the model, running it can be very time consuming depending on the number of different scenarios to be examined. The first hurdle which needed to be overcome in this particular project was the issue of time. When ACIL Economics submitted their proposed workplan, it only allowed two days to carry out the analysis with four different MIDAS models. Negotiations were needed to overcome these unrealistic expectations.

The scenarios (ie. 'now' and 'future') decided on by ACIL Economics consisted of current and future grain yields and prices. They wished for these scenarios to be analysed with the four different MIDAS models in order to cover as much of the agricultural region of the State as possible. Thus, there came a second hurdle: the yield data submitted by the ACIL Economics (estimates made by experts at the workshops) was WA state average yields, yet the analysis was to be conducted for four different regions with substantially different yield prospects. Furthermore, within each region, yields vary substantially between different soil types and between different rotations on the same soil type. MIDAS requires full details on these differences, but ACIL Economics provided no guidance on the breakdown of the State wide yield forecasts. This problem was addressed by adopting the assumption that for a given crop, proportional changes in yield will be the same in all regions, on all soil types and in each phase of the rotation.

The next hurdle concerned last minute changes to the scenarios, especially for prices. Every time the prices were changed, each of the models had to be re-programmed and the runs repeated, a process which even after practice, took considerable time, and compounded the problem of limited time.

This leads into the final and perhaps most significant hurdle. When ACIL Economics liaised with experts to identify scenarios for the analysis, sheep and pasture experts were not involved. Thus, potential increases in pasture and wool productivity were not considered rigorously in specifying the scenarios. This was perhaps overlooked because sheep/wool were not of particular interest to the client (a grain marketing body). However, pasture and wool productivity increases should have been represented in the scenario because sheep and pasture are as important as cropping in determining the output of grains. This is because there are important interactions between crops and livestock in the WA farming system (Pannell, 1995) and because they are substitute land uses. This will be discussed further later.

Model Inputs for the Scenario Analysis

When carrying out the scenario analysis with MIDAS, a scenario to represent the current situation (referred to as the 'now' scenario) was also analysed in order to make comparisons between the current situation and the scenario set for 2005 (the 'future' scenario). Thus a 'now' and 'future' scenario were analysed for each of the four regions which are currently represented by MIDAS.

Grain prices for the 'future' scenario were collated and supplied by ACIL Economics (estimates from the workshop involving AWB and The Grain Pool). The prices for the 'now' scenario were supplied by a grain price expert from Agriculture Western Australia, and are short-term forecast prices. Table 1 shows the grain prices used in

MIDAS for the 'now' and 'future' scenarios. All prices are gross prices expressed in 1995 Australian dollars per tonne.

Table 1: Grain prices ($/t) for now and future scenarios.

Commodity	Now	Future
Wheat	170	211
Malting barley	157	215
Feed barley	137	167
Oats	136	165
Lupins	180	190
Canola	295	365
Chick peas	367	363
Faba beans	236	197
Field peas	236	263
Albus lupins	231	213
Yellow lupins		195

All prices are gross prices expressed in 1995 dollars per tonne.

ACIL Economics did not provide an estimate of the future wool price. Competition for resources between sheep and crops, and also complementarity between these enterprises means that they are not independent and that a future price for wool should be included in the scenario. The advice of a wool price expert from Agriculture Western Australia was sought, who advised that the wool price for the 'future' scenario would be very similar to that for the 'now' scenario. Thus the market indicator price of 790c/kg was used for both scenarios.

Table 2: Grain yields (t/ha) for now and future scenarios.

CROP	EWM		GSM		LRNWM		MRNWM	
	Now	2005	Now	2005	Now	2005	Now	2005
Wheat	1.25	1.53	1.65	2.11	1.40	1.66	1.70	2.13
Barley	1.20	1.53	1.95	2.56	1.25	1.58	1.55	1.83
Oats	0.95	1.24	2.02	2.65	0.80	1.03	1.10	1.40
Lupins	0.69	0.81	1.40	1.63	0.90	1.01	1.11	1.30
Canola			1.51	1.80				
Field Peas	0.58	0.87	0.88	1.31	0.72	1.08	0.59	0.89
Chick Peas	0.63	0.93	0.80	1.10	0.73	1.03	0.87	1.17
Faba Beans	1.00	1.30	1.70	2.00	0.77	0.97	1.53	1.73
Albus Lupins	0.63	0.72	1.30	1.50	0.92	1.02	1.30	1.43
Yellow Lupins		0.90				0.90		0.90

As mentioned earlier, ACIL Economics supplied the yield data for the scenarios after consultation with various experts at workshops. The forecast State average yields were used to estimate yields for different regions, as shown in Table 2.

Pasture and wool productivity increases were not rigorously considered. Due to this it was decided to carry out a sensitivity analysis, increasing pasture production by 30 percent, and wool productivity by 10 percent and 20 percent.

Results and Discussion.

A sample of the results from one model only will be presented: those for the Eastern Wheatbelt which were presented at the farmer workshop held in Kellerberrin. Given the yields and prices of ACIL Economics' scenario (the 'future' scenario), the optimal farm plan shifted radically from one involving crop on 60 percent of the farm area to one of 97 percent crop by 2005 (Table 3). Farmers at the workshop agreed that in the future the percentage of farm put into crop would increase, but not to the extent predicted by MIDAS from the scenario. The over-riding reason given for not adopting a complete cropping enterprise was 'sustainability', particularly problems with increasing herbicide resistance. The farmers felt that there would always be at least 30 percent of the farm in pasture.

Table 3: Eastern Wheatbelt MIDAS Model Results.

	Now		Future	
Crop	Price ($/t)	% of farm	Price ($/t)	% of farm
Wheat	170	45	211	70
Barley	147		191	
Oats	136		174	
Lupins	180	10	190	7
Field Peas	236	5	263	14
Yellow Lupins			195	7
Total Crop		60		97
Pasture		40		3

The area of wheat and field peas increases substantially in the 'future' scenario (Table 3). Farmers agreed that grain legumes (particularly faba beans and chick peas) would play a larger role in the future on heavier textured soils. The farmers felt that if the area of cereal was as high as that on the MIDAS farm, yields would decline without inclusion of more legumes in rotation with cereals, and that barley would play a significant role in future rotations. Barley or oats were not selected because wheat is more profitable.

Yellow lupins were adopted in the 'future' scenario, replacing white lupins on some soil types (Table 3). Farmers agreed that this would be the case.

Results from the other MIDAS models, the LRNWM, MRNWM and GSM, also involved increased areas of crop. Farmers at all regional workshops agreed with MIDAS in that given the 'future' scenario which was presented, cropping would increase, but not to the extent which MIDAS suggested. All felt that grain legumes would play an increasing role on heavy soils in the future, as would canola. It was also felt that barley would play a significant role as a second cereal in the rotation.

At all regional workshops, farmers questioned the assumptions behind the 'future' scenario for wool. As increases in pasture and wool productivity were not considered rigorously when planning the scenario, this was a difficult issue to discuss. Sensitivity analyses showed higher cropping strategies to be relatively insensitive to changes in wool price, and wool and pasture productivity (Table 4). However, since completing the scenario analysis for The Grain Pool, pasture scientists have indicated that the 30 percent increase in pasture productivity which was used for the 'future' scenario in the sensitivity analysis is likely to be an underestimate. This will be discussed in more depth later.

Table 4: Sensitivity Analysis for Eastern Wheatbelt.

Percent of area of farm in crop with a 30 percent increase in pasture production and the specified increases in wool price and production

		% increase in wool price		
		0	20	40
% increase	0	97	80	80
in wool	10	97	80	73
production	20	80	80	54

The quantitative scenario analysis with all the MIDAS models indicated an increase in cropping in the future. Experts changed their estimate of the total area cropped in the scenario for future production of grain crops on the basis of the quantitative analysis, the results of which were generally supported by farmers. At the initial workshops where cropping experts defined plausible grain yields and production for the 'future' scenario, it was concluded that the overall area of arable land cropped in WA would not change. At the final workshop, which involved representatives from the major regions in the state, and members from ACIL Economics and The Grain Pool, the MIDAS results were presented along with the feedback from farmers. At this meeting, the initial conclusion that 6.25 million hectares would be the area of arable land sown to crop in 2005, was changed to 7.05 million hectares.

Further Analysis.

Following the completion of the project for The Grain Pool, a meeting was held with pasture and wool experts from Agriculture Western Australia in order to discuss future increases in pasture and wool productivity. They supplied information which enabled further scenario analyses with MIDAS, this time incorporating plausible wool and pasture productivity increases.

The further assumptions which were added to the 'future' scenario supplied by ACIL Economics were:

- In ten years time wool growth per head would increase by 10%, and the mean fibre diameter will be approximately half a micron finer than that now.
- In ten years time, pasture productivity will be significantly higher than that now. On some soil types for which cropping is not very profitable, increases in pasture production of around 70% will occur.

The Grain Pool recommended that averages of the 1991/92 to 1993/94 gross prices be used for the 'now' scenario. Thus, they supplied the grain prices which were used in the modified 'now' scenario. Wool price for the 'future' scenario was changed to represent a finer clip. The Costs associated with the productivity increases for all commodities were also accounted for.

Results from the analyses of the modified scenarios carried out with EWM indicated that percentage crop would increase from 50 percent now to 62 percent in the future scenario (Table 5). A shift of this magnitude would be more likely than a shift to nearly 100 percent crop, as the 'norm' for 2005 in this region (the Eastern Wheatbelt of WA). The scenario compiled by ACIL Economics for the Grain Pool study did not include potential increases in pasture or wool production, thus over stating the profitability of cropping relative to pasture. This is demonstrated by the results of the modified scenario analysis.

Table 5: Modified Scenario Analysis Results with MIDAS for the Eastern Wheatbelt.

	Now		Future	
Crop	Price ($/t)	% of farm	Price ($/t)	% of farm
Wheat	166	30	211	40
Barley	147		191	
Oats	126		165	
Lupins	188	10	190	15
Faba Beans	252	10	197	7
Yellow Lupins			195	
Pasture		50		38
Total Crop		50		62

In the modified 'future' scenario, yellow lupins did not come into the rotation (Table 5). As increases in pasture productivity were accounted for in this scenario, pasture on soil types suited to yellow lupins was now able to compete for that land, and subsequently was selected by MIDAS as the more profitable option. Pasture also competed with faba beans in the modified scenario analysis, substituting for faba beans to some extent (Table 5). As discussed earlier, barley or oats were not selected.

Conclusions.

This paper highlights the use of the mathematical programming model MIDAS as a useful tool for carrying out quantitative analyses of scenarios which deal with farming systems in Western Australia. The human mind is incapable of carrying out a thorough and detailed analysis of a system which involves a large number of interactions, even if one has a complete grasp of all relevant information. Thus when scenarios are defined and analysed by a group of experts by the means of workshops, there is a chance of inconsistencies arising with the scenario. This was clearly demonstrated by this paper.

Production estimates were made without any quantitative connection to price projections, and wool and pasture productivity increases were overlooked when setting the scenario for future grain production for The Grain Pool study. MIDAS was able to quantitatively analyse this scenario, accounting for all the interactions of the farming system and thus adding value to the study. The results of the scenario analysis with MIDAS revealed that the increased grain yields and prices in the scenario were not consistent with the estimated area sown to crop. Even when further analysis was carried out incorporating increases in wool and pasture productivity, the optimal area cropped still increased. Thus the results of the quantitative analysis highlighted the inconsistencies in the initial scenario, and these were then able to be amended.

This paper also demonstrated some of the hurdles one may encounter when carrying out analyses of this type.

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