Chapter 6: Drafting of Cohorts

6.1. Introduction

The efficiency of animal production is influenced by not only how efficiently individuals produce the desired product but also by how efficiently the system produces these individuals (Kinghorn 1985). This has major consequences in terms of the management of animal production systems. If animals were grown in accordance with what they were capable of achieving (matching their potential) then desired market endpoints could be met with a high degree of uniformity along with high efficiency, which would help satisfy the requirements of components further down the supply chain. The Australian beef industry services a number of different markets which complicates the process of achieving these objectives, but these markets also offer a means of achieving these objectives. The diversity of carcass characteristics required by these markets can be utilised to take advantage of natural variation present in animal growth potential. Successfully matching market variation with animal variation would have the added benefit of reducing both the costs and environmental impact of production, further securing the sustainability of both individual production systems and the entire beef industry.

In Australian animal production systems, there are currently examples of efficiency and profit being compromised due to the abilities of animals not being matched to the end product that is desired. The colloquial term, "butter ball" has been used to describe animals that produce excessive quantities of subcutaneous fat while grown to achieve a desired level of intramuscular fat for the lower end Japanese markets (e.g. B2) within a feedlot environment. For these animals to be depositing these quantities of fat indicates that the animal may have reached its lean growth capacity and is simply partitioning excess energy into undesirable lipid deposits. The conclusion could thus be drawn that such an animal does not have the potential to achieve the carcass characteristics required by these markets and thus should have been allocated to another market whose requirements more appropriately match the animal's production abilities (e.g. allocated to either the European Union or Hotel/Restaurant markets that do not require marbling or carcasses of such a large size). Achieving such an outcome has roll-on effects in terms of the more appropriate utilisation of resources and consequently reduced environmental pollution and waste as well as improved profit.

The allocation of animals to markets that are appropriate to their growth potential has similarities with well researched allocation problems including the Travelling Salesman Problem (TSP) (Johnson 1997) and the Job Shop Scheduling Problem (JSSP) (Fang 1994; Fang et al. 1993). Both these problems are concerned with arranging a series of events in an order that achieves a desired outcome with the lowest cost and highest efficiency possible. The TSP is concerned with finding the least cost route of connecting N cities during a closed tour (Ryan et al. 2004). The solution is directly dependent upon the distance between each distinct pair of cities. The JSSP is focused on allocating tasks within a series of jobs to different machines while maintaining the task order of each job, only processing a single job on any one machine at any one point in time and not scheduling simultaneous tasks for a single job. The overall objective while following these rules is to minimise the time that elapses between the first job being initiated and the final job finishing (Fang et al. 1993). Allocating animals to different markets can be viewed simply as partitioning X animals into M markets to maximise an objective function that attempts to reduce costs while increasing income.

Recently, a method has been presented that uses Genetic Algorithms (GAs) in conjunction with the Random Key Representation (RK) to solve both the TSP (Snyder and Daskin 2006) and scheduling problems similar to JSSP (Norman and Bean 1999). RK decodes a solution to the problem by using random numbers that act as sort keys (Norman and Bean 1999) eliminating the problem of unfeasible offspring being produced during recombination operations when using standard genetic operators in evolutionary search methods. RK relies on the concept that any sequence of numbers can be sorted to provide an order that is a solution to the allocation problem. Using random numbers allows small and continuous changes in sequence order to occur (e.g. mutation and recombination) without compromising validity. Sequences of integer values would also allow ordering to be performed but the mutation and recombination operations performed by evolutionary search methods would result in illegal solutions being developed. An example of illegal solutions includes sequences containing multiple and missing values (e.g. 1, 6, 3, 5, 2, 5). This sequence contains two 5's and no 4's which represents an illegal solution, because each value between 1 and 6 should be present once.

In its present form RK would be capable of allocating animals to market cohorts using fixed thresholds. However, this allocation would not be optimal because drafting ages could not be manipulated to increase efficiency. To overcome this deficiency a mechanism is required for determining the appropriate time to make drafting decisions. Allowing search procedures to also optimise drafting thresholds rather than using fixed values would not increase RK's ability to allocate animals to market cohorts but it would facilitate the process reducing the computation time required to find optimal solutions.

The aim of this study was to draft cohorts of animals in a simulated production system into market groups that most appropriately match the production potential of the animals and the prevailing production conditions, using RK in conjunction with Differential Evolution (DE). The RK will be extended to allow DE to determine the appropriate timing of drafting events and facilitate the partitioning of the cohort into market groups, thus increasing its flexibility enabling it to be applied in any given production system where cohorts of animals will differ and the markets available to the system will vary.

6.2. Materials and Methods

6.2.1. Simulated Production System

The testing of RK and DE for allocating animals to different market groups was conducted using a simulated production system that was modelled on a beef cattle production system located centrally in the Northern Tablelands of New South Wales. This enterprise was simplified to only take the growth and production costs of a cohort of Angus steers into consideration to reduce the level of complication associated with a whole beef cattle enterprise (i.e. including the production of cows, heifers and bulls) whilst remaining representative of the production systems seen in Australia.

Available Markets

The markets available in the simulated production system are presented in Table 6.1 along with the slaughter characteristics of the animals required by each. These slaughter characteristics were derived from information obtained from NSW Agriculture (2004; 1997) and the Angus Society of Australia (2005). The markets available in this simulation excluded the live export markets as they are seldom supplied by production systems located in this region of Australia, but it is recognised that other areas of Australia (e.g. northern Queensland) are heavily reliant on such markets and live export would need to be included for such enterprises.

Table 6.1: Slaughter characteristics of the markets available in the simulated production system.

Market		Live Weight (kg)	Carcass Weight (kg)	Fat Depth (mm)	Marble Score	Teeth
Local Trade		250-340	140-200	4-10	-	0
Supermarket:	Light	270-370	140-240	5-12	-	0-2
	Heavy	350-520	180-350	4-17	-	0-2
Food Service		500-650	260-330	6-15	-	0-2
European Union		500-600	240-350	7-17	-	0-4
Japanese:	B1	550-720	300-400	10-22	-	0-4
	B2	650-740	350-420	12-25	>2	0-6
	B3	650-800	350-450	12-25	>3	0-6

The allocation of animals was dependent on which markets the simulated production system was attempting to service. All four scenarios discussed below were run with the 'Heavy Supermarket' (HS), 'European Union' (EU) and 'Japanese B3' (B3) markets as target markets for the simulated production system. These markets were chosen to reduce solution complexity and to be representative of the number/type of markets targeted by Australian production systems while illustrating the benefits of using such a drafting system. The graphical presentation of market characteristics in Figure 6.1 was used to select which and how many markets were targets for the allocation method. This was performed by clicking on the area of the graphic that corresponded to the desired market(s). On the right hand side of Figure 6.1 are the slaughter characteristics of the selected markets, which are identical to those in Table 6.1 except number of adult teeth or dentition has been converted to an age in days, based on Dodt and O'Rourke (1988).

Feedlot Entry Characteristics

Table 6.2 contains the markets from Table 6.1 that require animals to undertake periods of time in a feedlot prior to slaughter. The number of adult teeth (Entry Teeth) an animal can possess (used as a measure of age) and the allowable live weight range prior to feedlot entry along with the desired ranges in growth rate and time spent in the feedlot are presented for each market. The markets not present in Table 6.2 only require animals be grown on pasture with paddock supplementation allowed if desired.

Table 6.2: Live animal characteristics at feedlot entry for those markets that require animals to spend periods of time in feedlots prior to slaughter.

Market	Entry Weight (kg)	Entry Teeth	Time on Feed (days)	Growth Rate (kg/day)
Supermarket:				
Light	240-300	0	60-90	1.3-1.7
Heavy	280-350	0	60-90	1.3-1.7
Japanese:				
B1	400-500	0	100-120	1.3-1.7
B2	400-500	0-4	150-200	1.2-1.6
B3	360-480	0-2	240-300	1.0-1.5

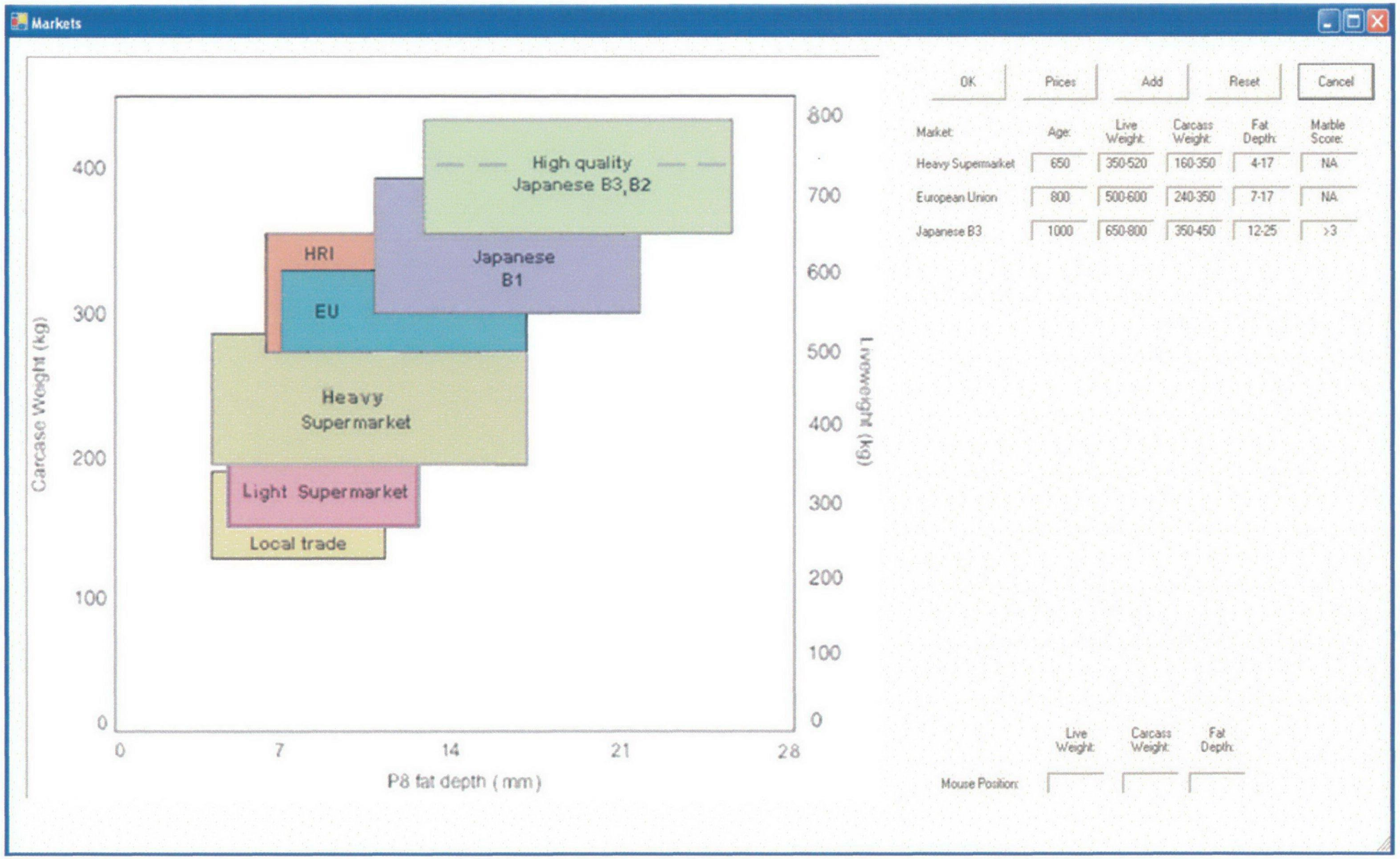

Figure 6.1: Interface that uses a graphical representation of the slaughter characteristics of the markets in Table 6.1 and allows those available to a given simulated production system to be selected. The characteristics printed on the right hand side are the slaughter characteristics of the selected markets.

Slaughter Prices

The monetary value of each carcass was determined using slaughter grid prices for each market obtained from stock and station agents in the Glen Innes area for the period January 2007. Table 6.3 contains an example grid used for the heavy supermarket trade in Australia. The agreed price for animals when the carcass requirements are exactly met is inserted in the grid squares where "Price" is present and when carcass characteristics differ from those desired the appropriate deduction is made on that agreed price. The price used during this simulation was $3.45/kg carcass weight. For example, animals that had carcass weights between 200-280 kg and P8 fat depths between 4-17 mm would receive $3.45/kg while an animal that had greater than 21 mm of subcutaneous fat and a carcass weight of greater than 290 kg would receive a deduction of $0.80/kg thus making the price received, $2.65/kg.

Table 6.3: Example of a slaughter grid used to determine the value of individual carcasses destined for the heavy supermarket trade.

		Carcass Weight (kg)					
		<199.9	200-239.9	240-269.9	270-279.9	280-289.9	>290
P8	21<	-40	-30	-30	-30	-60	-80
Fat	18-20	-30	-10	-10	-10	-60	-80
Depth	4-17	-20	Price	Price	Price	-25	-80
(mm)	3>	-40	-40	-40	-40	-60	-80

The pricing system used for the Japanese B2 and B3 markets are different to the other markets due to the importance that is placed on marbling. The minimum carcass weight accepted by both markets is 350 kg. The Japanese B2 market will only accept carcasses with marble scores of 2 and greater while the Japanese B3 market will not accept carcasses with marble scores below 3. Any carcasses that do not meet these requirements are down graded e.g. if a Japanese B3 carcass has a marble score of 2 it is marketed in the Japanese B2 market or if a Japanese B2 carcass is less than 350 kg then it is down graded to the Japanese B1 market. The pricing system used by both the Japanese B2 and B3 markets is a linear plateau system (Figure 6.2) similar to that used by Barwick and Henzell (1999; 2003) and based on the price offered in the Japanese B1 market for an optimum carcass.

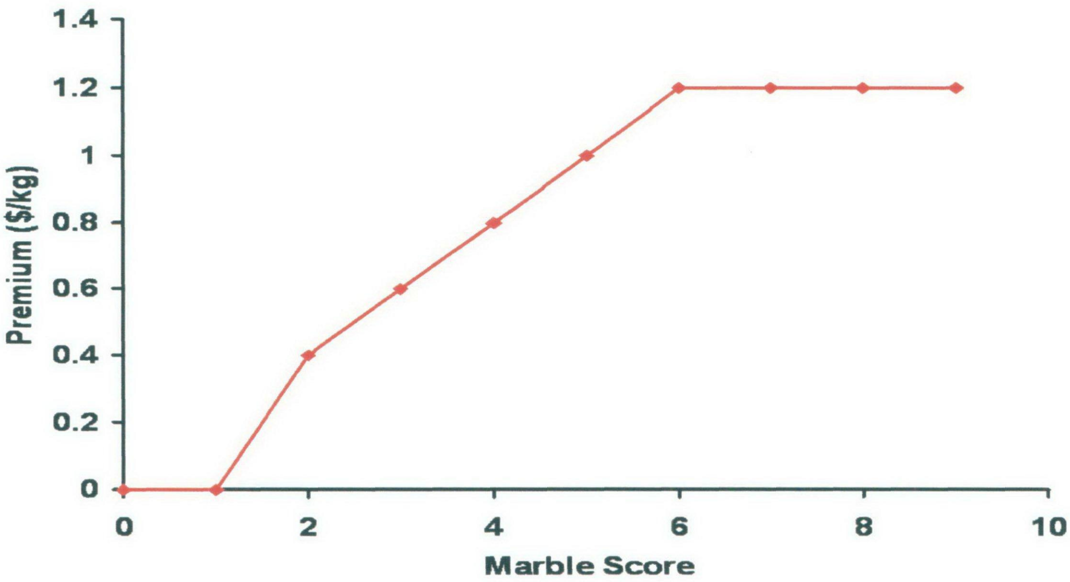

Figure 6.2: Example of the linear plateau system used to model price premiums for marbling in the Japanese B2 market.

Production Costs

The costs associated with growing animals on pasture were determined from Beef Cattle Gross Margin Budgets researched and developed by the NSW Department of Primary Industries (2006). These gross margin budgets included the costs of transport, pasture maintenance, vaccination, drenching and selling (e.g. NLIS tags, etc). It should be noted that these costs do not take pasture establishment into consideration.

The costs associated with growing animals in feedlots were determined using information from these gross margin budgets along with the practices that are specific to feedlot production described by NSW Agriculture (1997) and Blackwood et al. (1998), particularly during entry. The costs of these practices and the feedlot rations used to produce animals for each market were obtained during September 2006 from Agricultural produce stores (e.g. Elders, etc) in Glen Innes and feed manufacturing companies.

Pasture Characteristics

The pasture system used by the simulated production system was modelled using the GrassGro decision support system (Moore et al. 1997). This pasture system was based on the soil and pasture characteristics described by Ayres et al. (2001) for the Glen Innes Agricultural Research and Advisory Station, located centrally in the Northern Tablelands of New South Wales. The climate is characterised by summer dominant rainfall, averaging approximately 852 mm with maximum and minimum temperature ranges of 25°C and 13.4°C in summer (January) to 12.2°C and 0.7°C in winter (July). The soil is described as an acidic self-mulching, heavy clay-loam derived from basaltic parental material (Ayres et al. 2001). The pastures were comprised of introduced cool-season perennials including Phalaris, Cocksfoot, Rye Grass and White Clover as well as native grasses, which included *Bothriochloa* and *Danthonia* spp., in minor proportions. The pasture production curves presented in Figure 6.3 represent the average of twenty, one year simulations (1980-1999) when the soil and pasture characteristics described above are entered in the GrassGro decision support system. This annual pattern of pasture production is repeated every 12 months in the simulated production system to represent continuous pasture production. Although this is a simplified representation of pasture production, an avenue is available for including pasture simulation systems such as GrassGro to describe pasture production given prevailing weather conditions.

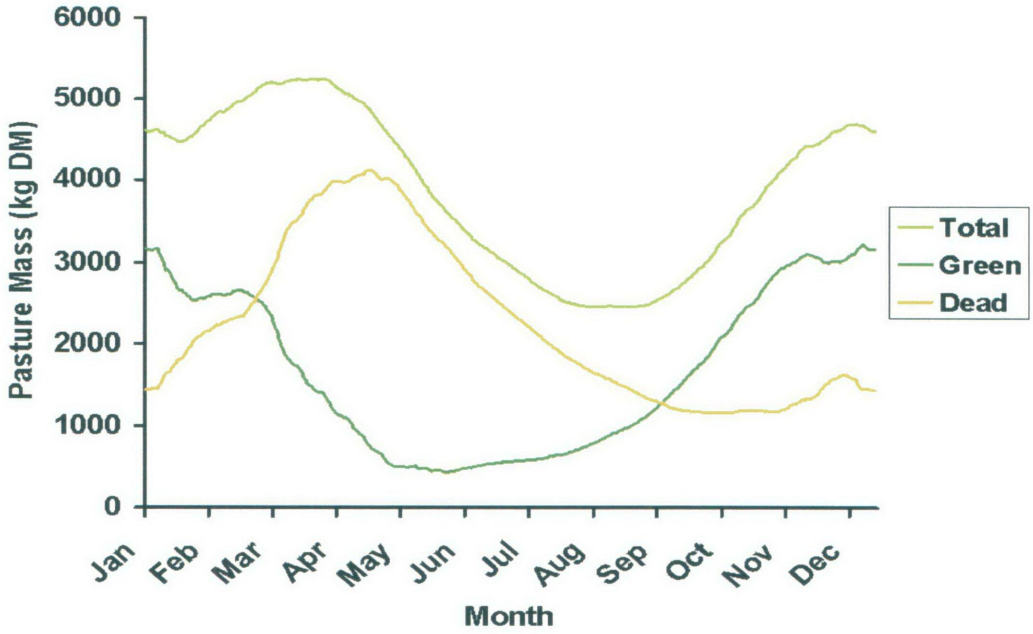

Figure 6.3: Annual cycle of green and dead pasture production along with total available pasture for the simulated production system obtained from the average of twenty years (1980-1999) of simulation for the Glen Innes Agricultural Research and Advisory Station using the GrassGro decision support system (Moore et al. 1997).

6.2.2. Feeding and Growth Model

The growth model presented by Amer and Emmans (1998) along with the extensions presented in chapter 3 was found to be the most accurate of the growth models tested. This model was used to simulate animal growth across time when consuming milk, pasture, paddock supplements and feedlot diets. The model takes the same form as that presented in chapter 3 in equations (3.10) to (3.46). The Newton-Raphson iteration method used to estimate initial body protein content takes the same form as equation (3.101) in the Appendix. The data used for chapter 3 only included the intake of feedlot rations, therefore to accommodate the intake of pasture, paddock supplements and milk; further extensions were made to the Amer and Emmans model.

Milk Production

Milk available for consumption was simulated to occur for the first 300 days of an animal's life using the model presented by Emmans and Fischer (1986) and tested by Friggens et al. (1999). Daily milk production $\left(\frac{dY}{dt}\right)$ was modelled using:

$$\frac{dY}{dt} = a\left\{\exp\left[-\exp\left(G_o - b.t\right)\right]\right\}.\left[\exp\left(-c.t\right)\right] \quad \left(kg\ day^{-1}\right) \tag{6.1}$$

where t is days from calving, a is a scalar, b is a growth rate parameter, c is a decay parameter and G_o is the initial state at $t = 0$, given by:

$$G_o = \ln\left[-\ln\left(\frac{M_o}{a}\right)\right] \tag{6.2}$$

where M_o is initial milk production at parturition. M_o was set at 3.1 so G_o would closely approximate the value given in Table 5 of Friggens et al. (1999) while the values of b and c, 0.0918 and 0.00417, respectively, were also taken from this table. The value of scalar a was given the value of 9 in order to attain a peak daily milk production of approximately 8 kg/day which represents the mean maximum daily milk production of Angus cows (Fox et al. 2004). The patterns of fat, protein and lactose production across time were modelled based on the percentage contribution of each to total milk volume. McDonald et al. (2002) demonstrate in their Figure 16.3 that the pattern of lactose production follows a similar pattern to total milk production and thus percent lactose production was modelled using equation (6.1). The values of a, b, c and M_o were assumed to be 7, 0.009, 0.003 and 4.5 to obtain an average lactose percentage of 4.5 (Waite et al. 1956) across the 300 days of lactation. Also shown in Figure 16.3 of McDonald et al. (2002) is the contrasting pattern of fat and protein production in comparison to the pattern of total milk production. It can be seen in this figure that fat and protein production decrease during the initial stages of lactation following parturition and then increase again as lactation progresses towards completion. They follow a pattern that could be considered to be some what of a mirror image of the total milk production curve. The pattern of percent protein and fat production were modelled by making alterations to equation (6.1) by removing the negative sign between the two exponents in the first component to produce:

$$\frac{dY}{dt} = a\{\exp[\exp(G_o - b.t)]\}.[\exp(-c.t)] \quad (kg\ day^{-1}) \tag{6.3}$$

The patterns produced by this curve are sensible and consistent with the patterns seen in Figure 16.3 of McDonald et al. (2002). The values of *a*, *b*, *c* and M_o were assumed to be 3.2, 0.04, -0.001 and 2.4 to obtain an average protein percent of 3.8 (Fox et al. 2004) across lactation while they were assumed to be 2.8, 0.05, -0.002 and 1.7 to obtain an average fat percent of 4 (Fox et al. 2004; Waite et al. 1956). No variation was modelled in milk production resulting in the same quantity of milk being available for each animal to consume, if capable, between birth and weaning (300 days).

Milk Utilisation

The consumption of milk offers some complication to modelling animal growth in terms of dealing with the energy available from the milk and how this energy is utilised by the growing animal. In young ruminants, the first two compartments of the stomach, the rumen and reticulum, are undeveloped and milk is channelled directly to the omasum and abomasum via a tube-like fold of tissue known as the oesophageal groove. This allows the high-quality nutrients contained in milk to avoid rumen fermentation and be digested by the gastric stomachs even when the animal is consuming herbage (McDonald et al. 2002). Consequently, when young animals were consuming milk they were treated as monogastric animals (e.g. pig) and the equation presented by Emmans (1994) for single-stomached animals is used for determining the available effective energy:

$$EE = (1.17ME) - \left[4.29\left(\frac{CPC}{1000}\right)\right] - 2.4 \quad (MJ\ EE\ kg^{-1}) \tag{6.4}$$

where *CPC* is the crude protein content of milk and *ME* is the metabolisable energy content of milk and is calculated following Emmans (1994) as:

$$ME = DigE - 5.63\left(\frac{CPC}{1000}\right) \quad \left(MJ\ ME\ kg^{-1}\right) \tag{6.5}$$

where *DigE* is the digestible energy content of milk which is considered to be 98.6% of the gross energy of milk ($DigE = 0.986GE$ (Walker 1975)). The gross energy of milk was calculated from the equation presented by McDonald et al. (2002) that takes the percentage of fat (*F*), protein (*P*) and lactose (*L*) in milk into consideration:

$$GE = \left(0.0384F\right) + \left(0.0223P\right) + \left(0.0199L\right) - 0.108 \quad \left(MJ\ kg^{-1}\right) \tag{6.6}$$

The efficiency of use of ideal protein for growth (k_{DPLS}) is dependent upon whether the protein is derived from milk or solid sources and is determined using the ratio between DPLS derived from milk and total DPLS (Freer et al. 1997).

$$k_{DPLS} = \frac{0.7}{1 + \left(\frac{0.7}{0.8} - 1\right)\frac{DPLS_{milk}}{DPLS}} \tag{6.7}$$

Intake of Pasture, Paddock Supplement and Feedlot Rations

The intake of pasture and paddock supplement was modelled using the system proposed by SCA (1990) and used by the GrazPlan decision support system, equations (2) through (30) (Freer et al. 1997). Recent developments in the GrazPlan system were also included in the intake equations. These included the factor *CF* that was introduced to reduce the potential intake of non-lactating animals with relative body condition scores (BC) >1 and can be found in the technical paper presented by Freer et al. (2006).

$$\begin{aligned} CF &= BC.\left(\frac{1.7 - BC}{0.7}\right) && \text{when, } BC > 1 \\ &= 1 && \text{Otherwise} \end{aligned} \tag{6.8}$$

The relative size (*Z*) used by the GrazPlan system was replaced by the degree of maturity of the protein content (u_t), which is simply the current protein content divided by the mature protein content (e.g. $\frac{ActP_t}{P_m}$). The standard reference weight (*SRW*) required by this system was replaced with an estimate of mature EBW made when the degree of maturity of protein was equal to 1.0 using equations (3.13) to (3.16) in chapter 3. A limit was imposed on the intake capacity of animals consuming feedlot rations using equations (25) and (26) presented by Freer et al. (1997) that is dependent on the digestibility of the feedlot ration being consumed and the quantity of the ration available to the animal.

Body Composition

The carcass characteristics of the markets presented in Table 6.1 require measures of P8 fat depth and carcass weight as well as in some cases measures of marbling score. The hierarchical degree of maturity (HDOM) model developed and tested in chapter 4 was used to predict physical body composition that includes carcass weight. Methods for predicting both P8 fat depth and marbling score were developed based on equations derived using live weight, age and carcass data obtained from Angus steers bred by the Cooperative Research Centre (CRC) for Cattle and Beef Quality. The experimental design and breeding program used to obtain these data are described by Upton et al. (2001). Equations (6.9) and (6.10) were developed using the statistical package R (R Development Core Team 2004) by performing linear regression analysis on the square root of P8 fat depth data and log transformed IMF data. These transformations were performed to normalise variance. The independent variables tested for both P8 fat depth and IMF percent included live weight at slaughter, age in days, carcass weight, carcass flesh weight and carcass bone weight. Independent variables of insignificant effect were sequentially removed until only variables of significant effect remained. The equation used to predict P8 fat depth in millimetres (mm) was:

$$P8 = \left[1.75 + (0.0158Cwt) - (0.058Bone)\right]^2 \quad (mm) \qquad (6.9)$$

where *Cwt* is carcass weight and *Bone* is carcass bone weight. This linear regression analysis produced an adjusted R^2 value of 0.58. The equation used to predict IMF percent was:

$$IMF = \exp\left[0.584 - (0.00161Wt) + (0.011Flesh) - (0.0136Bone)\right] \quad (\%) \quad (6.10)$$

where *Wt* is live weight at slaughter, *Flesh* is carcass flesh weight and *Bone* is as above. This linear regression analysis produced an adjusted R^2 value of 0.54. The predicted IMF percent was then used to estimate a marble score using Table 6.4, taken from Bindon (2001b).

Table 6.4: Relation between AusMeat marble score and chemically extracted intramuscular fat (IMF %) at the 12/13th rib site taken from Bindon (2001b).

	AusMeat Marble Score						
	0	1	2	3	4	5	6
IMF%	2.70	4.35	5.37	7.11	8.96	10.32	10.50

Simulated Animals

The individual animals contained in this production system were simulated from the growth model input parameters estimated by deterministic sampling in chapter 5, when using only partial data (e.g. only used body weight data taken at 250 and 450 days of age, see section 5.2.3 for a description). Each animal was created by assigning a value for the three input parameters of the growth model described above (mature protein content (P_m), mature lipid:protein ratio (Q) and general rate parameter (B^*), see section 3.2.3 for a description) and for birth weight. The estimated means (SD) for P_m, Q and B^* and birth weight were 52.3 (9.2), 3.9 (0.1) and 0.021 (0.0022), respectively. The mean (SD) birth weight (W_o) of 29.2 (4.8) kg was taken from the Trangie experiment (Perry and Arthur 2000) that is described in chapters 3, 4 and 5. The parameter values were assigned to animals from uniform distributions with the purpose of obtaining a uniform distribution of model outputs in order to fully demonstrate the functionality and value of the drafting system developed in this study. These values were randomly drawn from a uniform distribution that allowed values to be up to 6 deviations either side of the parameter mean. A correlation was also established between the P_m and B^* parameters to fully demonstrate the functionality and value of the drafting system. In a production environment it is envisaged that input parameter distributions would not be of this nature and it would be more appropriate to sample parameter estimates from normal distributions.

6.2.3. Production Scenarios

There were four different production scenarios explored during this study. The first scenario was the base scenario where animals were drafted into market cohorts based on the characteristics of the simulated production system. The second scenario tested how the drafting system would react to changes in price structure that may be a result of a disease outbreak e.g. BSE. This was achieved by reducing the price offered by the Japanese markets shown in Figure 6.2. The third scenario simulated the occurrence of a drought reducing the quantity of pasture produced by the production system and the fourth simulated a reduction in the profitability of feeding for the Japanese B3 market due to an increase in production costs.

6.2.4. Animal Allocation to Markets

Random Key Representation

In this study DE used the RK representation as a means of drafting cohorts of animals into market groups that most appropriately match the production potential of those animals. An individual Random Key is a real-valued number usually in the range [0, 1] (Ryan et al. 2004) and a series of these numbers are created and sorted to develop an allocation sequence for the problem. Perhaps the most helpful means of understanding how RK works is to illustrate how it is used to solve the TSP (Figure 6.4). Each city in the TSP is assigned to one of the random numbers in the unsorted RK representation. This random number sequence is then sorted and the associated cities are placed into the position that corresponds to the random number to which they were initially assigned. RK eliminates the problem of unfeasible solutions that can be produced using standard genetic operators in evolutionary search methods, by simply changing the random number sequence rather than attempting to use the designated city numbers i.e. rather than directly assigning a random rank to each city.

1	2	3	4	5	6	7	8	City
0.34	0.02	0.70	0.39	0.40	0.99	0.82	0.16	Unsorted Representation
0.02	0.16	0.34	0.39	0.40	0.70	0.82	0.99	Sorted Representation
2	8	1	4	5	3	7	6	Permutation (City Order)

Figure 6.4: An example of how the Random Key Representation is used when attempting to solve the TSP. City 2 inherits the lowest RK and is thus the first-ordered city while city 6 inherits the highest and is ordered last.

In order to achieve the outcome of optimally drafting animals into market cohorts extensions to RK were required that would increase its flexibility by allowing DE to determine the appropriate timing of drafting events and facilitate the partitioning of animals into market cohorts. These extensions are illustrated in Figure 6.5. The RK sequence was extended to include drafting thresholds and drafting ages. The drafting thresholds are not strictly needed as fixed thresholds will still produce optimal results by 'clumping' RK's as required. However, they facilitate the allocation of animals to market cohorts which reduces the computational time required to find optimal solutions. The thresholds are used once the RK sequence has been sorted to partition animals into their market cohorts. In the simplified example given in Figure 6.5, RK is applied to 8 animals and following the sorting step the threshold values are used to partition the animals into three market groups. The drafting ages define when these drafting events occur during the time line of the production system.

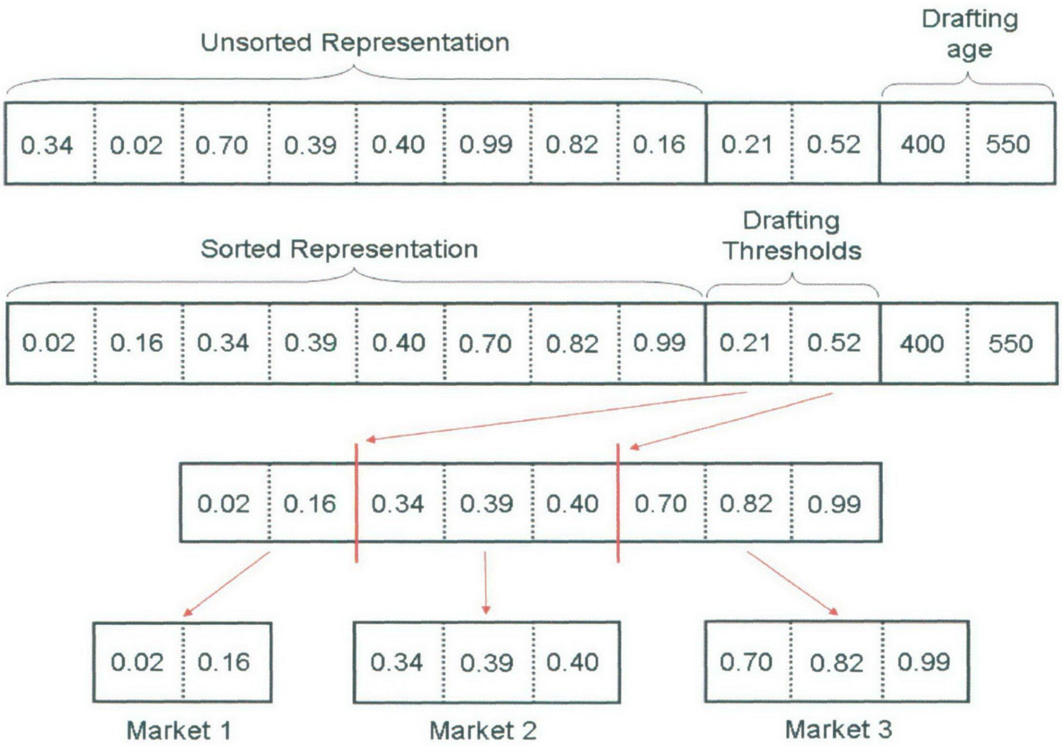

Figure 6.5: Representation of random keys used by Differential Evolution that includes the drafting thresholds and drafting ages used to draft animals into their most appropriate markets.

Differential Evolution

The DE algorithm (Price and Storn 1997) as described in chapter 2 and used in chapters 3 and 5 used RK for allocating animals to markets whose requirements are appropriate for the animals' production abilities. The DE evolved the animal's random key representations while simultaneously evolving the proportions of animals entering each market cohort and the age that these cohorts were separated (as shown in Figure 6.5). The DE was allowed to run for 2500 generations or until the best solution found remained unchanged for 250 generations at which point convergence was considered to have been sufficiently achieved and the optimisation stopped. All simulations achieved convergence prior to 2500 generations. The optimisation procedures were also run from different random starting points and allowed to converge. Each converged to the same optimal scenario.

Optimisation Criteria

The optimisation criterion used to allocate animals to the different markets was simply a measure of profit, as shown in equation (6.11).

$$\text{Profit} = \sum_{i=1}^{N}\left(Income_i - \sum_{j=1}^{X} Costs_{ij} \right) \qquad (6.11)$$

where N is the number of animals, X is the number of costs, *Income* is the monetary value of the carcass of the i^{th} animal and *Costs* is the monetary value of the j^{th} cost incurred in order to grow the i^{th} animal to slaughter. Derivation of income at slaughter and costs of producing each animal accumulated across its whole growth trajectory are described above.

6.2.5. Graphical User Interface

The graphical user interface (GUI) seen in Figure 6.1 forms part of the software package developed as part of this study for allocating animals to market endpoints called 'Cohort Drafting'. Figure 6.10 is the main GUI of this software package where optimisation outputs are presented graphically. Figure 6.11 is another GUI in the software package that displays operational decisions associated with each management group of animals. 'Cohort Drafting' was programmed using Microsoft Visual Basic .NET in the Microsoft .NET Framework 1.1 (Copyright © Microsoft Corporation, 2003).

6.3. Results

The RK representation was used by DE to determine the optimal proportion of animals partitioned towards each target market and the optimal ages to draft these cohorts. The drafting points and the proportion of animals partitioned between the target markets are illustrated in Figure 6.6 for scenario 1. The red circle in Figure 6.6, and the value below, represents the final slaughter age (1000 days) for the B3 market while the green and purple circles represent the slaughter ages for the EU and HS markets (740 and 640 days, respectively). The initial drafting point partitioned 24 animals to the HS market while the remaining 76 animals were maintained as a single pasture cohort at 550 days of age. The second drafting point at 700 days of age partitioned 41 and 35 animals towards the EU and B3 markets, respectively. The large deviations immediately after drafting points are a result of selection based on phenotypes that are a result of the decisions made by DE.

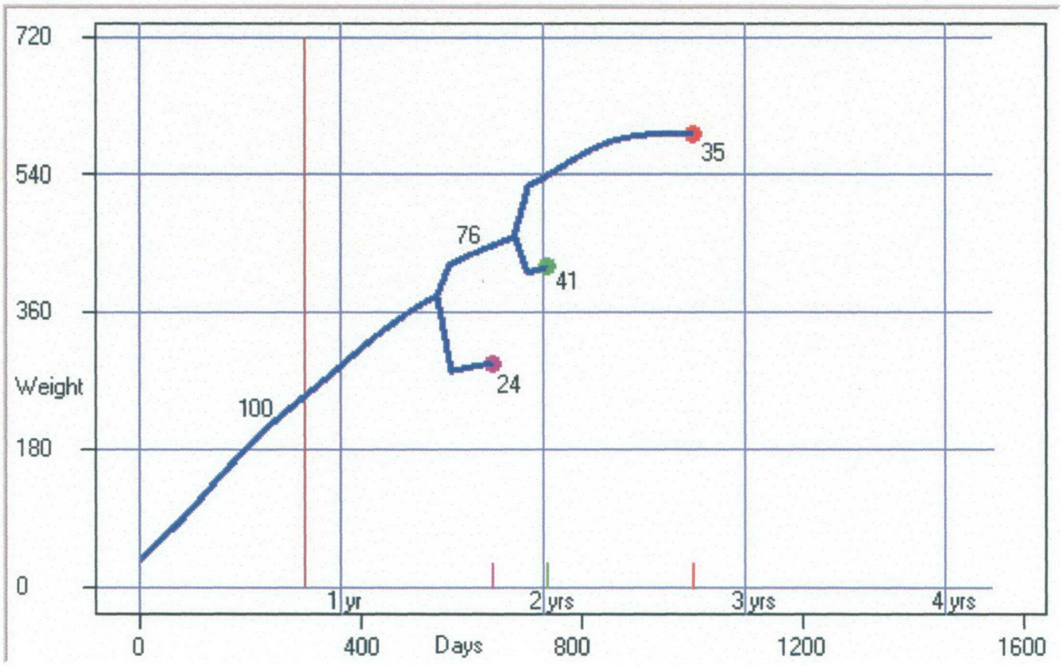

Figure 6.6: Drafting points and percentage of animals partitioned between market cohorts in scenario 1. Large deviations created immediately following a drafting age are the result of phenotypic selection which results from drafting decisions made by Differential Evolution.

Table 6.5 contains a portion of the simulation readout for scenario 1. The readout demonstrates how the drafting thresholds partition the animals into their respective target markets using the individual RKs. As would be expected animals partitioned towards the B3 market had higher carcass weights, P8 fat depths and marbling scores than animals destined for the EU market while animals destined for the HS market had lower carcass characteristics again. Consequently, the animals directed towards the B3 market also had higher incomes and higher costs than animals destined for the EU and HS markets. The total profit of this drafting plan is also shown.

Table 6.5: Simulation printout detailing carcass characteristics, market allocation, income and cost of 10 selected animals. The market allocation thresholds, drafting ages and total profitability of the production system are also presented for scenario 1.

Animal	Random Key	Market	Income	Cost	Cwt	P8	MS
1	0.3092	EU	1304.35	110.23	334.5	22.0	6
2	0.3935	EU	1031.56	106.83	279.0	17.5	4
3	0.8169	B3	2082.71	181.57	393.0	27.5	6
4	0.8155	B3	2207.12	186.51	416.5	29.5	6
5	0.2930	EU	971.98	105.62	262.5	16.5	3
6	0.4157	EU	1115.44	109.33	293.5	19.0	4
7	0.4193	EU	1023.26	106.81	276.5	17.5	4
8	0.7287	B3	2051.95	185.63	387.0	27.0	6
9	0.4248	EU	1015.92	115.06	274.5	17.5	4
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
100	0.1668	HS	758.43	101.09	220.0	13.5	3

Drafting Points:

Thresholds:		Ages:		Profit:
0.2086	0.5423	550	700	121,128.40

Figure 6.7 illustrates how the 100 animals were partitioned between the three target markets when the value of the B3 market is reduced. In contrast to Figure 6.6, partitioning animals towards the EU and HS markets only at 550 days of age was found to be optimal. This drafting plan partitioned 35 animals towards the HS market which is greater than the number partitioned to that market in Figure 6.6. The remaining 65 animals were partitioned towards the EU market. The optimal slaughter ages for the EU and HS markets were found to be 590 and 650 days, respectively.

Table 6.6: Simulation printout detailing carcass characteristics, market allocation, income and cost of 10 selected animals. The market allocation thresholds, drafting ages and total profitability of the production system are also presented for the second scenario when the value of the Japanese B3 market is reduced.

Animal	Random Key	Market	Income	Cost	Cwt	P8	MS
1	0.5718	EU	1111.90	80.33	292.5	18.0	4
2	0.0582	HS	919.25	97.48	266.5	16.5	3
3	0.7426	EU	1018.41	70.06	275.0	15.5	3
4	0.4215	EU	1278.57	78.22	328.0	20.0	6
5	0.1039	HS	862.66	96.37	250.0	15.5	3
6	0.6845	EU	935.60	80.44	260.0	16.0	3
7	0.1074	HS	913.72	97.25	265.0	16.5	3
8	0.9262	EU	1271.97	81.84	326.0	20.0	6
9	0.4926	EU	983.93	87.28	266.0	16.5	4
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
100	0.0436	HS	758.43	101.09	220.0	13.5	3

Drafting Points:				
Thresholds:		Ages:		Profit:
0.2093	0.9988	550	-	86,883.40

Figure 6.8 illustrates the optimal drafting plan found in response to a reduction in pasture availability due to the occurrence of drought. In comparison to Figure 6.6, 48 animals were partitioned towards the HS market while 52 were maintained as a single cohort, at 550 days of age. The second drafting point at 700 days of age partitioned 17 and 35 animals towards the EU and B3 markets, respectively. While the optimal slaughter ages for this scenario were found to be identical to those for scenario 1 it is evident that the growth trajectories were suppressed as a result of the reduced availability of pasture after 365 days of age.

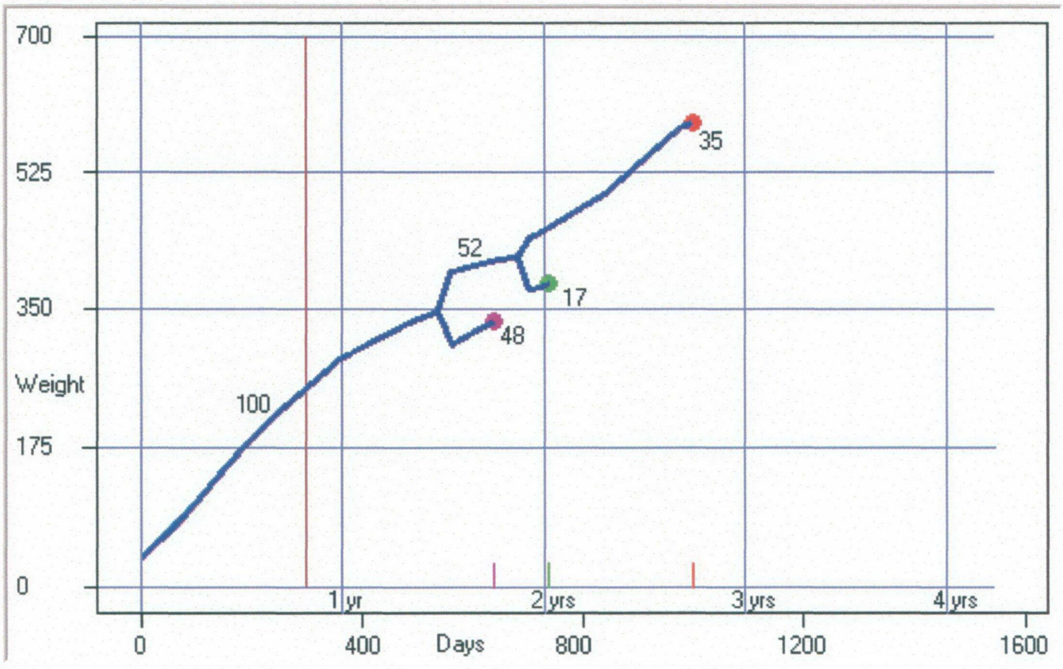

Figure 6.8: Drafting points and partitioning of animals between market cohorts in the third scenario when drought reduces pasture availability.

The smaller interval between the drafting thresholds shown in Table 6.7 illustrate the reduced capacity for animals to be partitioned towards the EU market while the lower threshold shows that more animals were able to be partitioned towards the HS market, compared to scenario 1. This is reflected in the number of animals destined for the EU and HS markets in comparison to scenario 1. Table 6.7 also shows that the simulated drought conditions reduced the carcass weights and P8 fat depths of animals 1, 3, 4, 7 and 8 that were destined for the same target markets as in scenario 1. This reduction in carcass weight is reflected in the income received from these animals. The cost of producing these animals is also increased as a result of the simulated drought conditions. As a consequence of the reduced number of animals partitioned towards the EU market and the increased feeding costs, the total profitability of the production system in this scenario is reduced in comparison to scenario 1.

Table 6.7: Simulation printout detailing carcass characteristics, market allocation, income and cost of 10 selected animals. The market allocation thresholds, drafting ages and total profitability of the production system are also presented for the third scenario when drought reduces pasture availability.

Animal	Random Key	Market	Income	Cost	Cwt	P8	MS
1	0.3618	EU	1017.11	115.69	275.0	16.5	3
2	0.2086	HS	860.44	104.41	249.5	15.0	3
3	0.8913	B3	1982.05	197.13	249.5	25.0	6
4	0.7728	B3	2200.36	204.92	415.0	29.5	6
5	0.0759	HS	824.34	103.73	239.0	14.5	3
6	0.0782	HS	896.40	104.81	260.0	16.0	3
7	0.3901	EU	873.00	112.82	242.5	14.5	3
8	0.6379	B3	2064.75	201.31	386.0	27.0	6
9	0.1748	HS	880.67	105.60	255.5	15.5	3
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
100	0.0241	HS	753.80	104.82	218.5	13.5	2

Drafting Points:

Thresholds:		Ages:		Profit:
0.3358	0.4443	550	700	112,772.30

Figure 6.9 illustrates the optimal drafting plan found in response to a reduction in the profitability of feeding for the B3 market due to increased production costs. In comparison to Figure 6.6, 35 animals were partitioned towards the HS market while 65 were maintained as a single cohort at 550 days of age. The second drafting point partitioned 62 and 3 animals towards the EU and B3 markets, respectively, at 551 days of age. The optimal slaughter ages for this scenario were found to be 591, 650 and 900 for the EU, HS and B3 markets, respectively.

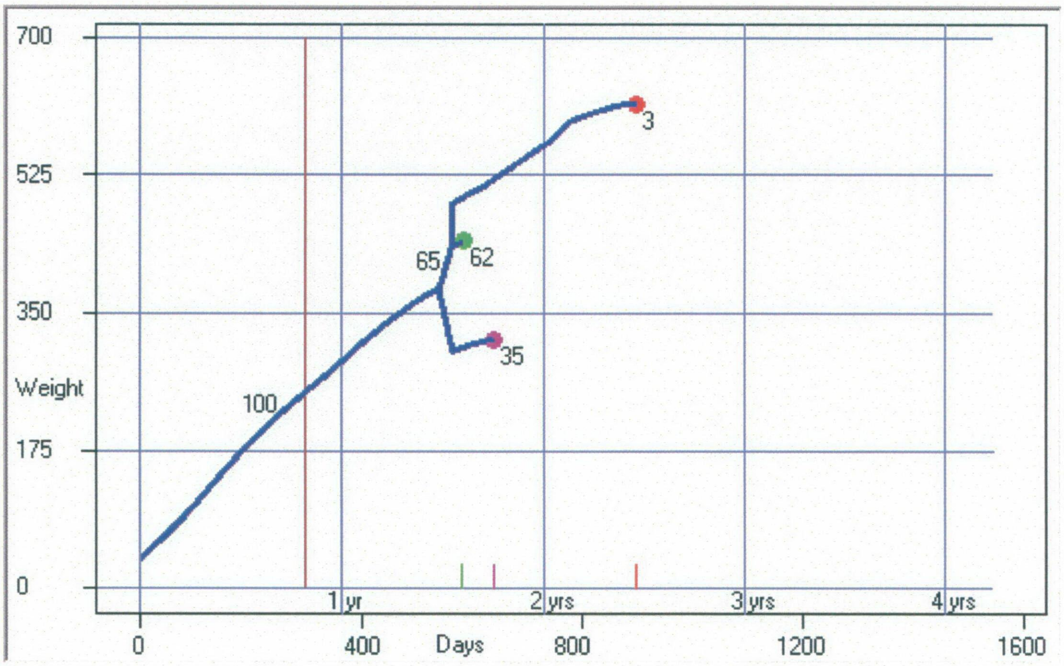

Figure 6.9: Drafting points and partitioning of animals between market cohorts in the fourth scenario when increased production costs reduce the profitability of the Japanese B3 market.

The higher drafting threshold shown in Table 6.8 reduces the capacity for animals to be partitioned towards the B3 market. This is reflected in only one of the selected 10 animals being partitioned towards the B3 market. The reduced optimal age of slaughter found for the EU market resulted in reduced carcass weights and P8 fat depths of animals (1, 6 and 9) partitioned towards the EU market in both scenarios 1 and 4 (Table 6.5). This is reflected in reduced incomes being received by these animals. The cost of producing these animals is also reduced as a result of the reduced slaughter age. The total profitability of this drafting plan is reduced in comparison to scenario 1 but is greater than that of scenario 2 because some animals (3) are still partitioned towards the B3 market.

Table 6.8: Simulation printout detailing carcass characteristics, market allocation, income and cost of 10 selected animals. The market allocation thresholds, drafting ages and total profitability of the production system are also presented for the fourth scenario when increased production costs reduce the profitability of the Japanese B3 market.

Animal	Random Key	Market	Income	Cost	Cwt	P8	MS
1	0.7982	EU	1111.90	80.33	292.5	18.0	4
2	0.1428	HS	919.25	97.48	266.5	16.5	3
3	0.9877	B3	2061.75	1084.14	389.0	27.0	6
4	0.5285	EU	1278.57	78.22	328.0	20.0	6
5	0.0223	HS	862.66	96.37	250.0	15.5	3
6	0.6312	EU	935.60	80.44	260.0	16.0	3
7	0.1880	HS	913.72	97.25	265.0	16.5	3
8	0.3922	EU	1271.97	81.84	326.0	20.5	6
9	0.3370	EU	983.93	87.28	266.0	16.5	4
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
100	0.1690	HS	758.43	101.09	220.0	13.5	3

Drafting Points:

Thresholds:		Ages:		Profit:
0.2276	0.9545	550	551	89,609.80

The market allocation pattern for the 10 animals presented in the tables above is reproduced in Table 6.9 for the four scenarios along with their respective growth model input parameters. The market allocation pattern across the four scenarios for all 100 animals is presented in the Appendix along with each animal's growth model input parameters. It is evident that animals with higher P_m and B^* values tend to be allocated to the B3 market while those with smaller values tend to be partitioned towards the HS market (e.g. in scenario 1 average P_m and B^* values for the B3 market were 67.63 and 0.025 compared to 35.60 and 0.017 for the HS market). This is a sensible result given higher P_m and B^* values are associated with larger mature weights at younger ages which result in heavier carcass weights and are considered desirable by the B3 market. There does however appear to be some interaction between parameters when production conditions are altered compared to the base scenario, which produces different allocation patterns for animals with what could be considered similar parameters. Table 6.9 shows two examples of these interactions. Animals 3, 4 and 8 are allocated to the B3 market in scenarios 1 and 3 but only animal

3 is allocated to this market in scenario 4 even though its P_m and B^* parameters are smaller than those of animals 4 and 8. The different allocation pattern of animals 5, 7 and 9 across scenarios 2 and 3 is a further example of the interaction between input parameters.

Table 6.9: Allocation pattern across the 4 scenarios explored for 10 selected animals along with their growth model input parameters.

	Scenario							
Animal	1	2	3	4	P_m	Q	B*	W_0
1	EU	EU	EU	EU	56.24	4.22	0.024	31.35
2	EU	HS	HS	HS	50.28	3.73	0.018	15.21
3	B3	EU	B3	B3	64.56	4.14	0.020	16.13
4	B3	EU	B3	EU	70.55	3.81	0.025	28.02
5	EU	HS	HS	HS	46.60	3.92	0.017	19.83
6	EU	EU	HS	EU	51.67	3.66	0.022	21.36
7	EU	HS	EU	HS	48.82	3.91	0.017	24.25
8	B3	EU	B3	EU	67.20	3.60	0.027	43.05
9	EU	EU	HS	EU	47.78	3.67	0.022	29.60
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
100	HS	HS	HS	HS	37.84	3.80	0.021	30.63

Table 6.10 illustrates why animals 3, 4 and 8 have different allocation patterns in scenario 4. Animal 3 was allocated to the B3 market even though it's P_m and B^* input parameters are smaller than those of animals 4 and 8. Table 6.10 indicates that animal 3 would achieve a smaller carcass weight than animals 4 and 8 in the EU market at 591 days of age, due to its lower B^* value. This smaller carcass attracts a lower carcass price reducing the animal's value. However, in the B3 market animal 3 is able to achieve a sufficiently large carcass by 900 days to make it of higher value than animal 8. This outcome is a consequence of the high value of Q this animal possesses giving it a higher expected mature body weight. Also evident in Table 6.10 is the greater cost of producing animal 3 in comparison to the average animal allocated to the B3 market in scenario 4. This outcome is again attributable to the higher Q value of animal 3. The higher mature lipid to mature protein ratio of animal 3 indicates that greater quantities of energy are required to grow the animal to maturity and thus greater costs would be incurred. Even though the average cost of growing animals in

the EU market is used in Table 6.10 it would be expected that growing animal 3 to its slaughter weight would incur a greater cost because of its higher Q value.

Table 6.10: Comparison between carcass characteristics and profitability of animals 3, 4 and 8 if grown for the European Union and Japanese B3 markets, in Scenario 4.

Animal	Market	Cwt (kg)	P8 (mm)	Price ($/kg)	Income ($)	Cost ($)	Profit ($)
3	EU	275.0	15.5	3.70	1018.41	80*	938.41
	B3	389.0	27.0	5.30	2061.75	1084.14	977.61
4	EU	328.0	20.0	3.90	1278.57	78.22	1200.35
	B3	415.0	29.5	5.30	2198.60	1045*	1153.60
8	EU	326.0	20.5	3.90	1271.97	81.84	1190.13
	B3	386.5	27.0	5.30	2048.71	1045*	1003.71

*Average production cost of animals allocated to the EU and B3 markets in scenario 4.

The reasons for the different allocation patterns of animals 5, 7 and 9 between scenarios 2 and 3 are illustrated in Table 6.11. In scenario 2, it is clearly evident from the results in Table 6.11 that the allocation of animal 9 to the EU market is due to its ability to produce a higher carcass weight at the age of 590 days compared to animals 5 and 7. This is a direct consequence of this animal having a higher B^* value than animals 5 and 7 even though all three animals have similar P_m values. Consequently, animal 9 required greater quantities of feed at younger ages which is reflected in the higher production cost of this animal compared to the average of animals allocated to the EU market in scenario 2. In scenario 3, animal 7 is allocated to the EU market while animal 9 is allocated to the HS market. The reason behind this reversal in animal allocation is the lower B^* value of animal 7 prevents it from achieving a carcass weight that produces a greater profit in the HS market than that achieved in the EU market. However, the difference in profitability of the EU and HS markets for this animal is expected to be smaller than that illustrated in Table 6.11. The reason for this is the production cost of animal 7 is expected to be lower than the average of animals grown for the HS market based on the fact that the cost of growing this animal for the EU market was lower than the average cost. In both scenarios animal 5 is allocated to the HS market because of its inability to produce a carcass weight that is of any value to the EU market. This outcome is a consequence of this animal's lower P_m and B^* values.

Table 6.11: Comparison between carcass characteristics and profitability of animals 5, 7 and 9 if grown for the Heavy Supermarket and European Union markets, in scenarios 2 and 3.

Animal	Market	Cwt (kg)	P8 (mm)	Price ($/kg)	Income ($)	Cost ($)	Profit ($)
Scenario 2:							
5	HS	250.0	15.5	3.45	862.67	96.37	766.30
	EU	231.0	13.5	0.00	0.00	82*	-82.00
7	HS	265.0	16.5	3.45	913.73	97.25	816.48
	EU	243.0	14.5	3.60	873.99	82*	791.99
9	HS	270.5	17.0	3.35	906.08	97*	809.08
	EU	266.0	16.5	3.70	983.93	87.28	896.65
Scenario 3:							
5	HS	239.0	14.5	3.45	824.34	103.73	720.61
	EU	235.0	14.0	0.00	0.00	115*	-115.00
7	HS	249.5	15.0	3.45	861.53	105*	756.53
	EU	242.5	14.5	3.60	873.00	112.82	760.18
9	HS	255.5	15.5	3.45	880.67	105.60	775.07
	EU	246.0	15.0	3.60	886.48	115*	771.48

*Average production cost of animals allocated to the HS and EU markets in scenarios 2 and 3.

6.4. Discussion

The purpose of this study was to demonstrate how managerial decisions could be made using predictions from growth and body composition models (described in chapter 3 and 4) that are presented with appropriate quantities of information. This study determined whether a given animal could achieve a desired production level (in terms of weight gain and composition) by presenting these models with parameter estimates down to an individual animal level and information relating to the prevailing environment. This study optimised drafting decisions given these model predictions with DE that used an extended version of RK. The results obtained during this study indicate that the drafting system was able to find optimal drafting proportions and ages for cohorts across a number of production scenarios. These optimisation outcomes were determined to be the true optimums for two reasons.

Firstly, repeated optimisations run from different starting points were found to converge on the same optimal scenario. Secondly, in scenarios with similar production circumstances identical animals were allocated to one target market e.g. in scenarios 1 and 3 the same 35 animals were allocated to the B3 market and in scenarios 2 and 4 the same 35 animals were allocated to the HS market. The results presented in Figure 6.6 and Table 6.5 illustrate how animals were allocated to the HS, EU and B3 markets given ideal production conditions in the simulated system.

The drafting system behaved in what would be considered a sensible manner during scenario 2 when the value of the B3 market was reduced as a result of a disease outbreak. Firstly, the optimal drafting scenario reallocated all animals that were destined for the B3 market in scenario 1 to the EU market in scenario 2. Secondly and perhaps most importantly, the drafting system also found new optimal drafting ages and reallocated animals from the EU market to the HS market to maximise the efficiency of the whole production system. The reallocation of animals was performed on the basis that these animals were unable to achieve the carcass requirements for the EU market at the new slaughter age of 590 days. An example is described in Table 6.10 where animal 9 was able to achieve a carcass weight that was acceptable for the EU market and more profitable than the carcass weight that would be produced for the HS market. Animal 5 was unable to produce a carcass acceptable for the EU market while the carcass produced by animal 7 for the EU market was found to be less profitable than the carcass it produced for the HS market.

The drafting system once again performed in what could be considered a sensible manner when pasture availability was reduced to simulate the effect of a drought during scenario 3. The drafting plan maintained the same number of animals (35) in the B3 cohort compared to scenario 1 because these were the only animals that had the growth capacity to meet the carcass requirements of this market. The drafting plan reallocated 24 animals to the HS market compared to scenario 1 which left only 17 destined for the EU market. These animals were maintained in the EU cohort because this is where maximum profitability was obtained. An example is described in Table 6.11 where animal 7 produced its maximum profit in the EU market while the maximum profit of animals 5 and 9 was achieved in the HS market.

The reduction in profitability associated with increased production costs for the B3 market explored in scenario 4 produced some expected and some unexpected results. Firstly, the drafting plan allocated 35 animals to the HS market which is identical to the allocation found in scenario 2. This is somewhat of an expected result given the optimal second drafting age was found to be 551 days. If reallocated, these animals were unable to obtain carcass weights required by the EU market or carcasses of high enough profitability compared to those they produced for the HS market. Some animals were maintained in the B3 market despite the reduced profitability of feeding for this market. Although this was not an unexpected result, some of the animals selected to remain in the B3 market was the surprising outcome. The animals displayed in Table 6.10 are an example of an unexpected outcome. Animal 3 was maintained in the B3 market cohort even though it had smaller P_m and B^* values than animals 4 and 8. These values reduce this animal's ability to produce a carcass that is highly profitable in the EU market. However, the higher Q value of animal 3 in conjunction with its P_m value indicates it has a mature body weight that allows it to achieve a carcass weight that is acceptable for the B3 market at 900 days of age and thus more profitable.

Table 6.9 displays the market allocation pattern for 10 selected animals in conjunction with each animals growth model input parameters. In some instances a simple correlation can be drawn between growth model input parameters and market allocation e.g. higher P_m and B^* values tend to be associated with the B3 market in scenarios 1 and 3. However, in the main, a high level of interaction occurs between the growth model input parameters, which inturn influences animal growth and thus market allocation. This interaction primarily involves the P_m, Q and B^* parameters. The P_m and Q parameters are determinants of mature body weight, which helps determine if animals have the capacity to reach market requirements (e.g. 350-420 kg carcass weight for the B3 market). The B^* parameter, along with nutrition, is the primary determinant of growth rate and consequently the ability of animals to reach desired carcass weights at given ages. Using DE to evolve RK with the objective of optimising animal allocation to market cohorts has the capacity to deal with complex interactions between growth model input parameters, resulting from the non-linear nature of growth models, which other search methods (e.g. linear programming) would not be capable of dealing with. These interactions also extend to include those between growth model input parameters and environmental influences including nutrition.

It is important to recognise that the results obtained during this study highlight the concept discussed by Michalewicz and Fogel (2000), in that every time a problem of this nature is solved, the solution is simply the solution in terms of the model used to represent the system under consideration. However, although these results are based on a simulated production system the outcomes of the drafting system are sensible and react in sensible ways when changes occur in the prevailing simulated production system. Initially, some of the outcomes seemed unexpected, but were found to be optimal when the growth model input parameters and their effect on growth were taken into consideration given the prevailing production conditions e.g. drought, price structures.

The sensible behaviour of the drafting system, in terms of an Australian production environment, given changes in the prevailing production system is not an unexpected result because the simulation components are representative of those found in Australian production systems. The pasture conditions simulated during this study (Figure 6.3) were the average of twenty, one year GrassGro (Moore et al. 1997) simulations (1980-1999) based on the soil and pasture characteristics described by Ayres et al. (2001) for the Glen Innes Agricultural Research and Advisory Station. The markets are those targeted by beef producers around Australia and the price grids are based on these markets. The feedlot rations used during this study are based on those used in feedlots throughout Australia and the costs of production were obtained from feed manufacturing companies and produce stores. However, the real beauty of this drafting system is its capacity to operate sensibly in any production enterprise regardless of its geographical location when given the environmental (including feed rations) and economic conditions surrounding that enterprise and the markets that are targeted by it.

The feeding and growth model used to predict animal growth was earlier found to be the most accurate of those tested in chapter 3. The HDOM model developed in chapter 4 and used here was shown to be the most accurate of the body composition models tested. The extensions made to the feeding and growth model including those relating to milk composition, energy utilisation and feed intake were undertaken using systems presented in the literature that have been shown to work sensibly. The combination of these models, their extensions and the simulation components build confidence that the simulation outputs are sensible and indicative of those that would be close to optimal in reality. However, further study is still warranted to test these and other such models, and the methodology developed, when used for different types of production systems and market endpoints.

6.4.1. Methodology

The simulation interface shown in Figure 6.10, illustrates the interaction that occurs between feed intake, growth and body composition components and form the basis for drafting decisions. The output for scenario 2 where only HS and EU cohorts are produced has been selected for ease of understanding.

The top right graphic shows the predicted live weight trajectories presented in Figure 6.7 for scenario 2. The bottom left graphic illustrates the average wet weight feed intake of milk (blue), pasture (green), paddock supplement (pink) and feedlot ration (orange). The oscillations in the pasture intake coincide with the oscillations seen in the pasture production curve in Figure 6.3. Paddock supplement is offered at times when decreased pasture availability reduces growth rate. The point where feedlot rations begin to be consumed on the feed intake graphic is seen to coincide with the drafting point because this represents the time when this cohort is drafted and transported to the appropriate feedlot. It is also shown that the feedlot ration is consumed for a greater period of time following the drafting point. This occurs in order to meet the 100 days of feedlot feeding required by the HS market compared to the short pasture interval that occurs prior to slaughter for the EU market. The bottom right graphic illustrates the growth trajectory of the carcass and how the carcass is partitioned between flesh and bone by the HDOM composition model. The dressing percentage on display in Figure 6.10 is above 60 % which is unexpected for Australian production environments but this value is consistent with those contained in the Trangie dataset used in chapter 4. Although not explicitly used in this study these body components could feasibly be used for matching the productive capacity of animals to target markets. Figure 6.11 illustrates the production operations (e.g.

weaning, drafting, slaughter, etc) that are associated with the calf cohort and market cohorts, in scenario 2 that are a consequence of the drafting decisions prior to drafting occurring. These are also used to calculate the production cost of each animal.

This simplification of an actual beef production system illustrates the potential benefits that could be obtained in beef cattle production if such a system could be used to assist decision making processes. In scenarios 2, 3 and 4 the drafting system allocated animals to market endpoints to maximise the profitability of the whole production system by compromising the profitability of individual animals. The optimal drafting ages also indicate that the drafting system functioned sensibly. In scenarios 2 and 4 when animals were reallocated to the EU market, instead of the B3 market as done in scenario 1, the EU-B3 drafting age and consequently the slaughter age of the EU market were reduced. This occurred to compensate for animals with higher P_m and B^* values reducing the time required to reach market specifications.

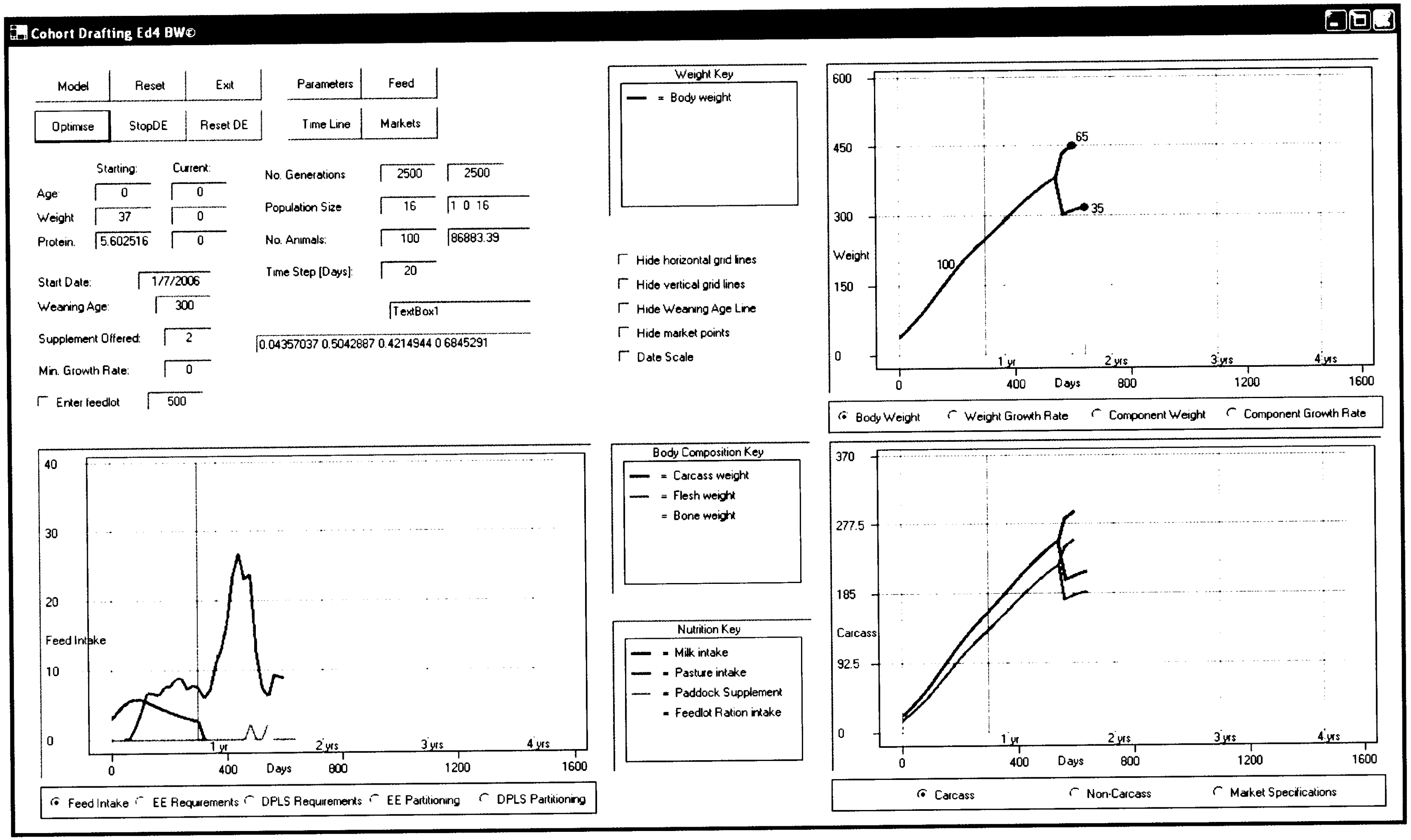

Figure 6.10: Simulation interface displaying the live weight and carcass growth pathways as well as feed intake patterns for the optimal drafting plan found in scenario 2.

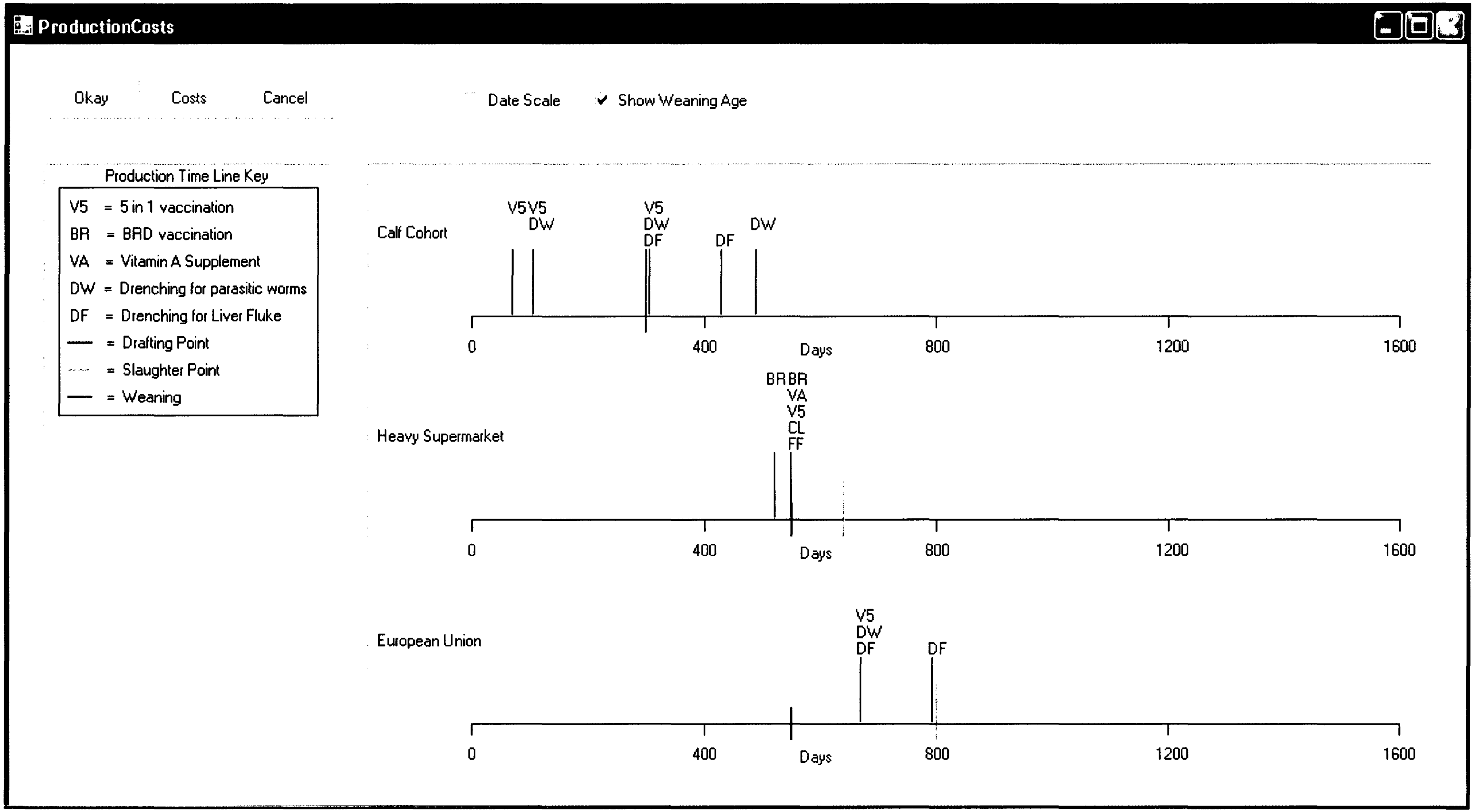

Figure 6.11: Production operations associated with the calf and market cohorts in scenario 2.

Even though the drafting system has been shown to function sensibly in the base scenario and when prevailing production circumstances change it does have limitations and further refinements are possible. Although not a limitation, an important attribute of the system presented here is that the results obtained are the consequence of the production costs (e.g. selling, drenching and pasture) and market prices taken in September 2006 and January 2007, respectively for the Glen Innes area. These costs and prices, whether known or projected, will change both across time and location thus producing different drafting outcomes for different enterprises and locations. The dynamic nature of cost and price schedules requires that an optimisation procedure such as this is firstly, run repeatedly for a single enterprise and secondly, is run independently for each enterprise being optimised as the results obtained are specific to the inputs used for that enterprise at that point in time. When run for a single enterprise the frequency of rerunning the system to obtain optimal animal allocations would be dependent upon the level of change seen in production costs, market prices and environmental conditions. The greater the rate of change the higher the frequency of re-evaluation will need to be to maintain optimal allocations.

The production system simulated in this exercise, that only considered Angus steers, is a small segment of an entire beef production system. It was designed as a representative first step to illustrate how the drafting system could be applied to entire beef production systems. The drafting system also has the capacity to draft mixed breed groups of animals into different market cohorts given models that are capable of predicting and exploiting breed differences i.e. estimating genetic input parameters and modelling differential growth patterns of breeds. Drafting animals in this manner is only one of numerous logistical decisions that are made in beef production systems. The optimisation performed throughout this study could potentially be extended to include not just mixed breeds but also mixed sexes. Drafting could be conducted with the purpose of allocating both steers and cull heifers to market endpoints. The allocation of animals to market cohorts could be extended to include the optimisation of mating dates and purchasing of animals from outside enterprises. Extensions of this nature would facilitate further expansion to include optimisation of whole supply chains to increase consistency of supply.

The extension of this drafting system to include an entire production system would require that the feeding and growth models be extended to include other production characteristics. This study does not take the energetic and thus financial costs of milk production into consideration. The equations presented in the appendix of Coffey et al. (2001) could be used to calculate the effective energy requirements of milk production and thus part of the financial cost of maintaining cows. The effects that genetic and environmental factors have on milk production are also not considered in this simulation. Incorporating these into this simulation would allow variation in milk production to be modelled as well as allowing the impact variable milk production has on calf growth to be explored and possibly exploited.

The limitations applied to feed intake capacity during this study were those proposed by SCA (1990) and used by Freer et al. (1997) including the limitation on the consumption of feedlot rations which is based on feed digestibility and availability. A recent development made to the GrazPlan system relating to the potential intake of non-lactating animals with high relative body condition scores (Freer et al. 2006) was also included. These intake limitations have been used successfully in other applications, however, the possibility exists for the moisture holding capacity of forages to be used as another means of limiting intake. Using information from a number of experiments John and Ulyatt (1987) have demonstrated that pasture dry matter percentage has a positive impact on dry matter intake, i.e. pastures with higher dry matter percentages are consumed in greater quantities by animals. Incorporating this information into the prediction of feed intake may increase the predictive accuracy of the feeding and growth model, thus increasing the confidence placed in the results obtained from the drafting system.

An obvious improvement that could be made to the modelling system used during this study is development of more representative models for predicting P8 fat depth and IMF percent. Equations (6.9) and (6.10) were developed by linear regression analysis performed on normalised data taken from Angus steers bred by the Cooperative Research Centre (CRC) for Cattle and Beef Quality. The adjusted R^2 values produced by these analyses were 0.58 and 0.54 for P8 fat depth and IMF percent, respectively. These values indicate that the independent variables of live weight at slaughter, carcass weight, carcass flesh weight and carcass bone weight only partially explain the development of these traits as animals grow. However, the mix of variables included in these equations is sensible when viewed from the perspective of how each trait develops. An example is the P8 fat depth equation that uses carcass weight and carcass bone weight. Bone weight is used as a qualifier against carcass weight to give an indication of an animal's body condition, e.g. animals with bone weights that are relatively high compared to carcass weight are in poorer body condition and thus have lower P8 fat depth.

The largest limitation of the P8 fat depth and IMF regressions is they only consider the effect nutrition has through variables such as live weight, carcass weight and flesh weight. They ignore any direct effects that nutrition has been shown to have on P8 fat depth (Hopkins et al. 1993) and IMF percent (Harper and Pethick 2001; Pethick et al. 2006). This is also a limitation of the body composition models developed in chapter 4. The importance of the role nutrition has in determining not only the growth and development of animals cannot be over stated and therefore requires that it be included in any models developed for the purpose of predicting body composition. Incorporating the effect of nutrition into composition models would require serial slaughter experiments similar to the experiment conducted by NSW Agriculture at the Agricultural Research Centre, Trangie, New South Wales, reported by Parnell et al. (1997) but with greater depth of information recorded (e.g. P8 fat depth, $11/12^{th}$ rib fat and IMF percent) rather than simply coarse carcass component weights (e.g. muscle, bone, subcutaneous) when experiencing an array of nutritional conditions. Other factors, such as disease and environmental characteristics, have also been shown to affect the deposition of fat in intramuscular depots (Harper and Pethick 2001; Pethick et al. 2001). Again serial slaughter experiments would be required to provide the information needed to make model developments. Even though the effects of sex and breed were removed in this study, they are important variables that need to be considered when making decisions in production systems that involve different breeds and sexes.

The models and extensions described in this study as well as those in chapter 3 are extremely detailed in their portrayal of animal growth and development. This model complexity could be questioned in terms of both the information required to construct such models and the information required to drive them. Using models of reduced complexity would have benefits in terms of their ease of application and a reduction in the quantity of information needed to drive them. However, there are disadvantages associated with using models of lower complexity. The predictive testing of growth models undertaken in chapter 3 illustrated the weaknesses of less complex models for predicting animal growth, particularly when applied in changing nutritional environments. Another weakness associated with less complex models is they do not have the ability to deal with complex interactions present in reality. The interactions between growth model input parameters described in Tables Table 6.10 and Table 6.11 that directly affected animal allocation are a reflection of those present in every day life.

The full knowledge of growth model input parameters for all animals, as conducted in this study, is somewhat unrealistic. In production environments, few animals, if any, will have enough information recorded to estimate or have their mature protein contents or mature lipid to protein ratios directly measured. A more realistic situation would be to estimate population parameters, as performed in chapter 5, or assign constants that experience has shown to be appropriate, which would then produce distributions around model outputs. The drafting procedure would then partition animals to different target markets based on where their measured production traits are located in the distribution of observed production traits. If this system where applied throughout this study animal allocation would have been driven primarily by measured live weight and age. Development of the body composition functions as discussed above however could allow practical measures such as body condition score or ultrasound measured fat depth to be used as driving forces also.

The allocation of growth model parameters from uniform distributions was designed to artificially create variation in growth model outputs that the optimisation procedure could then base its allocation decisions upon. As stated above (section 6.2.2, Simulated Animals) it was recognised prior to this study that parameter distributions would most likely be normally distributed. However, using normal parameter distributions would have resulted in more animals being clustered near the model output means and reduced the illustrative powers of the study. The allocation results obtained also demonstrate that the functionality of the drafting system is not adversely affected in circumstances where input parameters are not normally distributed and adds confidence that sensible results can be obtained.

Full knowledge of growth model input parameters for all animals would also allow animal allocation to appropriate target markets to occur at birth if full knowledge or probability estimates of future environmental conditions were available. However, as discussed above, the reality is full knowledge of input parameters and future environmental conditions are not available. The purpose of this study was to use RK following extensions to allocate animals to appropriate target markets in the given simulated production system. The sensible behaviour of this method for animal allocation during this study points towards its possible use for allocating animals to target markets based the method discussed above which would use the location of measured production traits relative to the remainder of the cohort and the prevailing market requirements.

The optimisation criterion used in this study was purely focused on economic optimisation by simply using the difference between income and production costs (equation (6.11)). The increasing importance of nutrient use in agricultural production that has arisen in the last fifty years in Australia could also be incorporated into the optimisation criterion. The studies of Wang et al. (2000a; 2000b) included the impacts that nitrogen and phosphorus have on the production and external environments in their criterion when allocating home-grown feedstuffs across a dairy herd with linear programming. These studies could be used as the starting point for including nutrient use in the optimisation objective and one step in the direction of optimising multiple enterprises in a single production system.

6.5. Conclusion

Drafting of animals into market groups that satisfy the production potential of the animals and the prevailing production conditions was achieved by Differential Evolution using the Random Keys approach. The extensions made to Random Keys allowed the optimal proportion of animals allocated to each market and the optimal ages for the drafting events to be determined. The drafting system behaved sensibly when the production conditions changed in response to changes in market prices, environmental conditions and production costs.

6.6. Recommendations

This study does possess some shortcomings including the body composition functions used to predict P8 fat depth and IMF percentage, having full knowledge of the input growth model parameters and the limitations on feed intake. The functions used to predict P8 fat depth and IMF percent would require development to include a mechanistic structure similar to that developed in chapter 4 for the body composition models. This structure would also need to take the effects that nutrition has on metabolic pathways into consideration before model predictions could be used with any confidence in optimisation procedures. Using full knowledge of growth model input parameters is unrealistic and could be addressed by partitioning cohort trait distributions between target markets and allocating individual animals based on how they compare to their cohort. The sensible behaviour of Random Keys throughout this study points to the need to explore the possibilities of using it to partition cohort trait distributions in order to allocate animals to target markets. Although less important than developing the body composition models, moisture holding capacity of forages could provide a means of improving the limitations placed on feed intake. If these shortcomings were addressed this would allow this approach to animal allocation to be applied to an entire production system, rather than simply a single breed/sex group.