Evaluating labour requirements within a multi-objective land-use planning tool

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Abstract:

In undertaking participatory testing of a multi-objective land use planning tool, patterns of labour availability and utilisation were identified as key evaluation metrics for alternative land use strategies. Labour availability was seen as a potential constraint to patterns of land use and land-use change as an opportunity to eliminate underemployment or reduce peaks of seasonal demand. Labour and associated equipment costs were also highlighted as highly influential for financial impacts.

This paper presents the implementation and application of a resource scheduling tool (RST). The RST allows the evaluation of the options for, and impacts of, labour usage as part of a spatial, multi-objective, land-use planning system. The RST considers full-time, part-time and seasonal workers, with options for normal working time and overtime, the type and availability of equipment and the use of contractors. The financial implications of both operational and capital costs of resources are also modelled.

The RST uses a pair of linked schedulers interfaced to a geographic information system (GIS) and relational database (RDB). Individual jobs are user-prioritised and have time-windows within which they have to be completed; these time windows are determined by prevailing environmental conditions. The scheduled tasks are stored in the RDB allowing the counter-factual analysis of scenarios, interrogation of utilisation rates and costs and financial analysis.

The application of the RST analyses is demonstrated using a series of land-use plans collected in a soft-systems evaluation. The RST analyses have enhanced the objectivity of the land use planning tools in discriminating between alternative land use strategies, in particular emphasising the potential importance of voluntary labour from off-farm family members for sustaining agriculture in marginal areas.

Keywords: *Land-use planning, multi-objective, scheduling, labour*

1 INTRODUCTION

The multi-functional or multi-objective nature of land management is increasingly being recognised by policy makers and society. This has led to a desire for policy makers to be able to assess policy instruments for their likely financial, social and environmental impacts. One response has been the development of computer-based decision support systems (DSS) to assess existing patterns of land use and where appropriate suggest alternative patterns of land use or management regimen that satisfy multiple objectives. Potential roles for these DSS have been identified in regulatory compliance, technical management, consultancy and facilitated social learning (McCown, 2002).

This paper presents the implementation and application of a resource scheduling tool (RST) to whole-farm land-use planning. The development of the RST is the direct result of the participatory evaluation of an existing multi-objective land use planning tool (LADSS) (Matthews et al., 1999, 2002). This workshop consultation emphasised the central importance of labour and capital equipment in assessing the financial viability of alternative land use plans. The amount and quality of employment provided by such systems is, however, also of significance to the social sustainability of rural areas.

The paper first outlines the background to the development of the RST, in particular the previous soft-systems evaluation of the multi-objective land use planning tools. The structure and operation of the

RST is then presented including the relationship of the RST with the other components of the DSS. Examples of using the RST to evaluate the current pattern of land use for a case study farm and analysis of the workshop delegates' proposed land use plans are then presented and conclusions drawn regarding the potential utility of the RST.

2 RELATED WORK

2.1 Pareto-optimality

For many land-use planning problems, as there is conflict between objectives, no Utopian solution exists where all objectives are simultaneously optimal, (Figure 1). For such problems, optimality may use-

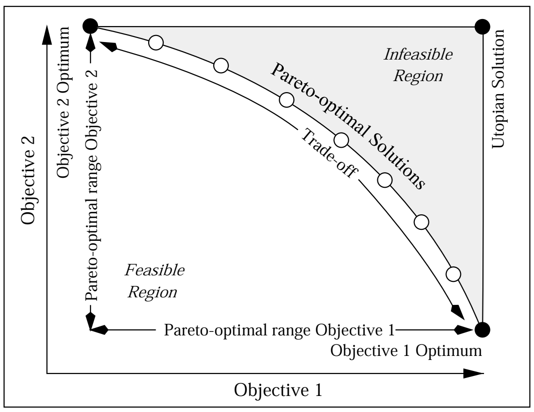

Figure 1. Two-objective maximisation example.

fully be defined as making the best possible compromise between objectives. There are usually a set of such *Pareto-optimal* solutions that define the *trade-off* between objectives (Coello Coello et al., 2002). The land use planning tools within the DSS use multi-objective genetic algorithms to find a subset of Pareto-optimal solutions that characterises the structure of the trade-off (Matthews et al., 2000b).

2.2 Participatory evaluation

To evaluate the land use planning tools, a soft-system workshop was organised where delegates, with a range of perspectives, undertook the same planning task as the DSS for a farm in upland Scotland (Matthews et al., 2000a). The delegates worked both individually and as sub-groups. The goal was to achieve the "best compromise" between financial returns (the net present value (NPV) over 60 years using gross margins) and the diversity of land uses present (the Shannon-Weiner index). The backgrounds for the workshop delegates and the codes used to identify their allocations are listed in Table 1 with the features of their allocations itemised in Table 2. Where delegates or groups proposed more than one allocation these are identified with -1, -2 etc.

Comparison of the land manager allocations and those of the land use planning tools revealed a wide variety of heuristics used by land managers that restricted the range of allocations considered feasible, Figure 2. The rules of the planning task were also challenged, with allocations proposed whose financial viability required the consideration of on-farm resources. These views reinforced those of the research team that further analysis of the resource implications of alternative land use plans was justified (Matthews et al., 2002).

Sub-group 1 (SG1)	**Sub-group 2 (SG2)**
BA1 - bank adviser	SA2 - systems analyst
AG1 - agriculturalist	AG2 - agriculturalist
B1 - biologist	C2 - conservationist
E1-1,E1-2 - estate manager	E2 - estate manger
F1 - farm manager	F2 - farm manager
G1-1,G1-2 - SG1 plans	G2 - SG2 plans

Table 1. Workshop delegates - with the codes used to identify their proposed allocations

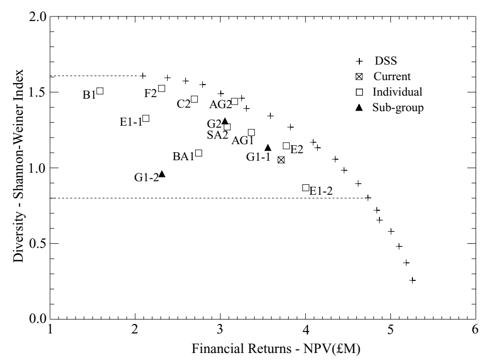

Figure 2. Land manager and land use planning tool allocations.

	NPV (£M)	SW Index	Sh'p Nos.	C'le Nos.	B'leaf (Ha)	C'fer (Ha)	A'ble (Ha)
Current	3.71	1.048	1223	348	23.3	0	15.2
E1-2	4.00	0.869	1187	401	21.8	0	0
E2	3.77	1.146	1016	355	26.8	0	32.6
G1-1	3.56	1.135	967	347	49.0	0	14.4
AG1	3.36	1.234	544	329	78.5	0	33.9
AG2	3.16	1.439	597	307	42.9	40.7	33.9
SA2	3.08	1.271	1098	251	36.4	0	45.1
G2	3.05	1.31	802	271	76.0	0	38.6
BA1	2.74	1.098	1150	246	103.0	0	0
C2	2.69	1.454	591	255	54.9	21.7	31.5
F2	2.31	1.525	898	187	76.1	36.5	30.6
G1-2	2.31	0.961	1982	137	71.4	0	0
E1-1	2.12	1.327	1651	133	57.7	34.3	8.3
B1	1.58	1.508	768	110	113.6	47.9	29.7

Table 2. Delegate allocations

3 MATERIALS AND METHODS

3.1 Resources

Two types of resources are represented in the RST, labour and capital equipment. Labour may be full-time, part-time or seasonal. In addition to normal-time (NT) labour, overtime (OT) may also be defined. Wage costs can be included if appropriate. The skills possessed by individual workers are used to classify their suitability for particular tasks. Items of equipment define the work rate for tasks and where appropriate the minimum size of tractor required (for trailed equipment) or the horsepower rating. All equipment also has definitions of: the replacement lifespan; rate of depreciation and depreciation period and repair, running, tax and insurance costs.

3.2 Tasks

The tasks required are defined by the pattern of land use and the management regimen. The magnitude of tasks is a factor of the land area, weight of materials or numbers of livestock.

Where appropriate tasks may be linked to prerequisite tasks (pT) that must be completed (or at least started) before the follow-on task (fT) task can be undertaken. A start-to-start relation between tasks is, in most cases, preferred since this means that the fT can be started before the pT has been completed. The proportion of the fT that can be completed is limited to that completed for the pT. This leads to more efficient utilisation of the available resources by interleaving tasks than is possible with finish-to-start relations where the pT must be completely finished before the fT can start.

The number and type of resources required to complete a task are also specified. This can vary depending on the management regimen or the on-farm machinery available so, where appropriate, this is specified as part of the land use plan. Tasks may also be fully assigned to contractors in which case no on-farm resources are required.

Each task is assigned a base priority (from -3 to +2) with higher priority tasks having the first call on available resources. The highest priority tasks are those relating to animal welfare, with high priorities also given to tasks with significant potential for financial impacts such as preparation for arable cropping or silage making. Lower priority tasks include forestry and maintenance work that may be fitted around high priority tasks.

Tasks are given fixed time-windows within which they should be completed. These windows may also be set using weather events rather than climatic conditions to test the robustness of a plan. Tasks are scheduled to start as soon as possible within the time windows and to be completed as early as possible within the limits of the normal-time labour available rather than attempting any form of just-in-time completion. If a task cannot be completed within the window then OT may be assigned and if still incomplete then the remainder of the task is contracted.

3.3 RST architecture

The RST consists of a pair of linked heuristic-schedulers (OTs and NTs) implemented in Gensym's G2 knowledge-based development environment. Each scheduler has four queues. future (fQ), ready (rQ), incomplete (iQ) and complete (cQ). The NTs tasks to be scheduled are created using task definitions held in an Oracle RDB, parameterised using data from the land-use planning tools or GIS and passed into the NTs' fQ. The tasks remain there until their time window opens when they are transferred to the rQ and can have resources assigned. Tasks that are completed pass into the cQ where performance metrics are calculated and the tasks recorded in the RDB. Tasks incomplete when the time window closes are transferred to the iQ. The iQ for NT scheduler is the fQ for OT scheduler. The OTs scheduler operates as the OT except that incomplete tasks are contracted out.

3.4 Scheduler operations

Figure 3 presents a schematic of the operation of the resources scheduler. The NTs and OTs are specialisations of this generic class. The figure presents the operations of the schedulers as a series of numbered steps with transitions between them. The algorithmic transitions are simply calls to start methods that will further process that task. The task transfers cause tasks to be passed either to another scheduler, the RDB or another method for further processing.

The allocation of resources to tasks is accomplished in steps [2] to [7]. The tasks in the rQ are updated dependent on the current value of the scheduling clock. The clock advances in one week time steps. While the time taken to carry out a task is estimated based on hourly work rates, when a task occurs within the week is not determined. The schedulers thus have sub-hourly precision but weekly resolution. Since the objective of the RST is to look at strategic land use change, this resolution, with the consequent simplification of the scheduling task,

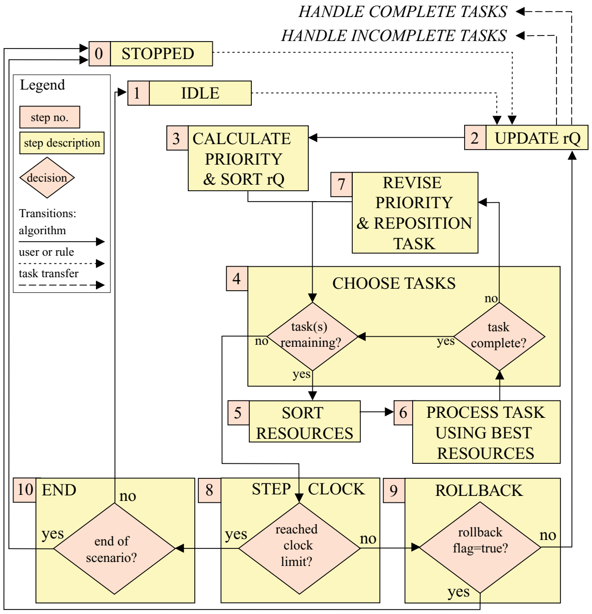

Figure 3. Scheduler operations schematic.

was thought adequate to determine the work that can reasonably be completed within the week. Given this level of generalisation, the definition of the resources available incorporates an efficiency rating that makes allowance for the myriad of short duration or unplanned tasks, tea breaks and the like that are associated with the main tasks.

Within a week the order in which tasks are assigned resources is determined by their priority. Each task has an integer base priority (bP) and a floating-point variable priority (vP) with vP used by the schedulers. The vP for a task is the bP value adjusted such that tasks proportionally less complete and tasks closer to their deadlines are assigned higher priorities. Adjustment of the vP cannot, however, mean that its value exceeds the lowest value of a task assigned the next higher bP. Since the vP's are floating-point values there is no need for explicit tie-breaking between tasks.

Steps [4] to [6] select the most appropriate resources from those available and assign them to the tasks. The ordering of resources is heuristic based. Labour resources with the most unallocated time, prime movers of the minimum size required for any trailed machinery required and the equipment or implement that has the fastest work rate for the task are preferred. The maximum number of hours that a single labour resource may have allocated in a single pass is limited by a parameter of the scheduler. Where there are tasks requiring variable numbers of labour resources it is desirable to interleave such tasks otherwise task blocking can reduce efficiency. The minimum time that may be allocated to a task (other than to complete the task) is also limited to avoid the unrealistic allocation of labour resources for very short periods remaining at the end of weeks.

While the RST can proceed in a single pass, circumstances often mean that it is necessary to reconsider resource allocations. This is triggered by tasks in the OT rQ being incomplete when the queue is checked at the start of a time step. If the task has a pT that is also incomplete it may be that the pT has blocked the completion of the dependent task. For example, a three-man task could block a two-man task for which the resources are available. When this occurs the OT scheduler signals a rollback to the NT scheduler which is halted after clearing the tasks in the current week. The incomplete pT is contracted and any fTs are returned to the fQ of the NTs. The NTs and OTs clocks are reset to the week when the pT is completed by contractors and processing is restarted.

3.5 Outputs

For each task the timings, resources used and costs incurred are recorded. This allows the construction of week-by-week schedules of work. These schedules highlight periods where there is potential conflict between tasks competing for resources and allow the planning of seasonal or voluntary labour or periods where off-farm employment may be considered. Yearly rates of utilisation identify resources that are over- or under-committed. The labour, operational and capital costs are also calculated, which provide an estimate of the financial impact of particular management and equipment regimes.

4 Results

4.1 Case study - current land use

The current pattern of land use was considered with three full-time and one part-time worker available, each with up to one day of overtime per week. The available equipment was minimised while ensuring that it did not cause tasks to be contracted. The efficiency rating was adjusted to account for holidays and set at 75%.

The output from an RST run is shown in Figure 4(a,b). The upper graph (a) presents a week by week schedule for the first year, with the hours of labour broken down by enterprise and the cost of jobs that require to be undertaken by contractors shown in the lower graph (b). The figure clearly shows the dominant demand of the labour-intensive suckler cattle enterprise. The schedule

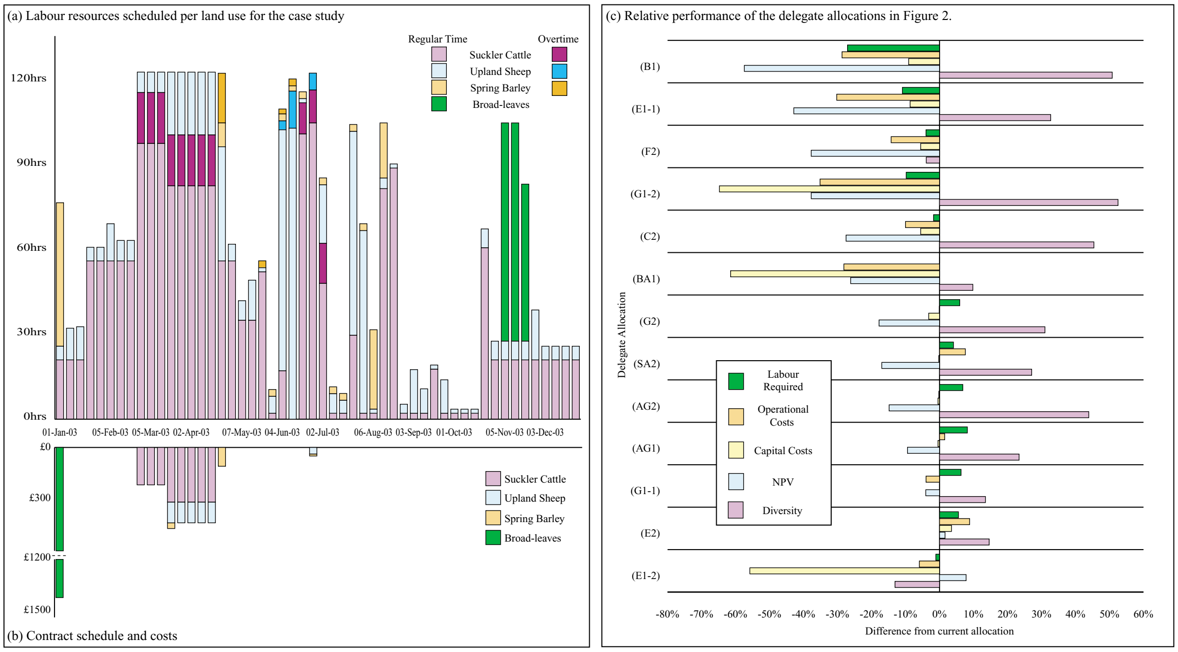

Figure 4. Outputs from the RST.

highlights the problem of resource scheduling facing land managers in marginal upland areas. The mix of enterprises means that there is a significant front-loading of the schedule and some conflict for resources between the suckler cattle and upland sheep enterprises. The peaks of demand are such that it is still necessary to contract out work, particularly for calving and lambing while having significant periods of under-employment, (the overall labour utilisation is 60%). Woodlands can reduce seasonality of labour demand but their introduction can significantly change the pattern of cash flow to an enterprise and reduce the overall demand for labour. Alternatives such as autumn calving can provide greater gross margins per unit, and would reduce the spring peak of labour demand. Such systems, however, make greater winter feed demands to maintain milk supply for the calves. The maintenance of the current system of land use thus relies heavily on the availability of either seasonal labour or on assistance being provided in periods of peak demand from the extended farm family.

4.2 Alternative land use patterns

The RST was used to investigate further the land allocations proposed by the workshop delegates, Table 2. Three metrics were used in addition to the NPV and land use diversity: the amount of labour required; the operational costs and the capital costs, each for the first five years. The amount of labour required was the total hours required to complete the required tasks. The amount of labour required makes no definite statement on the numbers of people that would have to be employed and is indicative only. Since work-rates depend on the machinery available a standard set of machines and equipment was provided such that lack of these resources did not prevent completion of tasks. The operational costs are the running, maintenance and overhead costs for the equipment used, equipment available but unused is ignored. For capital costs it is possible to use a formal depreciation costing within the RST but since the lifespan of machinery on relatively small enterprises is significantly longer then the depreciation period the capital cost is the per annum replacement cost over the expected lifespan of the equipment. As with operational costs unused equipment is ignored.

Figure 4(c) presents the evaluation metrics as percentages of the current allocation. From this figure and Figure 2 it is clear that making an improvement on the current pattern of land-use considering only NPV is difficult, with only E1-2 resulting in a clear gain.

When other factors are considered then overall profitability may be improved. The E1-2, BA-1 and G1-2 allocations are all effective in reducing the capital equipment costs of the unit by eliminating the arable enterprise. Arable enterprises are characterised by the need for expensive machinery and even allowing for extended lifespans, the cost of such machinery is prohibitive for upland mixed farming systems.

A further analysis using contractors for such operations could, however, change the balance, particularly where a premium is available for the use of feed-stuffs grown on farm.

In the mid-range of solutions G2 to G1-1 the increasing diversity of land use by adding forestry enterprises results in increased labour demand. This analysis has, however, only considered the first five years of 50-70 year rotations. There is significant labour demand in establishing plantations, particularly for site preparation and planting. The level of longer term labour demand for management operations such as thinning could be limited and periodic with harvesting of relatively small areas probably conducted by contractors. It is possible to stagger the establishment of plantations to achieve a reduced but sustained level of demand. In any case these more diverse patterns of land use suffer up to 20% reductions in NPV.

Allocation G1-2 was proposed as a reduced labour input system, and the RST analysis indicates that it has indeed reduced labour requirements (c.10%) and reduced capital and operational costs. This would improve its profitability. This allocation also proposed renting all the suckler-cattle land, and this would further reduce the cost base and improve margins. The G1-2 solution, however, has significant social costs and makes little improvement to the diversity of land use compared with the current allocation.

The allocation proposed by the bank-adviser (BA1) fell well away from the Pareto-optimum front defined by the land use planning tools, Figure 2. With the further RST analysis, allocation BA1 is seen as remarkable as it maintains employment levels (within the limits noted previously for forestry) while greatly reducing operational and capital costs.

5 CONCLUSIONS

The potential for the RST particularly when linked to the multi-objective land use planning tools would seem to be significant. With the wide range of metrics available there are possible roles in counterfactual analysis or in social leaning or conflict resolution. The analysis presented has again reinforced the view that land use planning is a highly multi-objective problem and that any system that seeks to assist in the process must be able to assess trade-offs between objectives and present ranges of alternatives. The RST produces such a wide range of metrics that there can be problems of deciding which are significant for the planning process; this will be addressed through further soft-systems workshops with stake-holders.

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