THE ECONOMIC VIABILITY OF AUTOMATIC MILKING SYSTEMS IN AUSTRALIA’S PASTURE-BASED DAIRY FARM SYSTEMS: A CASE STUDY ANALYSIS

William Taing

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Melbourne School of Land and Environment
The University of Melbourne
Abstract

Fluctuations in prices, costs and seasonal conditions, and increasing competition will continue to place pressure on profit margins for operators of all dairy systems. Good management and decision making skills is fundamental to ensuring that introducing new technologies, such as automatic milking systems (Mcwilliams et al.), are integrated into the whole farm system to make the best use of a given set of resources and circumstances, and realise the wide array of benefits technology has to offer some people in dairy.

Increasing intensity of dairy farms and rising labour costs have helped to induce wider adoption of AMS technology in Europe and other countries. Similarly, the characteristics that have led to the wide adoption of AMS technology are increasingly evident in Australia’s dairy industry. Adapting the AMS technology to Australia’s pasture-based dairy systems has in the recent past been considered a complex challenge and requiring careful implementation as information remains limited on a national and global level. However, in recent years, the knowledge around the adoption of AMS in Australia’s pasture-based dairy systems has increased markedly with the ‘practical operated experience’ of AMS farms being fine-tuned and operating competitively.

The key research question to be investigated in this thesis is if AMS technology adopted in Australia’s pasture based systems with voluntary cow traffic is competitive, in terms of profit, returns to capital, risk and non-pecuniary net benefits, when compared to Australian dairy farmers using conventional milking systems.

This proposition will be tested by assessing the biophysical and economic performance of two dairy farm case studies, a Gippsland farm using ‘single box AMS’ and a Tasmanian farm using the ‘automatic milking rotary’. These two dairy farm case studies were chosen because they are deemed to have successfully integrated AMS into their whole farm system and are realising the benefits that are available from AMS. The case studies represent the use of the AMS technology at a steady state. For each case study, its biophysical and economic performance for an individual year was compared with the
performance of other farmers in the region using conventional milking systems in the same year, where possible, and also over a hypothetical run of years with ranges of prices and seasonal conditions. Risk and uncertainty is also investigated in detail by running scenarios that represent long term typical prices, costs and rainfall.

The major finding of this investigation is that the two AMS farms studied in Gippsland and Tasmania are capable, under the current management, of operating competitively under the seasonal and economic conditions that have occurred in the past and are likely to occur in the future, when compared to farms using conventional milking systems in the same region and under the same conditions.

Ultimately, the success of incorporating AMS into Australia’s pasture-based dairy systems will depend almost completely on the human element. Good managers can make almost any system work well and profitability.
Declaration

This is to certify that

i. The thesis comprises only my original work towards the Masters except where indicated; and

ii. Due acknowledgement has been made in the text to all other material used; and

iii. The thesis is less than 50,000 words in length, exclusive of tables, maps, bibliographies and appendices.

_________________________________
William Taing
September 2016
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This study is only made possible with the support and help from the case study farmers who have generously shared their time and information of their farms.

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1 Introduction

1.1 THE AUSTRALIAN DAIRY INDUSTRY

The dairy industry is one of Australia’s most significant rural industries. In 2014, it was ranked third behind the beef and wheat industries with a farm gate gross value of production of $4.7 billion and employing around 43,000 people directly on dairy farms and dairy companies (Australian Bureau of Statistics, 2016). The South-East States of Australia are responsible for the bulk of milk production, with Victoria and Tasmania predominant.

Owner operator farms make up the great majority of business structures in the Australia dairy industry. The number of farms has fallen by around two-thirds over the last three decades, from 22,000 in 1980 to just around 6,000 in mid-2016 (refer to Figure 1.1). This trend is also observed in agriculture around the world, as reduced price support, increasing competition and changing business practices are encouraging a shift towards larger, more efficient operating systems. The average herd size per dairy farm in Australia has increased from 85 cows in 1980 to 285 cows in 2016. Over this period, the total cow numbers in Australia has remained relatively stable at just under 2 million, however per cow production has increased substantially from about 3,000 litres in 1980 to 5,730 litres in 2015.

Figure 1.1: Number of registered farms and average herd size per farm
In Australia, the dominant breed is the Holstein, accounting for around 65% of all dairy cattle. Other important breeds include the Jersey, the Holstein/Jersey cross, Brown Swiss, Ayrshire and local breeds, the Australian Red and the Illawarra. The majority of milk is produced from grazed pasture with supplements typically contributing from 25% to 40% of production.

Over the past 30 years, the average size of a dairy enterprise has increased considerably with owner-operators running larger herds with greatly expanded output per labour unit and per hectare (Harris, 2011). Larger herds have had major implications for labour utilisation and have required improvement in labour efficiency through infrastructure and machinery investment to manage larger herds at milking time and handling larger volumes of feed.

Over time, this increase in the intensity of dairy farms and rising labour costs have helped to induce wider adoption of AMS technology in Europe and other countries. Similarly, the characteristics that have led to the wide adoption of AMS technology are increasingly being experienced in Australia’s dairy industry.

1.2 DAIRY SHED TECHNOLOGY IN AUSTRALIA

Milking is a significant and time-consuming activity on farms. When the number of milking units is no longer a barrier to improving throughput, further improvement can only be achieved by automation and replacing elements of the operators work routine, thereby making the job less physically demanding and more efficient. Installing larger dairies or more milking units is unlikely to result in efficiency gains (Jago et al., 2007). Further gains in productivity are likely to be achieved by the milking routine or substituting labour for capital (that is, automation). Upgrading to larger, more efficient milking systems is a major capital expenditure for a dairy enterprise and is a complex decision requiring planning.

The intensification and consolidation of dairy farms has been accompanied by a trend to farmers investing to improve milking systems and equipment. Larger sheds allow for an
increase in milk production per week of farm labour. The type of shed is one important contributor to overall farm performance.

The types of dairy shed technology employed in Australia over the last 20 years have been walk-through, swing-over herringbone, double herringbone and rotary. The most common dairy shed used is the swing-over herringbone shed representing about half of all sheds in Australia. The double herringbone accounts for a further 27 per cent (see Figure 1.2). Since the early 1990s, farmers slowly shifted towards swing-over units and away from the double units. Farmers with large dairy herds (averaging 389 cows at peak milking time) favoured rotary dairy sheds. This was almost double the average number of cows for farms using a swing-over herringbone shed and over two and a half times more than for farms with a walk-through shed. Rotary dairies account for around 15 per cent of farms. The use of walk-through sheds are continuing in their long-term decline and now represents less than 10 per cent of Australian dairy farms. Improvements in milking shed layouts have contributed to productivity growth by reducing the amount of time required for milking and, in turn, the quantity of labour required (Ashton et al., 2014).

![Figure 1.2: Dairy shed types (proportion of farms)](image)

Source: ABARES Australian Dairy Industry Survey.

A study by Kompas and Che (2001) found that the key determinants of differences in dairy farm efficiency are the type of dairy shed used and the proportion of irrigated farm
area. Their results indicate that swing-over herringbone, herringbone and rotary sheds are all efficiency enhancing, with rotary sheds having more than double the capacity of swing-over units (Smale et al., 1994). In the Kompas and Che study the dairy farmers that were considered highly efficient used either rotary or swing-over dairy shed technology and had almost three times the proportional amount of land under irrigation.

In Australian dairy sheds, automation over the past decades has been a key feature allowing many labour dependent operations to be replaced with technology. Australia and New Zealand were the early adopters of machine milking technology with approximately 55 per cent of herds being machine milked by the 1940s (Janson, 1973). The key automated operations to date include vat cleaning, cup removers, backing gates, teat spraying, drafting gates, milk flow meters and individual cow bail feed. A survey undertaken by ABARES (Dharma et al., 2012) found that automation was highest in farms with rotary sheds. Herringbone sheds as well as swing-over units have also experienced significant automation (refer to Figure 1.3). Despite these changes, milking operations continue to rely on substantial labour input.

![Automation by shed type, 2010-11 (proportion of farms)](image)

Source: ABARES 2012, p.12

**Figure 1.3: Automation by shed type, 2010-11 (proportion of farms)**

Automation of dairy sheds in Australia has demonstrated that the physical and financial performance of different shed types can vary substantially. The ABARES 2010-11
survey revealed that farms with rotary sheds, on average, reported significantly higher farm cash incomes, farm business profits and rates of returns than compared to other shed types. On average, these farms were larger production units operating large areas (421 hectares) and with large herds (614 head of cattle). Notable differences are the significantly higher milk production as well as milk production per labour weeks worked (labour efficiency). Farms using the two types of herringbone sheds reported similar farm performance with respect to farm cash income, profits and rates of return on capital. Walk-through sheds on average were on farms with considerably lower farm cash income, farm business profits and rates of return on capital. Refer to Table 2.4.

Table 2.1 – Physical and financial performance, by shed type, 2010-11 (average per farm)

<table>
<thead>
<tr>
<th>Area operated</th>
<th>Double herringbone</th>
<th>Swingover herringbone</th>
<th>Rotary</th>
<th>Walkthrough</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy herd at 30 June</td>
<td>229 (10)</td>
<td>203 (7)</td>
<td>421 (6)</td>
<td>149 (14)</td>
</tr>
<tr>
<td>Stocking rate</td>
<td>1.4 (9)</td>
<td>1.5 (7)</td>
<td>1.5 (6)</td>
<td>1.3 (26)</td>
</tr>
<tr>
<td>Milk production</td>
<td>1,036 (7)</td>
<td>1,080 (4)</td>
<td>2,281 (7)</td>
<td>487 (4)</td>
</tr>
<tr>
<td>Milk yield per cow</td>
<td>L/cow 5,784 (5)</td>
<td>5,654 (3)</td>
<td>5,748 (3)</td>
<td>3,907 (23)</td>
</tr>
<tr>
<td>Milk production per labour weeks worked</td>
<td>L/wks 8,079 (6)</td>
<td>8,263 (4)</td>
<td>12,563 (5)</td>
<td>4,314 (13)</td>
</tr>
<tr>
<td>Grain inputs per cow</td>
<td>1.7 (7)</td>
<td>1.7 (6)</td>
<td>1.9 (6)</td>
<td>0.7 (63)</td>
</tr>
<tr>
<td>– concentrates</td>
<td>0.9 (4)</td>
<td>1 (13)</td>
<td>1.1 (18)</td>
<td>0.6 (58)</td>
</tr>
<tr>
<td>– grain</td>
<td>0.7 (17)</td>
<td>0.5 (77)</td>
<td>0.9 (16)</td>
<td>0.1 (244)</td>
</tr>
<tr>
<td>– by-products</td>
<td>0.1 (40)</td>
<td>0.1 (40)</td>
<td>0 (69)</td>
<td>0 ~ (99)</td>
</tr>
<tr>
<td>Feed costs per cow</td>
<td>$ 651 (8)</td>
<td>556 (6)</td>
<td>567 (7)</td>
<td>215 (52)</td>
</tr>
<tr>
<td>Farm cash income</td>
<td>$ 119,487 (13)</td>
<td>141,803 (13)</td>
<td>215,407 (17)</td>
<td>61,457 (74)</td>
</tr>
<tr>
<td>Farm business profit</td>
<td>$ 60,705 (26)</td>
<td>62,802 (27)</td>
<td>140,483 (23)</td>
<td>11,557 (313)</td>
</tr>
<tr>
<td>Rate of return excl. capital appreciation</td>
<td>% 3.7 (16)</td>
<td>3.7 (13)</td>
<td>4.9 (9)</td>
<td>0.4 (274)</td>
</tr>
</tbody>
</table>

Source: ABARES 2012, p.11

The survey by ABARES in 2010-11 (Dharma et al., 2012) found that virtually no farmers were intending to adopt automatic milking. This is not surprising given the commercial adoption of pasture-based AMS was still in its early phase and replacing or modifying the dairy shed is a significant outlay that is accompanied by substantial development or replacement of dairy shed equipment including milk vats and milking machines (Martin et al., 2000).

Many different types of dairy shed technologies (with different unit labour requirements) within the one industry will continue to compete because of the differences in costs associated with each technology type. Outdated capital equipment
which has less capital costs but more operating costs will be considered against new
equipment that has higher capital costs but lower operating costs. Currently, where
labour is available and herd sizes are large, conventional milking using rotary or swing-
over rapid release parlours equipped with features to increase throughput per labour
hour conventional milking systems will remain attractive.

1.3 BACKGROUND TO AUTOMATIC MILKING SYSTEMS
Automatic milking systems (Mcwilliams et al., 1998) – was first developed in the 1980s
in the Netherlands. An automatic milking system consist of several key modules
including the milking stall, teat cleaning system, teat detection system, robotic arm
device for attaching the teat cups, control system including sensors, electronic ID
readers, concentrate dispenser, system software and the milking machine.

Commercialisation of the first AMS occurred in 1992 with the major breakthrough in
AMS technology occurring in the late 1990s. As of 2015, it is estimated that there are
14,000-plus farms worldwide using AMS. It is estimated that more than 10,000 farms in
over 25 countries worldwide use AMS technology today (refer to DeKoning 2011). See
Figure 1.4. Although, more than 90 per cent of AMS are adopted on dairy farms in
North-western Europe with the largest numbers adopted are found in the Netherlands
with almost 2,000 farms (De Koning, 2010). In the early development phases, AMS
technologies were designed to accommodate small family farms with up to 150 cows.
Today AMS is being adopted by larger farms with an average herd size of more than
500 cows reflecting significant improvements in the technology and increased
management skills (Sauer and Zilberman, 2012). It is important to note that the majority
of these are for indoor systems rather than grazing systems as is the case in Australia.
Generally, there are two types of AMS designs including the single stall system and multi-stall system. The single stall system involves one milking robot that serves only one milking stall and has a throughput of between 8-10 cows per hour). Each single box AMS is able to perform approximately 150 milkings per day. Therefore, if cows are being milked twice per day, a single box unit would be sufficient for 60-75 cows. The multi-stall system consists of a transportable robot device that travels along a rail between multiple stalls where each stall can service fewer than 60 cows (Hyde et al., 2007). This means that more cows can be milked per day because the robotic arm is able to spend a higher proportion of the time cupping cows (and less time idle). These systems with 2 to 4 stalls commonly milk 80 to 150 cows up to three times per day. Past studies reveal that the multi-stall AMS has greater potential net return than the use of two or more single-stall units (Hyde and Engel, 2002, Hyde et al., 2007, Rotz et al., 2003). Finally, the herringbone rotary (a prototype designed by DeLaval) has been trialled and studies undertaken to assess its performance (see Kolbach, 2012).

As just discussed, one of the main reasons inducing the development of AMS was the rising labour costs experienced in the mid-1970s. In Europe, milk harvesting represents about 25-35 per cent of the annual labour demand on a dairy farm and therefore contributes substantially to the costs of the farm enterprise (Ruttan, 1996). In addition to
high costs of labour, increasing average herd sizes, and prevalence of the family farm structure and improving work conditions also were important drivers of adoption of AMS (Meijering et al., 2002). In the majority of studies, it was established that AMS technology reduced production risk in the long run due to less reliance on labour (reduction in labour-related risk). Further, Mathijs (2004) and Hyde et al. (2007) also stress that non-economic (or non-pecuniary) factors are very important to the adoption decision. Such factors or benefits include reduced labour management, reduced work time, improved operator and worker safety, lifestyle and convenience (Marra and Piggott, 2006).

It is also important to note that AMS adoption has also been more successfully and widely adopted in North Western Europe due to the high density of dairy production. This is a result of the lower costs involved in managing the requirements for technical support and allowing continuous operation (De Koning, 2010). For the case in Australia, one of the important determinants of successful adoption of AMS will be access to technical support provided for installations of automated systems and ongoing maintenance. This is because installations are likely to be spread thinly over large geographic areas making on-site service difficult and expensive to provide. Although, this has always been an issue that will need to be overcome as in previous technological advancements in milk harvesting systems.

In the literature, the key attributes that were identified as being most important to the decision to adopt AMS technology compared to conventional milking systems (CMS) are:

1. Cost of labour and labour cost savings;
2. Capital cost of the AMS;
3. Herd size requirements to allow for profitable adoption;
4. Expected increases in output resulting from higher milking frequencies (production per cow);
5. Throughput per AMS unit.
6. Improved animal health conditions leading to reduced veterinary expenses, higher milk quality and, therefore, increased output; and
vii. Milk prices
viii. Non-pecuniary factors.

1.4 AMS TECHNOLOGY IN AUSTRALIA

The adoption of AMS technology in Australia remains in a preliminary stage given these technologies have been developed and over time optimised for the size and nature of dairy farms in those countries. The implications for AMS in Australian dairy farm systems show there are significant differences to the challenges faced on European and North American farms, this is because of the larger farm sizes and dominance of grazed pasture-based dairy systems in Australia.

Adapting the AMS technology to pasture-based dairy systems will be a complex challenge and will require careful implementation as AMS within pasture-based dairy systems remains limited on a national and global level. As such, there remains some uncertainty over best practice and the ability to successfully integrate AMS into pasture-based systems.

Over the past few years of early adoption of AMS technology in Australia, a number of workshops have been conducted to better understand the likely barriers to adoption of AMS technology. These include:

- Higher cost of adoption compared to smaller-scale automation options;
- Need for significant changes to existing pasture-based dairy systems;
- Limited access to reliable, ongoing machinery maintenance and repair service providers in many regions;
- Need to learn new skills to operate the technology and concerns around the risk of technology issues.

The importance of grazing management practices, always high, is even more so with AMS systems as feed supply is the key motivation for effective cow traffic around the farm, through the milking units, throughout the day. Other factors in the farming system are also affected, such as mating practices and herd testing regimes. The nature and organisation of farm labour changes such that manual labour dealing with milking is
largely replaced by management and control activities. This has led to significant research into research on the production of specific AMS knowledge to the Australian context (Donohue et al., 2010, García et al., 2007, Jago and Kerrisk, 2011).

**Pasture-based AMS**

In 2001, AMS was introduced in a commercial grazing farm in Gippsland (Greenall et al., 2004), Australia and in Waikato, New Zealand as a research project (Jago et al., 2002). In these systems, the cows are not housed in barns and obtain over 50 per cent of their annual feed requirements from grazed pastures or forages. The major change to the pasture-based farm system through introducing AMS is the potential to integrate voluntary and distributed cow traffic. In 2006, an AMS research project demonstrated that pasture-based AMS could maintain high levels of pasture utilisation (Davis, 2006). The adoption of AMS in pasture-based systems across Australia has been growing as knowledge and understanding of these systems are becoming more widely known. By the end of 2015, AMS technology has been adopted by 37 farms across Australia and includes single and double box systems, and robotic rotaries. Following years of testing and refinement, the robotic rotary, known as the automatic milking rotary (AMR), was first commercially installed at the Gala farm in Tasmania in 2011. Specific details of this technology is provided in case study two of this research paper.

It is essential to consider the whole farming system before investing in AMS. If a farmer happens to be a poor manager of pasture, installing sophisticated milk harvesting equipment is not likely to create the increased profit that is required for the farmer to remain sustainable through challenging periods (e.g. periods of low milk prices, periods of increased cost of bought-in feed). Thus, poor pasture managers may be unsuccessful as adopters of AMS because the system simply cannot tolerate low levels of accuracy in pasture allocation, due to the negative impact on cow traffic.

The application of AMS in pasture-based systems creates many new challenges, as these systems aim to cope with moderate to large herds of over 200 cows, whilst facing the same distances between paddocks and the milking facility, whilst maintaining milk production targets. Successfully incorporating AMS into pasture-based dairy systems
will be important given 98 per cent of dairy farmers in Australia source at least a portion of feed from grazed pasture in 2009-10 (Dairy Australia, 2010, Little, 2010).

John et al. (2016) provides a comprehensive review of the current knowledge on both indoor and pasture-based AMS with a focus on feed, animal and management factors that impact on the AMS utilisation levels.

1.5 KEY QUESTIONS
The key research question to be investigated in this thesis is whether AMS technology adopted in pasture based systems in Australia, with voluntary cow traffic, is economically competitive with alternative systems, such as when compared to Australian dairy farmers using conventional milking systems. This question will be examined by assessing the biophysical and economic performance of two case studies. These two farm case studies were chosen because they have successfully integrated AMS into their whole farm system and realised to a considerable extent the potential benefits that are available from AMS. Therefore, these case studies represent the use of AMS technology at a well-developed steady state.

1.6 OUTLINE OF THESIS
This thesis contains an investigation of the current biophysical and economic performance of two case study farms using automatic milking systems and a comparison of these two case studies to farms in its respective regions using conventional milking systems. Case study 1 was a dairy farm in Gippsland with:

- 3 single box milking robots
- A herd size of 170 cows
- 102 hectares

Case study 2 was a dairy farm in Tasmania with:

- 24-unit automatic milking rotary (herringbone rotary platform)
- A herd size of 600 cows
- 270 hectares
The economic performance of the case study farms under a range of historical prices, costs and seasonal conditions was analysed in detail to understand the base farm system performance under risk. A number of debt scenarios were also considered to understand the impact of servicing capital equipment on the base farm system.

In the next chapter, the discipline of farm management analysis is defined and the literature on farm assessment techniques, technology adoption, AMS technology and the economic approaches used to analyse the adoption of AMS in a farm business are reviewed.
2 Literature Review

The prospect of commercially available AMS technology in Australia raises a range of complex questions for the Australian dairy industry. Automatic milking system technology is considered a labour-saving technology providing efficiency and lifestyle benefits and may provide a solution to one part of some farmers’ problems. Automatic milking system technology raises further implications for operating and managing the dairy farm system as a whole. Key challenges for the Australian dairy industry will be the ability to incorporate AMS technology into pasture-based dairy systems that are prevalent in Australia.

2.1 INTRODUCTION

In Chapter one, the reason for, and aim of this research was introduced. In this chapter, literature around innovation adoption in agriculture is presented and discussed. An introduction to AMS technology is provided including a review of the literature about the economic approaches used for assessing investment in AMS technology by farm businesses. These studies have predominantly focussed on intensive, non-grazing dairy farm systems in North Western Europe. In the final section is a discussion of existing milk harvesting technologies used in Australia and the introduction of AMS technology in pasture-based farm systems.

2.2 LITERATURE ABOUT AMS

2.2.1 Management aspects of AMS

The decision to switch from a milking shed to AMS will mean significant changes for many aspects of the farm system, for the manager, and the cows. Automatic milking system technology is not only a new milking system, but rather a new management system which facilitates 24-hour per day milking where cows move voluntarily to be milked via incentives, such as feed. One of the biggest changes with introduction of an AMS is the nature and organisation of farm labour. Here, the manual labour for milk harvesting is largely replaced with management tasks such as checking attendance lists and milking intervals from the computer. The visual checks required to ensure udder
health is at least partially taken over by automatic systems. This is also the case with teat cleaning and the separation of abnormal milk which are all incorporated into the automatic system. This alters cow management including routing within the dairy, feed management, grazing opportunities and also the use of mixed rations.

The introduction of AMS will change the skills required of management and labour. Farmers considering adopting an AMS will need to take account of the planned and unplanned adjustment costs such as his/her management, finding and training skilled staff, and adjustment costs relating to infrastructure. Inherently, these costs have the potential to be exacerbated by factors beyond the farmers’ control such as low milk prices, high exchange rates, and unfavourable climatic conditions. Such a significant change to infrastructure and labour organisation will affect the profitability, financial viability and management and risks of the farm business.

Automation of milking alters the management style of the farm manager changing from mostly physical work to much less physical work and more labour and office management. Strategies for managing labour, recruiting quality labour, training, negotiating and communication skills to manage labour successfully become even more vital to the success of the investment decision. Changes in office management include researching new ideas, cash flow control, keeping track of set goals, time management and prioritising, logistics of using contractors, and so on.

**Milking frequency and yield**

Gygax *et al.* (2007) explains that a number of key factors are important to achieve optimal AMS efficiency. These include milking frequency, inter-milking interval, milk yield, teat cup attachment success rate, and length of the milking procedure.

One of the key benefits of adopting AMS is the potential for increases in production that is maintained through a greater milking frequency and cows visiting the dairy a variable number of times each day. On average, the number of milkings per cow per day in European systems varies from 2.5 to over 3.0 milkings per day. In Australia, twice a day milking is widely accepted as the norm with an interval between milkings of 8-14 hours.
The milking frequency of a dairy herd is often influenced by cultural, production and economic factors.

With improvements through advances in genetic selection, cows are increasingly being bred to produce more milk and therefore needing to be milked more often. A study by Erdman and Varner (1995) measured the yield responses to increased milking frequency. The study concluded that increasing milk frequency from 2 to 3 times daily resulted in a fixed increase of 3.5 kg/day of milk yield (rather than percentage changes to increased milking frequency), irrespective of the yield variation around the average which may be attributable to genetics (Barnes et al., 1990) and nutrition (Yeo et al., 2003). This is due to the galactopoietic effects of increased milking frequency. A number of studies have reported that milking cows three times compared to two times daily have resulted in higher feed intake and production increases of 19 per cent (Allen et al., 1986), 19 to 25 per cent (Amos et al., 1985) and 17 per cent (Depeters et al., 1985).

In addition, greater opportunities to feed more frequently help to reduce the risk of acidosis and as a result increase the marginal response (milk/kg) to concentrates. Data collected from dairy farms using AMS across Europe indicate a production increase of 5-10 per cent (De Koning and Rodenburg, 2004, Bach et al., 2009, Bilj et al., 2007), although large variations are also recorded. Other studies also indicate that AMS allows for milking frequencies of more than twice per day and three milkings a day are expected to enhance lactation milk yield by 10-15 per cent on average (Billon and Tournaire, 2002, Speroni et al., 2006, Svennersten-Sjuanja et al., 2000, Wagner-Storch and Palmer, 2003). Others also argue that increased milk production is achieved because AMS treats the animals in the same way at each milking and the cows become accustomed to the routine (Rasmussen et al., 1990, Samuelsson et al., 1993).

Increasing milking frequency also has impacts on other parts of the farm system. This increases variable costs, particularly labour for CMS, but also affects shed and feed costs required if extra energy is supplied to the cows diet. On average, studies have found a 10 per cent reduction in total labour units required when using AMS compared.
to conventional milking systems with twice a day milking (De Koning et al., 2003, Sonck, 1995). These studies however have been undertaken on non-grazing systems.

Culotta and Schmidt (1988) undertook an economic evaluation of milking dairy cows three times daily and concluded that with a set milk and feed price, milking three times a day is only profitable if the associated increase in the cost of labour was very low, substantial increases in yield from milking three times a day, or if high milk yield per cow already existed with twice a day milking. In their analysis, the cost of labour was the single most important constraint when deciding to increase milking frequency. Dairy automation and mechanisation has made milking more frequently than twice a day to be an attractive option for some farmers. Automatic milking system technology may provide an opportunity to increase milking frequency without the significant additional costs of labour. Also, milk production is generally improved because of the increase in the frequency of milking (Garcia and Fulkerson, 2005).

Factoring in expected increases in milk production resulting from increased milking frequency needs to be considered carefully as a number of factors are involved, such as initial production level, energy intake, genetic potential and the physiological status of the herd.

**Capacity**

The major limiting factor of single-stall and multi-stall AMS systems reported in numerous studies is the capacity of the robot. It was reported in early 2000s that single-stall AMS technology could milk about 45 to 60 cows per day (De Koning and Rodenburg, 2004). More recently, studies have shown that throughput has increased from 60 to 80 cows per unit per day with an occupation rate (time AMS is available for milking per 24 hour day) of 85 per cent (André et al., 2010). On the other hand, a study by (Jago and Burke, 2010) was undertaken for a pasture-based system in New Zealand which reported lower milking frequency (1.5 milkings per day) for low producing cows and 92 cows could be milked per day.
The time taken for milking per day also includes a component of fixed ‘handling’ time (such as pre-milking teat preparation, attachment and post-milking tasks) which affects the AMS capacity. Also, there are period of ‘unproductive occupation time’ per day where the milkings are not successful (e.g. failure to attach cups). Gygax et al. (2007) found that the average percentage of successful milkings was 95 to 98 per cent, which equates to 25 to 100 minutes of ‘unproductive occupation time’ per day and reducing the AMS capacity by at least 2 to 7 per cent. The success of teat cup attachment has significant implications on AMS capacity. Over time, improvements in the technical performance of AMS operations has shown success rates of 84 per cent in early studies (Frost et al., 1993) and more recently 92.4 per cent (Bach and Busto, 2005), 94.5 per cent and 97.5 per cent (Gygax et al., 2007).

Because every milking has a fixed ‘handling’ time as well as ‘unproductive occupation times’, it is desirable to achieve greater number of higher yielded milkings. For example, increasing each cow milking sessions by 30 seconds will reduce the milking capacity between 5 to 8 per cent per day (De Koning et al., 2000).

**Data handling**

AMS technologies are equipped with sophisticated sensor technology and integrated data management systems to monitor and control the milking process. This allows for rich data to be collected and stored in the database. As a result, farmers will need to understand the data and use the necessary computer programs to control the settings and conditions for how cows are to be milked (Hogeveen and Ouweltjes, 2003, De Koning et al., 2000). New AMS technology will be equipped with sensors that control the milking process and also analyse milk quality such as composition, cell counts, blood detection, conductivity and others. Farmers will ultimately need to be familiar with the use of smart data handling software to maximise the benefits of AMS on their farm.

**Expectations**

Meijering et al. (2002) highlighted that successful implementation of AMS will depend on a number of key factors including the farmer having realistic expectations of the technology, consultancy support before, during and after implementation, an effective
system control and computer skills, suitable farm layout, effective and functioning cow traffic, technical functioning, and regular maintenance.

The attitude and expectation of the dairy farmer is a key factor to successful implementation (Mathijs, 2004, Ouweltjes and De Koning, 2004). It has been found that approximately 5-10 per cent of adopters have switched back to conventional forms of milking (De Koning and Rodenburg, 2004). The high amount of labour and management required during the start-up period have often been underestimated. De Koning (De Koning, 2010) identifies a number of key factors of successful implementation:

- Adapting to the different management style and incorporating the flexibility and discipline to control the system and the cows
- Realistic expectations
- Support by experienced consultants before, during and after implementation
- Technical ability to use computers and ensure functioning and maintenance of the AMS
- Attention to AMS design and good cow traffic
- Healthy cows with good mobility and aggressive eating behaviour.

**Milk quality**

Milk quality directly impacts on milk pricing, and therefore farm profits. Consumers expect a high and consistent level of quality and safety from the milk products that they purchase. In Australia, domestic and export demands are commanding ever increasing standards. While AMS uses the same milking principles as conventional milking methods, there are marked differences in these systems and have the potential to impact on milk quality. The quality of milk and the efficiency of the milking process depend on a range of farm factors and its interactions with one another. These include the cows, farmer, equipment, environment, management aspects such as feeding and housing, and other external factors such as weather and milk prices.

The key measurements that are used for assessing the effects of AMS on milk quality including both compositional and hygienic aspects are somatic cell count (SCC), total
bacteria count (TBC) and fat and protein content. A high SCC measurement could indicate a reduction in udder health resulting from Mastitis (udder infection) and leads to lower milk quality. See Klungel et al. (2000), Kruip et al. (2002), Berglund et al. (2002), Zeconci et al. (2003), Bennedsgaard et al. (2006) or Svennersten-Sjaujna and Pettersson (2008). In relation to TBC, the most important factors affecting the level of TBC is the cleaning of the milking equipment and cooling of the milk seem. See Klungel et al. (2000), Rasmussen et al. (2002) or Van der Vorst (2002). For studies relating to the fat and protein contents see Svennersten-Sjaunja et al. (2000), Justesen et al. (2000) or DeKoning (2003).

Animal Health

Hillerton et al. (2004) undertook a significant project in the EU monitoring the impact of transitioning from conventional milking to AMS on animal health. The study analysed body condition, locomotion, somatic cell count and fertility. Overall the conclusion was that there are no major problems when converting from a CMS to AMS, although from a sample of 44 no farms were found to have achieved any substantial improvement in any aspect of cow health.

In other studies of AMS and its impact on animal health, factors such as chronic stress (measured as heart rate variability) was observed when cows were kept in an AMS compared to a loose housing system. The literature shows that the stress levels observed varied. Hagen et al. (Hagen et al., 2005) did not observe any differences in stress levels and Gygax et al. (2006) could not confirm variations in milk cortisol between cows milked in AMS versus conventional systems. A study by Hopster et al. (2002) found that cows being milked in an AMS had a 13 per cent lower heart rate, half the adrenaline levels and a 38 per cent increase in cortisol levels compared to cows milked in CMS. Finally, a large study undertaken in the Netherlands (Neijenhuis et al., 2009) showed that risk factors for mastitis relating to AMS are similar to those observed in conventional milking systems. This was also consistent with a recent study conducted in north west Spain (Castro et al., 2015).
In relation to cow lameness, it was observed in a recent study in Canada that the prevalence of lameness in the studies population of AMS herds was lower than that observed previously in freestall herds without AMS. Though, it is important to note that the main risk factors for lameness in AMS farms involved stall design, similar to freestall farms with conventional milking systems, rather than being related to the management of the AMS. In the case studies considered in this thesis, there is no incidence of lameness due to the voluntary nature of the system. There is no herd pressure that is associated with batch milking.

### 2.2.2 Dairy shed layout

The fundamental alteration to the farm system compared to conventional milking sheds is the reliance on the cow’s motivation to enter the AMS voluntarily. The main motive for this is the supply of feed concentrate during the milking process. The key challenge is to ensure that cows visit the dairy often each day, and on a regular basis throughout lactation. As a result, the layout of the dairy shed is vital to the success of AMS implementation (Lind *et al.*, 2000).

In addition, the success of encouraging voluntary milking is affected by the layout of the dairy shed with respect to the distance of the pasture paddocks from the dairy (Spörndly and Wredle, 2004). This is a fundamental issue as the motivation of a cow to be milked is weak compared to her motivation to graze (Prescott *et al.*, 1998b). An effectively design grazing-supplement system is therefore vital to optimise the efficiency of AMS units (Garcia and Fulkerson, 2005).

**Cow traffic**

Cow traffic can be referred to “the series of gates (or lack thereof) that force cows to follow a set pattern through the barn” (Jacobs and Siegford, 2012). Within AMS, cows are able to potentially stipulate their own milking schedule assuming that the behaviour of the herd does not influence the cows individual decision. As just discussed, the layout of the dairy shed will directly influence the frequency of cow visits, number of feedings, and also the number of cows that will need to be fetched to an AMS (Ipema, 1997, Ketelaar-De Lauwere *et al.*, 1998).
The core concern has been around how different types of cow traffic systems affect both high AMS visit frequency and also provides adequate access to lying stalls and feed (Ketelaar-De Lauwere et al., 1998, Hermans et al., 2003, Bach et al., 2009). The three common types of cow traffic systems are forced (or one-way), controlled (or guided) and free cow traffic systems. In a one-way cow traffic system, a circuit is formed to force cows to move in one direction to feed, lie down, and be milked. A controlled traffic system uses cow identification and selection gates to assess whether cows are due for milking and allows cows to access the feed area only when the interval since the last milking exceeds the pre-set minimum. If the desired milking interval has expired, the cows are guided to the AMS for milking prior to accessing the feeding area. Finally, the free cow traffic system provides cows with unrestricted access to the feeding area, lying stalls and the AMS. Supply of concentrate feed in the AMS is the only incentive for cows to be milked.

Harms (2005) studied how different cow traffic systems influence milking frequencies and the number of cows requiring to be fetched. A key finding was that free cow traffic resulted in lower milking frequencies and a higher number of cows fetched due to long milking intervals. Many researchers have found that the performance of cow traffic significantly affect the feasibility and operational efficiency of the AMS and a key factor to success (Prescott et al., 1998a, Koning et al., 2002, Jago et al., 2002, Davis et al., 2007, Halachmi et al., 2009, Utsumi, 2011).

In pasture-based systems, a study undertaken by Scott et al. (2014) demonstrated that offering supplementary feed to cows post milking increased cow traffic through the pre-milking yard, and is a useful management strategy to help encourage cow traffic at the dairy. It was also found that placement of the supplementary feed influenced where the cows selected to stay.

**Grazing**

Grazing is a common practice during the summer time for many European countries, and compulsory in some. As dairy farmers in these regions increasingly adopt AMS
technology, there is an increasing interest for successfully incorporating AMS technology into pasture-based systems such as in Australia and New Zealand. One of the key challenges in a pasture-based AMS is the reliance on the cows to voluntarily and individually enter the milking unit several times a day (Spörndly and Wredle, 2005). It will be important to understand the motivations and mechanisms to be put in place to effectively ensure cows that have access to pasture also return to the AMS to maintain the desired level of milking.

Pasture-based systems will also experience the challenges of greater variability in the frequency of cows visiting the AMS unit. For example, in southern parts of Australia surplus spring pasture is likely to reduce the frequency of cow visits (especially for cows in late lactation). Accurate daily allocation of pasture will be critical to ensure that the desirable frequency of visits is achieved (Greenall et al., 2004).

A recent study by Clark et al. (2016) was the first study of its kind to highlight that high levels of pasture utilisation can be achieved irrespective of the system used to harvest milk. However, discussions with the case study farmers indicate that to achieve the same level of pasture utilisation is challenging requires close attention to farm layout, pasture allocation, cow behaviour and AMS settings (such as gate prioritisation settings etc.).

There is a perceived technical limitation on the number of cows that can be milked on a predominantly pasture-based dairy farm. Sinnett and Malcolm (2006) identify that these maximum limits on the size of the farm reflects the diseconomies of size that result from:

- The cows walking distance per day before time and energy requirements become excessive. In an Australian AMS example it showed that a maximum of 700 metres was acceptable (Greenall et al., 2004) and 900 metres in New Zealand from anecdotal evidence (Woolford et al., 2004);
- The limit on the amount of pasture that cows can consume imposed by grazing habit and time and the rumen capacity at levels that will produce around 5,000 litres per cow per year;
• The capacity of the current infrastructure (e.g. paddock size, shed size, yard size, laneway size, gateway size etc.); and
• The number of cows that can be managed logistically. While a shed can be used for 24 hours, this is not usually possible given the added logistical, lifestyle and staff retention issues.

AMS in pasture-based dairy systems is discussed later in the chapter.

2.2.3 The Australian context
Increasing intensity of dairy farms, rising labour costs and labour retention issues have helped to induce greater adoption of AMS technology in Europe and other countries. Similarly, the characteristics that have led to the wide adoption of AMS technology are increasingly evident in Australia’s dairy industry.

In Australia, milking remains a significant and time-consuming activity on dairy farms. When the number of milking units is no longer a barrier to improving throughput, further improvement can only be achieved by automation and replacing elements of the operators work routine hereby making the job less physically demanding and more efficient. Installing larger sheds or more milking units is unlikely to result in any efficiency gains (Jago et al., 2007). Further gains in productivity are likely to be achieved by optimising the milking routine or substituting labour for capital (that is, automation).

Increase in intensity of Australian dairy farms
Traditionally, dairy farm systems have mainly been based on pasture, but over the past 30 years there has been a significant increase in the intensity of production systems, with a corresponding increase in concentrates fed as a proportion of the total diet of the herd. The number of farms has fallen by approximately two-thirds from 22,300 in 1982 to below 6,770 in mid-2012 and is accompanied by increasing average dairy herd sizes (refer to Figure 2.1). The average stocking rates on Australian dairy farms have had large increases from 1 cow per hectare in 1991-92 to 1.5 in 2010-11. See Figure 2.2. The average herd size per farm has increased from 85 cows in 1980 to an estimated 284
cows currently and there is also a trend emerging to very large farm operations of over 1,000 head of cattle (Dairy Australia, 2011). In Victoria, the average herd size is about 272 cows currently. This is a similar trend being evident in other high milk producing countries (see Table 2.1).

Table 2.2 – Global trend; decreased number of farms with increased number of cows per farm among high milk producing countries in the world (Koopstra, 2011)

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of Farms</th>
<th>2000</th>
<th>2005</th>
<th>2008</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Farms</td>
<td>11,800</td>
<td>9,200</td>
<td>7,900</td>
<td>7,500</td>
</tr>
<tr>
<td></td>
<td>Cows/farm</td>
<td>183</td>
<td>202</td>
<td>212</td>
<td>213</td>
</tr>
<tr>
<td>United States</td>
<td>Farms</td>
<td>105,200</td>
<td>78,300</td>
<td>65,000</td>
<td>62,500</td>
</tr>
<tr>
<td></td>
<td>Cows/farm</td>
<td>88</td>
<td>116</td>
<td>142</td>
<td>146</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Farms</td>
<td>29,500</td>
<td>23,500</td>
<td>20,300</td>
<td>19,800</td>
</tr>
<tr>
<td></td>
<td>Cows/farm</td>
<td>51</td>
<td>61</td>
<td>74</td>
<td>75</td>
</tr>
<tr>
<td>Germany</td>
<td>Farms</td>
<td>129,900</td>
<td>108,000</td>
<td>94,100</td>
<td>90,400</td>
</tr>
<tr>
<td></td>
<td>Cows/farm</td>
<td>35</td>
<td>39</td>
<td>44</td>
<td>46</td>
</tr>
<tr>
<td>Denmark</td>
<td>Farms</td>
<td>9,700</td>
<td>5,900</td>
<td>4,100</td>
<td>3,900</td>
</tr>
<tr>
<td></td>
<td>Cows/farm</td>
<td>66</td>
<td>94</td>
<td>140</td>
<td>147</td>
</tr>
<tr>
<td>Sweden</td>
<td>Farms</td>
<td>12,200</td>
<td>8,600</td>
<td>6,400</td>
<td>6,400</td>
</tr>
<tr>
<td></td>
<td>Cows/farm</td>
<td>35</td>
<td>45</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Argentina</td>
<td>Farms</td>
<td>17,000</td>
<td>13,500</td>
<td>11,000</td>
<td>11,000</td>
</tr>
<tr>
<td></td>
<td>Cows/farm</td>
<td>144</td>
<td>156</td>
<td>191</td>
<td>191</td>
</tr>
<tr>
<td>New Zealand</td>
<td>Farms</td>
<td>13,900</td>
<td>12,200</td>
<td>11,600</td>
<td>11,700</td>
</tr>
<tr>
<td></td>
<td>Cows/farm</td>
<td>251</td>
<td>336</td>
<td>396</td>
<td>415</td>
</tr>
</tbody>
</table>

Figure 2.1: Number of registered farms and average herd size per farm
Increases in stocking rates were made possible through increasing intensive feeding practices. Supplementing pasture production with other feeds has allowed for increased stock to be carried. This also meant dairy farmers increasing feed production on the farm, with greater use of fertiliser and irrigation water use, use of more productive pastures, increased planting of fodder crops and fodder harvesting, conservation and feeding technologies. Another significant motive for intensification has been the successive droughts during the early 2000s which have limited the scope for increases in production from pasture and has therefore caused a shift to more intensive feeding systems.

The quantity of concentrates, grain and by-products fed has increased from around 0.7 tonnes per cow in 1991-92 to 1.7 tonnes per cow in 2010-11 (see Figure 2.3). This has been partially driven by the widespread drought that resulted in a fall in pasture production, particularly during 2006-07 and 2008-09. Today, almost 100 per cent of dairy farmers feed their herd with supplement. Although, 98 per cent of dairy farmers in Australia obtain at least a portion of feed from pasture in 2009-10 (Dairy Australia, 2010, Little, 2010).


Figure 2.2 – Farm areas, cow numbers and stocking rates (average per farm)
In the past 20 years, the production and use of supplementary feed, including silage, concentrates and grains, have increased a proportionally more than the increase in the number of cows milked. Increasing feeding intensity has allowed farmers to increase their milk production per cow, from an average of 3,811 litres per cow in the early 1990s to approximately 5,630 litres per cow in 2010-11 (Dharma et al., 2012). The rates of return to high intensity (feeding more than 1.5 tonnes of grain and concentrates per cow) and low intensity farms (feeding less than 1.5 tonnes) was also studied. The finding was that while high intensity farms recorded higher performance in almost all measures (cows milked, milk produced per hectare and milk yields per cow) compared to low intensity farms, similar average rates of return were achieved between both low and high intensity farms. However, high intensity farms also exhibited higher variability in average returns.

In addition, there has been an increase in the intensity of land use on dairy farms. The number of cows milked per dairy farm has risen faster than the areas used by the milking herd (Rodriguez, 2003). Associated with this increase in intensity of Australian dairy farms is the implied growth in capital and labour inputs (Cameron et al., 2010).
Labour

Earlier, the changing structure of the dairy industry was discussed. The key change has been the reduction in number of dairy farms and the significant increases in average herd size per farm (from 85 cows in 1980 to 284 cows currently). A major response to increasing herd sizes has been the increase in the proportion of farms employing people other than family, moving from about 30 per cent in 2004 to approximately 70 per cent by 2009 (Doyle et al., 2010). Currently, a typical dairy farm would have 2-5 people working in the business with an average labour and management cost of $634 per cow (see Table 2.2 and Table 2.3).

<table>
<thead>
<tr>
<th>Number of people</th>
<th>1</th>
<th>2-5</th>
<th>6-20</th>
<th>21-50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herds</td>
<td>26%</td>
<td>63%</td>
<td>10%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

Source: Dairy Australia, 2008.

<table>
<thead>
<tr>
<th></th>
<th>Average of 71 farms across Victoria (Dairy Industry Farm Monitory Project 2010)</th>
<th>Range from over 200 farms in southeastern Australia (Red Sky)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cows milked per full-time equivalent (50 hours)</td>
<td>94 cows / FTE</td>
<td>&lt;60 to &gt;200 cows / FTE</td>
</tr>
<tr>
<td>Labour and management costs per cow</td>
<td>$634 per cow</td>
<td>&lt;$300 to &gt; $800</td>
</tr>
</tbody>
</table>

Source: Doyle et al. (2010, p. 143).

In Australia, three quarters of all dairy farmers spend over five or more hours per day herding cows for milking, milking and cleaning up after milking. This is regarded as the three major task groups of milking labour. This time represents approximately 50 per cent of the workload on Australian Dairy farms (Doyle et al., 2010). In addition to this, dairy farmers have had difficulties finding suitable skilled and committed people. Over the period from 2005-06 to 2010-11, almost 60 per cent of dairy farms have attempted to fill vacant positions and over half of these farms encountered difficulties and had negative effects on farm performance. Staff turnover has been costly and loss of expertise has placed pressure on remaining people (Doyle et al., 2010). It is considered that labour productivity during milking time is one of the key factors limiting overall farm productivity. Therefore, it is reasonable to consider that automation of some or all of the milking process could be potentially beneficial.
AMS technology in Australia

The deregulation of the dairy industry as well as a range of uncontrollable factors such as prolonged drought and fluctuations in exchange rates will continue to place considerable pressure on farm cash income and farmers are increasingly required to search for new ways to operate more efficiently. The adoption of AMS technology in Australia remains in a preliminary stage given these technologies have been developed and over time optimised for the size and nature of dairy farms in those countries. The implications for AMS in Australian dairy farm systems show there are significant differences to the challenges faced on European and North American farms, this is due to the larger farm sizes and dominance of pasture-based dairy systems in Australia. Adapting the technology to a pasture-based dairy system will be complex and will require careful implementation as AMS within pasture-based dairy systems remains limited on a national and global level. As such, there remains uncertainty over best practice and the ability to successfully integrate AMS into pasture-based systems.

Over the past few years of early adoption of AMS technology in Australia, a number of workshops have been conducted to better understand the likely barriers to adoption of AMS technology. These include:

- Higher cost of adoption compared to smaller-scale automation options;
- Need for significant changes to existing pasture-based dairy systems;
- Limited access to reliable, ongoing machinery maintenance and repair service providers in many regions;
- Need to learn new skills to operate the technology and concerns around the risk of technology issues.

The importance of grazing management practices in systems using AMS is heightened, as feed supply is the key motivation for effective cow traffic around the farm, through the milking units, throughout the day. Other factors in the farming system are also affected, such as mating practices and herd testing regimes. This has led to significant research into the production of specific AMS knowledge to the Australian context (Donohue et al., 2010, García et al., 2007, Jago and Kerrisk, 2011).
Pasture-based AMS

Since the introduction of AMS in Europe in the early 1990s, there has been a significant research focus on the uptake of AMS and its successful integration in indoor feeding barn, incentive based, dairy systems where the cows are housed for all or most of the year. Few studies have been carried out into the suitability of AMS on pasture-based dairy systems; those done in Europe have limited applicability in Australia because it is not common practice to graze cows throughout the year.

In 2001, AMS was introduced for the first time in commercial grazing farms in Gippsland (Greenall et al., 2004), Australia and in Waikato, New Zealand as a research project (Jago et al., 2002, Jago and Woolford 2002). In these systems, the cows are not housed in barns and obtain over 50 per cent of their annual feed requirements from grazed pastures or forages. The major change to the pasture-based farm system through introducing AMS is the potential to integrate voluntary and distributed cow traffic. In 2006, an AMS research project demonstrated that pasture-based AMS could maintain high levels of pasture utilisation. The adoption of AMS in pasture-based systems across Australia has been growing as knowledge and understanding of these systems are becoming more widely known. Following years of testing and refinement, the robotic rotary, known as the automatic milking rotary (AMR), was first commercially installed at the Gala farm in Tasmania in 2011. Specific details of this technology is provided in case study two of this study.

The application of AMS in pasture-based systems creates many new challenges, as these systems aim to cope with moderate to large herds of over 200 cows, whilst facing the same distances between paddocks and the milking facility, whilst maintaining milk production targets. Successfully incorporating AMS into pasture-based dairy systems will be important given 98 per cent of dairy farmers in Australia source at least a portion of feed from pasture in 2009-10 (Dairy Australia, 2010, Little, 2010). John et al. (2016) provides a comprehensive review of the current knowledge on both indoor and pasture-based AMS with a focus on feed, animal and management factors that affect the AMS utilisation levels.
2.3 APPROACHES TO ANALYSING THE PERFORMANCE OF AMS

2.3.1 Farm Management

The research methods of this study is based on the disciplinary field of farm management economics. This was developed by a wave of agricultural economists who began working on farm management questions from the 1940s. Farm management has evolved over time from deciding the course of action of the farming business as a profit maximising unit to one concerned about other objectives, such as the goals of the farmer and family (Boehlje and Eidman 1984). Currently, it is seen as the marriage of economics and technology and human elements into whole-farm analysis, considering risk: an approach defined by Jack Makeham (Malcolm, 2004b).

There are many definitions of whole-farm analysis, but Dillon (1980) provides a complete definition:

My preference, if we want to go beyond saying “farm management is what farmers do”, is for what ... is generally a more succinct, and to my view, more complete definition of farm management as the process by which resources and situations are manipulated by the farm manager in trying, with less than full information, to achieve his goals (italics Dillon’s emphasis, p. 258).

The dynamic nature of farm management is emphasised in this statement. The statement highlights that farm management is what farmers do and is not farm management research or teaching. It highlights the risks that farmers face and the uncertainty of the environment within which they operate versus sure achievement of the farmers’ goals. Also, by referring to ‘goals’ rather than ‘profit’, it stresses that farmers’ goals are varied, and profit is a means to ends. It also depicts farm management as being an active role of manipulating the environment as opposed to a passive role of organising and controlling.

The dynamic nature of the separate components of the farm system and how they operate as a whole system over time is highlighted. These components of the farm system include human, technical, economic, financial, risk, uncertainty and institutional
elements. Further, the components of the economic system beyond the farm gate that affect the farm system includes the behaviour of other firms, suppliers and customers, non-agricultural sectors, political, and social forces. Understanding all these factors involve an understanding of numerous disciplines. Whole-farm analysis involves applying an appropriate balance of disciplinary knowledge, with economics as the integrating core discipline.

McConnell and Dillon (1997) categorises these components of the farm system into five subsystems which make up the ‘whole-farm approach’ (discussed later in this chapter), each of which are directly or indirectly related. Briefly, these subsystems are:

- The *technical subsystem* where resources, technology, knowledge and opportunity are combined to produce agricultural products. On any one farm, the nature of these subsystems is determined by geographic, social, economic and technical constraints.
- The *organisational structural subsystem* refers to the formal structure of the authority, communication, job responsibilities and task allocation. Small farms will not have a complex structural subsystem.
- The *informal structural subsystem* exists in farm systems with two or more people consisting of individual’s motivations and behaviour etc. This subsystem is abstract and becomes more complex the greater the number of people involved in the farm’s social organisation.
- The *goals and values subsystem* are the goals and values held by the farm system in meeting the organisations’ purpose and aims. This subsystem will be influenced by the goals and values of individual members within the farm system, as well as the social and political environment that the farm system operates within.
- The *managerial subsystem* relates to the entire farm system and is an abstract subsystem. It encompasses all of the managers’ activities required to manage the farm system as a purposeful entity. These activities include, but are not limited to, setting goals, specifying short and long term plans, making technology choices, allocating resources, specifying the organisational structure, and ensuring the competing requirements of all other subsystems as well as the environmental suprasystem (everything external to the individual farm system including social, economic, institutional, economic and political) are managed.
As illustrated in Figure 2.6 the managerial subsystem straddles all four subsystems and is associated with the people within the farm business, their knowledge, experience, judgements, preferences and information systems to exercise management, or making choices about resource use between alternatives. The emphasis here is that the managerial subsystem places economics at its core as it is the integrating and core discipline of whole-farm analysis (Heady, 1948, 1950, 1952).

Makeham and Malcolm (1993) emphasise that management involves combining and investigating each component of the whole system, their responses and linkages, the effects of time, and the risks and uncertainties. The result of good whole-farm analysis is that practical solutions for the use of resources are proposed for the whole of the farm system and not part of the farm system. Malcolm et al. (2012) emphasise that ‘the behaviour of parts of a farm business, considered in isolation, cannot explain the behaviour of the whole-farm business’.

Source: McConnell and Dillon 1997, p. 334

Figure 2.4: Generalised schematic representation of the farm system
Farm management concepts
The decision making process that a farmer makes can be classified into strategic, tactical and operational decisions. Strategic decisions are long-term decisions that impact on the farm system such as implementing new farm infrastructure. Tactical decisions are those made on a weekly, monthly or seasonal basis such as the amount of supplementary feed to purchase and feed to cows. Operational decisions are those made on a day-to-day basis such as the amount of pasture to allocate to cows. Boehlje (1994) refers to 12 important farm management concepts that encapsulate the broad and complex nature of running a farm business successfully.

1. Management functions: planning, implementation and control in the areas of production, marketing and finance.
2. Low cost production.
3. Ability to spread fixed costs over more output.
4. Focus on profit margins rather than prices.
5. Learning to obtain the best price and service combination when purchasing inputs.
7. Undertaking strategic planning and considering two to three alternative futures, so that a contingency plan is in place.
8. Assess and manage potential risks.
9. Ownership of capital structure.
10. Control, measurement of performance and correction of deviation from expected behaviour or plan.
11. Negotiation skills and interpersonal relationships.
12. Openness to new ideas and technology.

2.3.2 Farm level evaluation methods
There are several economic methodologies that are frequently applied in the literature to undertake farm-level evaluation. Broadly, these can be categorised into budgeting techniques, programming techniques, whole-farm systems approach and econometric approaches. These methodologies have different data requirements and abilities to
measure particular components of farm systems. Pannell (1999) identifies categories of information that is generally required to evaluate agricultural research at the farm-level. These include:

- biological, technical and/or management changes from the new technology;
- cost of implementing the new technology;
- economic benefits on a per hectare or per farm basis;
- extent of adoption on the individual farm; and
- flow on impacts of the new technology to the farm (both internal and external), including environmental impacts or price changes as a result of supply shifts of a farm output.

The following sections provide a brief discussion of the advantages and disadvantages of the farm-level economic evaluation methodologies applied in the literature.

**Technical ratios**

Technical efficiency ratios and partial budgets (discussed in later sections) are typically used as an initial assessment method as it has limited information requirements and are simple to apply (Ghodake and Hardaker, 1981). The technical efficiency ratios compare the new technology with the CMS in terms of input-output ratios. A firm's technical efficiency is measured as the deviation from the best production or efficient production frontier. Critically though, this is only one component of overall economic efficiency. Candler and Sargent’s (1962) critique of average technical ratio explained that maximising the average technical ratios of output to input is not the means to maximising profit, and there use can lead to opposite conclusions being drawn about what to do. As such, there is limited use for this type of analysis for understanding the economic state of farm affairs (see Malcolm, 1990, Ferris and Malcolm, 1999).

**Partial budgets**

Partial budgeting techniques have often been used to investigate changes to parts of the whole-farm business. These changes include all favourable and unfavourable aspects that are incurred or directly affected from its implementation on the farm. With this approach, as much as possible of these elements are assigned a monetary value. This
includes the extra costs and extra returns resulting from the change and also the costs and returns foregone from implementing the new technology (Malcolm et al., 2005).

Partial budgets are typically used to investigate one year of operations that are typical of the way in which the investment is likely to perform over its life. Therefore, they are more suited to analysing investments that take place over a short time where there is little lag time between the initial outlay and benefits of the new technology accruing over time. Where this occurs, discounting will need to be applied to properly compare them with current costs. Tronsco (1985) identifies two significant limitations of using the partial budgeting approach for evaluating technologies at the farm-level, The approach is able to identify the returns on all the capital involved in the activity as well as the returns associated with the extra capital invested. Further, often the effect on the balance sheet and on additional business and financial risk is not straight-forward to discern, and worse, is often overlooked.

**Gross margin analysis**

Gross margin analysis have been applied frequently to evaluate the economic benefits of new technologies at the farm-level. These methods rely on a sound foundation of technical knowledge which are then converted into economic information using budgets. These methods have been reviewed extensively by Dillon and Hardaker (1980), Makeham and Malcolm (2005), Farquharson (1991), and others.

The key advantage of budgeting methods is the relative ease of developing the budgets and the technical and price assumptions applied can be transparent. It is a simple method that allows for comparing the performance of enterprises that have similar requirements for capital and labour. A further advantage of budgeting methods is that they are able to incorporate various degrees of sensitivity analysis to investigate the impact of uncertainty on the evaluation results. Importantly, risk can be captured by including probabilistic estimates for key risky variables.

A key limitation of the gross margin analysis is that it does not include overheads and change usually involves changes in capital and fixed costs. As such this method is
unsuitable for planning a major change involving change in overheads. The issue of how and to what extent the farmer is likely to adopt a new technology amongst farm activities remains undetermined (Alford et al., 2004). In particular, this study analyses changes in the mix of capital and labour resulting from adoption of AMS which gross margin analysis is not equipped to do.

**Whole-farm analysis**

This approach to analysing farm systems and conducting farm systems research is well-established and fully documented, see Barnard and Nix (1980), Boehlje and Eidman (1984), Heady (1948, 1950, 1952), Malcolm et al. (2005), McConnell and Dillon (1997), but often it tends to be missing in analyses of farm systems (e.g. described by Malcolm 2004a, 2004b).

The approach views a farm as a *unique goal-setting* (i.e. purposeful) *open stochastic dynamic artificial* (i.e., man-made) *system*. The choice of the words stochastic and dynamic is critical to the method as it emphasises evaluating farm systems over time and the importance of risk and uncertainty. The theoretical framework that underpins whole-farm analysis approach is a body of economic theory called ‘production economics’. For this study, a number of economic principles and concepts form the basis of the analysis. These are:

- the *principle of comparative advantage* in production
- the *principle of diminishing marginal returns* to extra inputs to production
- the *principle of increasing financial risk* to capital invested in the farm
- the *probability principle*, which affects all decisions and their outcomes.

Malcolm et al. (2009) emphasises these four principles that are fundamental to whole-farm budgeting.

The premise of this technique is that it is essential to consider the whole-farm system before investing in a technology. As an example for AMS technology, if the farm has poor pasture management practices in place, installing sophisticated milk harvesting
equipment is unlikely to generate the increased profitability. Importantly, it will not enable the farm to remain sustainable through adverse circumstances (such as periods of low milk prices or periods of increased cost of bought-in feed). It will be particularly important to understand the impact of pasture management on the productivity of the AMS technology, especially when feed is the key incentive for maintaining good cow traffic.

The use of the whole-farm approach to analysing AMS technology helps to analyse a number of key variables and interactions in the farm system versus one particular variable. For example, maximizing any partial productivity measure (e.g. pasture consumption per hectare, milk protein, fat production per cow or per hectare or milk protein, fat harvested per labour unit) does not necessarily translate to maximising profit or improved performance of the whole-farm system. This is because the law of diminishing returns applies both in economics and biology (as defined by the components comprising the biophysical system). This approach will become increasingly important as farm systems intensify and the effects of interactions between components on overall farm performance become more pronounced.

The approach gathers key economic, financial and technical information and uses a range of techniques, predominantly budgeting and simulation to analyse the information. Budgets are about the future and therefore many of the numbers that are used in the budgets are ‘soft’. This is because future yields, prices, and costs are often soft and are formed by opinions. The key to successful budgeting is making good judgements about the items and numbers that go into budgets (Malcolm et al., 2005).

A key advantage of this approach is its ability to incorporate risk analysis by estimating probability distributions and the joint probabilities of events and their effect on outcomes. Risk analysis undertaken through simulations are used to (i) test the sensitivity of the outcomes to volatility in the key variables, using probabilistic analyses; (ii) analyse the combined effects of various levels of the key variables occurring at the same time, and the likelihood of these scenarios occurring; and (iii) assess the mean and variable of outcomes to changes in the farm plans.
Risk can be given various meanings and can be used in varying contexts. In whole-farm analysis, it relates to the volatility of potential outcomes and can be classified into two types of risk: business risk and financial risk. Implicitly, risk is where some probabilities can be formed about the outcomes. Risk of a business surviving can be an inducement to growth and investment. Also, risk creates returns so taking on more risk is necessary to increase returns to capital. This is in contrast to uncertainty, where no probabilities can be formed about uncertain events happening (Malcolm et al., 2009).

The explicit use of probabilistic models to undertake sensitivity analysis and examine discrete scenarios and identify break-even circumstances is a simple but effective and practical method of incorporating risk in farm models. This was supported by Lindner et al. (1979) highlighting that research on risk management is concerned about how to respond tactically and dynamically to unfolding opportunities or threats and helping to define the expected outcomes. This seemed to be the information that farmers desired.

Pannell et al. (1984) study concluded that accounting for farmers’ risk preferences in a formal way was much less important to good decision analysis than making sure that the technical and dynamic aspects of such decisions are well represented in the models used. Their paper employed methods to test the relative importance of accounting for farmers’ attitude to risk when analysing a decision, as compared with the relative importance of getting right other aspects of the decision, such as its technology and relationship to other parts of the farm system, and dynamics.

Further, most analysis of changes to farm systems studies use static models. Static models refer to the farmers’ decisions to adopt an innovation at a specific place and specific point in time. A key limitation of these models is that it does not account for time in the adoption process which involves changes in farmers’ perceptions and attitudes, and also learning as information is progressively collected.

Marra et al. (Marra et al., 2003) provides a comprehensive review of the roles of risk, uncertainty and learning in the innovation decision process.
The use of dynamic models allows for time and change and helps to address the issues associated with static models. This is particularly important as technology adoption decisions are inherently dynamic. Malcolm (1998) stresses that care is needed to concentrate on the essence of what information on dynamic relationships is critical, and for which decisions. Accounting for dynamics in farm systems contains a multitude of interactions, scenarios and combinations that can make the analysis complex. Sensibly selecting a small set of key comprehensive scenarios will be important for successfully considering the most critical dynamics in farm systems.

**Linear Programming**

Linear programming (LP) is a technique that is commonly used at the farm-level to select a combination of alternative production systems or activities that maximises an objective function, usually profit. This technique is able to examine different farm activities within the physical, financial and labour constraints. The LP method is attractive because not only does it determine the optimal farm enterprise mix to maximise the objective function, it also provides the information including shadow costs and prices which show the sensitivity of the optimal enterprise mix to changes in gross margins of alternative farm activities that are not included in the current farm plan (Pannell, 1997). Another benefit of the approach is the ability to extend the model to incorporate risk and the farmers’ attitude towards risk to more accurately evaluate the extent of adoption of the new technology in the farm system. The idea is to more closely reflect the decision making priorities of the farmers, however, Pannell *et al.* (2000) suggest that “if the purpose of the farm model is to predict or evaluate change at the farm level, then the inclusion of risk aversion is often of secondary importance” (p. 75).

Key limitations of LP are that the relationships between input, output and the constraints on production are assumed to be linear and observe constant returns to scale; combined effects of inputs and outputs are additive; and that inputs and outputs are constrained to be positive. This is problematic for dealing with real world farm systems which involve non-linear input-output relationships (particularly diminishing returns) and risk associated with yields and prices. Although, modern computer software is making it possible to segment non-linear relationships and address some of these shortcomings
through advanced forms of mathematical and risk programming as outlined by (Hardaker et al., 2004). Another limitation of the LP approach is that the objectives and constraints specified are not usually completely the goals that are pertinent to the operator of the farm system (Mcconnell and Dillon, 1997). Since receiving a lot of attention in the 1960s, refinements to the standard static LP model such as using non-linear segments were developed for situations where the assumption of constant returns and perfectly divisible resources such as machines and paddocks, was no longer acceptable. Quadratic risk programming and other techniques enabled variability and risk to be considered in the analyses. Many authors have reviewed these methods, for example Anderson et al. (1977), Patten et al. (1988) and Hardaker et al. (2004). In the Australian farming context, LP has mainly been an occasional research tool, and few LP models have been adopted in studies. Often in crop and livestock mixed systems few choices are involved in which simple gross margins selection are adequate (Makeham and Malcolm, 1993).

In Wade et al. (2004), linear programming (LP) is used to optimise results for different farm situations (Berentsen and Giesen, 1995). The objective function of the model maximises labour income which is the amount the family labour and management earn after all the costs have been covered. Andersson et al. (2003) also developed an LP model for different herd sizes of dairy farms. These farms also had different characteristics such as tillable area, soil types, yields, and climate. Constraints such as area of tillable land, pasture area, storage capacity, number of stall-floors, and milking system capacity are the constraints on the choice of an economically optimal solution. Similar to Wade (2004), this model maximised net farm income on both the CMS and AMS. The analysis shows that the results are highly sensitive to factors such as how much milk yield is increased and how much labour is saved.

**Dynamic Programming**

Dynamic programming (DP) is a method that has been applied in evaluations of new technologies at the farm-level over several time periods (Kennedy, 2012). The approach aims to solve problems by identifying a collection of sub-problems and solving them one by one. In the case of new technology, the problem is separated into a series of
stages where key decisions are made. The decisions made on variables at this stage can also affect the outcomes of subsequent stages.

The key ideas behind DP rests upon the principle of optimality, as such the method is a mathematical optimisation method as well as a computer programming method. This method has been used at the farm-level to examine the dynamics of a farming system and also track how a new technology might impact on the farm system over time. One of the key advantages of DP is the ability to incorporate non-linear biological relationships and stochastic problems can be solved (i.e. uncertainty can be incorporated). Trapp (Trapp, 1989) posits that DP remains appealing to biologists because stochastic variables and the optimality of resource-use principles can be used as the basis of solving problems.

A significant limitation of this approach is the increasing complexity of the model and its data requirements. As such, the well-established problems of dimensionality becomes an issue and its use for solving whole-farm problems becomes a challenge even for modern day computers (Nuthall, 2011). Further, the large number of variables used to reflect the complex farm system quickly become impracticable to solve in reasonable time, this is also a problem with stochastic linear programming (Cacho and Gooday, 1998).

**Econometric methods**
An alternative method for evaluating economic benefits of agricultural technologies is the econometric approach. A large number of studies in the literature have applied econometric approaches to examine the rates of investment in research at the regional, state and country level. The econometric approach tends to be employed within the framework of a production function that incorporates conventional inputs (e.g., land and labour), non-conventional inputs (e.g., infrastructure etc.) and stock of technical knowledge (e.g., investment in research and extension). The use of regression models is commonly used to study AMS technology.
A significant limitation of this method for evaluating agricultural technology at the farm system level is the requirement for good quality time-series and cross-sectional data. This data is costly to obtain below the national or state level, and often not available as they generally take the form of aggregate data across farms and regions and not individual farms. The data-intensive requirements has excluded this approach from being widely applied to evaluate the impacts of new technologies at the farm level.

**Economic surplus approach**

Finally, the economic surplus approach aims to measure aggregate social benefits of a technological change. The centre piece for this type of analysis is the shift in the supply curve (K-factor) that results from the technological change. This is the explanatory variable, and measures of economic surplus are often produced as outputs (Alston *et al.*, 1995). This method can be used to estimate the return on investment by calculating a variation of consumer and producer surplus from adopting a technology. Following this, the cost of the technology is utilised with the economic surplus measures to generate the net present value (NPV), internal rate of return (IRR), or the benefit-cost ratio (BCR).

Economic surplus models are used to estimate aggregated outcomes for all producers in the unit of analysis. These models are best used to depict an industry where farmers buy and sell in commercial and well-organised markets. Although it is possible to disaggregate producers by their size, the economic surplus model is not designed to model effects at the individual farmer and/or household level (Falck-Zepeda *et al.*, 2007). The approach requires first estimates of the change in costs at farm level in order to estimate change in industry supply. Therefore, the economic surplus approach to research evaluation has limited use for understanding investment decisions at the farm level.

In this section the common approaches that have been used to analyse farm management research questions. In particular, the whole-farm systems approach has been widely used to undertake economic evaluations of new technologies at the farm level. This is particularly when the agricultural technology is complex and involves changes to various components of the farm system. The approach evaluates technology
adoption through time and allows for different elements of risk to be incorporated. This is highly relevant to the technology being assessed in this research paper.

In this research paper, the whole-farm systems approach to examining technology adoption is used and the design of the method guides how the case studies are selected and the key variables that are the focus in the analysis. Given they are case studies, they may differ significantly from any other individual farms which have differing resource endowments, management capabilities, climatic factors, market prices and costs.

### 2.3.3 Case study analysis

Yin (2011) suggests that the choice of the case study method versus other types of empirical methods can be rationally made against three conditions:

a. The type of research question;
b. The degree of control required over behavioural events; and
c. The degree of focus of the research on contemporary as opposed to historical events.

The three conditions will be used to help assist in deciding the appropriate empirical method to be used for this study and is summarized in Table 2.5.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Form of research question</th>
<th>Requires control of behavioural events?</th>
<th>Focuses on contemporary events?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>How, why?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Survey</td>
<td>Who, what, where, how many, how much?</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Archival analysis</td>
<td>Who, what, where, how many, how much?</td>
<td>No</td>
<td>Yes/no</td>
</tr>
<tr>
<td>History</td>
<td>How, what, where, how many, how much?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Case study</td>
<td>How, why?</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Source: Yin (2011)

The “who, what, when, where, why and how” questions help to define the type of research question. While most research approaches can help to answer these questions, this is accomplished at varying degrees of efficiency. From undertaking a review of economic literature, it is evident that past researchers have endeavoured to learn about
AMS technology adoption on-farm through asking ‘what’ types of questions (and their derivatives “how many” or “how much”), such as:

- How much labour savings are achieved from adopting AMS technology?
- What is the economic cost and benefits to the farm from implementing the new technology on a per hectare or per farm basis?
- What are the key influences affecting the decision to adopt the new technology?

Research approaches such as surveys and archival analysis are appropriate methods to answering ‘what’ questions as well as the ‘who’, ‘where’ which are explanatory (Yin, 2011). This research differs from previous research into on-farm analysis of AMS technology because it will focus on ‘how’ and ‘why’ type questions, that is, the exploratory and descriptive questions. For example:

- Why adopt AMS technology?
- How does the situation on a dairy farm business in Victoria or Tasmania at one point in time (particularly in relation to capital and labour) affect the success of adopting AMS technology?
- How does the process and achievement of adoption affect the subsequent operation of the dairy farm business and therefore the growth in the wealth of the farmer?
- How does the real cost of capital and labour over time impact on the farmers’ return on capital?

Case study, formal experiments and historical accounts can be employed to investigate ‘how’ and ‘why’ questions. To further distinguish between the appropriate method for this study, the extent of the investigators’ control of behavioural events is considered. Formal experiments require an ability to control and precisely manipulate behavioural events compared to case studies and historical analyses which do not. This research does not require control over events and therefore the remaining methods for use in the study are between case studies and historical analyses.

The third condition as described in Yin (2011) is the degree of focus on contemporary events as opposed to historical events. The case study method is suitable for dealing
with contemporary events in which the behaviour of the systems being researched cannot be manipulated, whereas historical analyses focus on the past. This study is interested in the process of adopting AMS on a dairy farm today and not about the historical adoption decisions. Therefore, the case study method is most suitable for this research paper.

The case study method has been adopted widely and many authors have provided critiques of this method. Refer to Yin (1994), Sterns et al. (1998), Eisenhardt (1989) and Crosthwaite et al. (1997). The advantages and disadvantages of the case study method are also discussed. The design of the research and how the case study method is applied in the research is presented in the following section.

Yin (2011) provides an abbreviated definition of the case study method as an empirical inquiry that:

(i) investigates a contemporary phenomenon (e.g., a “case”), set within its real-world context; especially when

(ii) the boundaries between phenomenon and context are not clearly evident (p. 4).

This definition is highly relevant and representative of the investigation being conducted in this research. By the end of 2015, AMS technology has been adopted by 37 farms across Australia and includes single and double box systems, and robotic rotaries. Its application to pasture-based dairy farm systems in the southern hemisphere is a contemporary phenomenon pertinent within Australia’s current dairy farming context. Improved understanding of how AMS technology fits into the whole-farm system will help to make the option of adopting this technology closer to reality across a wider range of dairy farm systems. The complexities (boundaries) of the technology (phenomenon) and adoption at the farm level (context) are not clearly evident. This is because the structure and stage of each individual farm’s development will place different limitations on the feasibility of adopting AMS technology, emphasizing the real-world context that phenomenon and context are highly variable and idiosyncratic on each farm.

Advantages of the case study method
The application of the case study approach has seen wide adoption in farm management research. Given the typically complex nature of farming systems, an approach that is able to use multiple sources of evidence (e.g. documents and surveys) becomes vital. This information helps to make an educated assessment of the ad hoc management decisions, dynamic processes and uncertainties that influence the farming system. This is made possible as the method allows for a few cases to be examined by drawing on a broad range of disciplinary knowledge to analyse complex systems in depth (Crosthwaite et al., 1997).

The literature on AMS technology suggests that the decision to adopt the technology is not a simple one as it will impose significant changes on many aspects of the farm system for the herdsman and the cows. Automatic milking system technology is not only a new milking system, but rather a completely new management system. As such, a naïve extrapolation of experimental results undertaken by other studies is potentially misleading when investigating the farm-level benefits of the technology from farm to farm (Alston et al., 1995). This is a result of a diversity of factors such as resource endowments between farms and farming regions, climatic conditions, different farming systems, as well as farm managers with different levels of experience, skills, risk attitudes, perceptions and wealth (Pannell, 1999).

Other advantages of the case study method include:

• Generalising from case studies is effective for theory development and generalisation to theory (analytical generalisation) compared to its misuse when generalising to populations (statistical generalisation). Individual cases are not sampling units in any statistical sense (Crosthwaite et al., 1997);

• Examination of the data is often conducted within the context of its use. I.e., the subject is observed in their natural setting (Zainal, 2007, Orum et al., 1991);
The approach allows for both quantitative and qualitative analyses of the data. Case studies should not be confused with qualitative research and case studies can be based entirely on quantitative evidence (Zainal, 2007);

The detailed qualitative accounts produced in the case studies help to explore and describe the data in real-life environment and the complexities of real-life situations that may be missed in experimental or survey research. This is emphasized in Zainal (2003);

Flexibility to draw on a wide range of disciplinary knowledge (Crosthwaite et al., 1997);

Examining a phenomenon at its most complete form and uncover its historical dimensions (Orum et al., 1991); and

The ability to examine the managerial black box unlike other research methods that examine simple decision rules like profit maximisation and cost minimisation. The case study method is applied to understand the motivations and strategies that underpin decisions.

Disadvantages of the case study method

While the case study method allows for a mix of disciplinary knowledge to inform the analysis, there are trade-offs between the number of cases to be examined and the disciplinary depth and breadth brought to bear in the analysis (Crosthwaite et al., 1997).

A common criticism of the case study method is its dependency on a single case making it challenging to arrive at a generalising conclusion (Tellis, 1997). Standard agricultural economic empiricism has been designed to generalise from samples of populations to whole populations. The view has been that few general principles could be derived from single case studies. It needs to be kept in mind that case study research is used to generalise to theory, not to whole populations. Case studies of real and representative farm businesses help to provide information about real world phenomena and allows testing of whether the findings are consistent with theory or not, and challenge accepted wisdoms (Malcolm et al., 2012). Importantly, the analysis can inform other farmers that operate similar systems on their future options.
Other disadvantages of the case study method include:

- Case study methods have been accused of lacking rigour as the investigator has allowed equivocal evidence or biased views to influence the findings and conclusions (Yin, 2011);
- The method provides limited scope for scientific generalisation given the small number of subjects, some with only one subject (Yin, 2011);
- The method can be time consuming, difficult to conduct and producing large amounts of documentation (Yin, 2011);
- Users have the tendency to include too much, resulting in a theory that is rich in detail but may lose its overall perspective (Eisenhardt, 1989); and
- As the case study method is not subject to statistical analysis (such as regression analysis) theorists may be unable to assess the which relationships are more important versus those which are idiosyncratic to a case (Eisenhardt, 1989).

2.3.4 Labour and capital

As with the previous section, this section on labour and capital issues is to provide context on the considerations required to undertake an economic analysis of the operations of AMS systems. A focus of this study is on how the ratios of labour and capital inputs are combined within a business to meet the objectives of the business owner (that is, the input-input technical relationship). The type of method required to assess whether the use of labour and capital inputs amongst other resources in one way is better than another is whole-farm budgeting.

Labour and capital substitution

The literature on labour and capital substitution is applied at a macro level concerning industries and sectors and also at the micro level concerning firms, and in this case at the farm level. The theory explaining the substitution of labour for capital has predominantly been undertaken in the context of economic growth and development. The neo-classical growth theory, also known as the Solow-Swan growth model, was pioneered by Solow (1956, 1957) and Swan (2007). This model was an extension to the Harrod-Domar model that was developed in 1946. Solow extended the Harrod-Domar model by adding labour as a factor of production and allowing the ratio of capital-labour
not to be fixed as they are in the Harrod-Domar model. Solow (1956) explains a model of long-term growth which accepts all the Harrod-Domar assumptions except that of fixed proportions and explores the production of a single commodity produced by labour and capital under standard neoclassical conditions. This allows increasing capital intensity to be distinguished from technological progress. Refer to Solow (1956) for an explanation of his long-run growth model. Solow’s model has been adopted and applied widely at the macro and industry level. Here, the adoption of technology in agriculture over time is an amalgam of adjustments to changing technology in agriculture and changing relative factor and product price ratios.

At the firm level, in practice, we are concerned with the different ways resources are combined to complement or substitute for one another in the production process (called the input-input technical relationship). In the case of AMS technology, capital can be substituted for labour while maintaining the same level of output. The substitution between factors inputs is a well-established theoretical basis in microeconomic production theory (see e.g., Varian, 1992).

Technological progress can be classified as being capital-using (labour saving), labour-using (capital saving) or neutral depending on its effects on the marginal rate of technical substitution of capital for labour (Hicks, 1963). According to this, technology progress is defined as labour-using if its initial effect is to raise the marginal productivity of labour relative to that of capital; capital using if its initial effect is to raise the marginal productivity of capital relative to that of labour; and neutral, if the marginal productivities of capital and labour are both raised by the same proposition (here, the slope of the isoquant at a given capital-labour ration remains unchanged).

Where the wage rates are rising faster than the price of capital inputs, there is an added incentive for the substitution of capital for labour in the production of the current output. The creation of additional farm capital is therefore a strategy adopted by farmers to raise the productivity of their own labour and maintain incomes comparable to those of persons in non-rural industries. This is because the marginal product of labour eventually diminishes as there is at least one fixed factor of production, such as capital.
Producers can use combinations of three broad classes of factors of production called labour, capital and raw materials (inputs) to produce one or many products (outputs). The law of substitution in economics can be referred to the process by which changes in relative price of inputs modifies the optimal mix of inputs and outputs that are defined by a production function.

The law of substitution was further extended by Hicks introducing the concept of elasticity of substitution to measure the effects of changes in the capital to labour ratio on the relative shares of capital and labour. This is also known as the induced innovation hypothesis. This hypothesis conceptualises that differences in the level of relative factor prices influences the direction of innovation activity. It can be expected that a fall in the capital to labour ratio will see increased use of capital. This has been the long-term trend in the farm sector as the substitution of labour for capital continues to occur.

Importantly, this isn’t just the case for dairying but for any labour-intensive forms of agriculture. A recent study by Beltran et al. (2012) showed that the increased demand for labour in non-agricultural sectors of the economy translates to high labour costs that directly influence the management decisions of producers. This is especially the case for rice farms in the Philippines concerning the trade-off between the use of manual weeding and herbicides for weed control (Beltran et al., 2011). The study concluded that if the cost of labour is cheap, the traditional labour-intensive transplanting approach to seeding is the most profitable option. However, as labour costs increase, direct seeding becomes more profitable because it requires much less labour. In addition, if labour is cheap and weed numbers are not excessive, it is best to rely on manual weeding, with people pulling up every weed in the crop by hand. However, at higher labour costs, application of chemical herbicides becomes the more profitable option.

**Labour considerations**

For the given technology set being assessed in this study, capital is a substitute for labour. This is because AMS is a labour-saving technology (Molfino et al. 2015). The
main premise for the adoption of AMS in Europe has been the rising labour costs experienced in the mid-1970s (Sauer and Zilberman, 2012). This is discussed further below. Central is the substitution of labour for capital that is devoted to harvesting milk and activities in other parts of the farm system. With increasing intensification and use of genetic selection, increasing milking frequency is being considered as an option for increasing the productivity of dairy cows. In this analysis, the cost of labour can be equated as the opportunity cost of labour (such as when family labour is able to get incomes off-farm).

However, adoption of AMS will generate labour savings (and therefore labour cost savings) only if the technology is being adopted by farms utilising several labour units (particularly those relying on external labour). For example, a one-family farm will see little cash flow benefits from adopting labour-saving technology because the operator’s own labour is saved, or the labour of his family is reduced. This results in decreased workload and partial unemployment that does not reduce business costs. An important message here is that while surplus labour is created, this may be a desirable aspect of the technology for the adopter. These non-economic (lifestyle) factors can only be evaluated by the farmers themselves. On the other hand, from a business growth perspective, unused productive services from this labour surplus could induce business expansion by increasing the size of operation (Sinnett, 2004).

One of the key aspects of technology adoption that has been overlooked in the literature, of particular relevance to this study, is the change in the nature and organisation of labour and management. Hutt (1993) explains:

In agriculture we have viewed management as a generic term describing essentially anything dealing with the successful operation of a farm business. We have failed to give the term definition and rigour. The result is that management has not been a subject of study or improvement for the dairy industry and has become an almost mystical term we use to explain why some farms have higher productivity and/or profitability (p. 130).
While there has been theories developed on the roles of management (see Boehlje and Eidman, 1984, Giles and Stansfield, 1990), there has been a general shortage in the literature of AMS technology adoption and the implications for labour organisation and management for the whole dairy farm system. After all, the managerial subsystem is the integrating and core discipline of whole-farm analysis.

One of the main aspects of adopting more automated technologies is the management style of the farmer changing from physical work to, little physical work and more labour and office management. This is a key challenge in the adoption of AMS technology given dairy farmers generally have relatively little personal experience as employees or employers (Doyle et al., 2010).

Also, a factor that needs to be considered in this adoption process is the transition period between implementing the technology into the farm system and reaching the stage when the business is in ‘steady’ state. This is more commonly known as the "start-up year" problem in the business growth literature (Boehlje and Eidman 1984). This period involves learning the new technology and the shift in priorities that the technology places on different parts of the farm system. The case study farmers have indicated that AMS with voluntary milking requires a longer adaptation phase than other technological innovations in the dairy industry.

**Capital considerations**

Salter (1966) developed a theory to explain from an economic perspective when a firm should replace its existing capital equipment with new capital, which often has embodied technological change. He argues that capital equipment should be replaced ‘...when the plant fails to yield any surplus over operating costs; to abandon it earlier would be to forego any surpluses the plant could earn, while to abandon it later would be to make losses. Put simply, a firm will choose not to invest in a new irreversible technology until the value of the investment reaches a critical value that exceeds the cost of the investment (Mcdonald and Siegel, 1986).
This criterion recognises the well-established principle that outlays for specialised capital equipment are irreversible (p. 56). This is relevant for analysis of investment in AMS technology as it will involve sunk costs because of a fixed cost portion and the risk linked to a potential resale of the equipment. The nature of the capital and its salvage value will need to be carefully considered in this analysis as this could have implications for the capital recouped. This value is the difference between initial capital invested and the depreciation cost over the life of the project. It is important to factor salvage values to ensure that calculated returns to capital are adjusted to account for changes in the initial stock of capital over time.

Salter’s theory of capital replacement is highly relevant in the case for wider AMS adoption in the dairy industry. Firstly, this is because dairying compared to other forms of agriculture involves considerable investment in specialised fixed capital which can have low or zero salvage values in non-dairy farm activities – for example, sheds, paddock layout, irrigation infrastructure, yards and effluent disposal. As such, it is only economically sensible to replace existing capital equipment at the point Salter refers to, that is, when it no longer covers operating costs. See Johnson’s (1960) and Salter’s (1966) theory for further explanation of these concepts.

Similarly, this could also be the case when an expanding dairy business wishes to take over the land and herd of an obsolete dairy farm where the fixed dairy capital exhibits low or zero salvage value. However, on these farms, older milking facilities may be reaching the end of their useful life for reasons, including (Davies et al., 2010):

i. low labour efficiency compared to modern dairies,
ii. facilities are too small to accommodate for expanding herds, and
iii. the costs of repair and maintenance are increasing and reliability is declining.

The capacity of the farm business capital infrastructure impacts can constrain or motivate business expansion and growth for a period of time. This was exhibited in case study analyses undertaken by Sinnett (2004) on dairy farm business growth.
Secondly, Salter (1966) argues that the rate of replacement of capital infrastructure is a function of factor prices (the price of labour in comparison to the price of new capital equipment). This is because the main cost of adopting new technology is the cost of the capital equipment compared to the higher operating costs which is the price paid to maintain older technologies (in this case, more labour-intensive milking sheds). For example, an increase in the wage rate of labour would encourage earlier replacement of capital equipment because of the higher operating costs required to maintain older technologies. This is further emphasised by Salter:

The relevant comparison is between operating costs of the whole plant if the existing machine were retained, and the future operating costs if the new machine were installed. For replacement to be profitable, the present value of this cost saving must exceed not only the purchase price of the new machine but, in addition, any other special investment outlays associated with installing the new machine (Salter, 1966, p. 86)

Equally, a higher interest rate would also increase the cost of the new capital equipment and delay the replacement of old capital equipment. A study by Sinnett (2004) found that the replacement of existing capital equipment is influenced by the cost of labour (opportunity cost of labour), the amount of output produced (in this case, throughput in AMS will be important), and the capital cost of the new technology. In recent times costs of capital have fallen relative to cost of labour.

For investment decisions around whether a farmer will be persisting with the present milking facility or investing in a new facility, there are a number of technologies to consider (depending on current and future herd size etc.). The future life of this new capital investment will ultimately depend on the following considerations (Salter, 1966, Johnson, 1960):

i. the price of the product or products the equipment can produce,

ii. the quantities of current factors required to operate the equipment, and

iii. the prices of these current factors (Salter, 1966, p. 61).
As articulated by Salter (1966), ‘This is true irrespective of whether the equipment is a marvel of technical efficiency or a museum piece; once in existence it is there to be used or not and the only criterion of its economic usefulness is the ability to earn a surplus over operating costs’ (Salter, 1966, p. 61.). In addition to this qualification, it is also important to keep in mind that above average returns to capital will most likely only be possible if the capital is exposed to above average risk (Malcolm, 2004a).

2.3.5 Economic approaches used to analyse investment in AMS

The literature around the economic impact of adopting AMS technology is widespread in European dairy farming countries and is now well established. It is important to highlight at this point that the existing literature on AMS technology is of limited use in the Australian context for two key reasons. First, studies around the economic viability of AMS technology in these European countries such as Denmark, Sweden and The Netherlands are less applicable to Australian dairy farmers because of the focus on pasture-based grazing systems in Australia. While Australian dairy farm systems are becoming increasingly intensified, pasture-based systems, will continue to dominate into the foreseeable future. This is because pasture-based systems represent the lowest cost feed for dairy cows and will continue to underpin Australia’s international competitiveness (Dillon, 2007).

Second, the economic studies undertaken to date have been based on normative models where the benefits of AMS technology (labour saving, and increased production) were compared with increased costs (depreciation, maintenance, and interest) (Bilj et al., 2007). As discussed earlier, adoption of AMS not only changes labour requirements and milk production but fundamentally alters the whole operational management of the farm system. As in a paper undertaken by Tarrant and Armstrong (2012), while cash labour savings are a major attraction to the adoption of new technologies, there are a number of costs and benefits that are difficult to quantify, but are important when considering an investment. These include herd health, occupational health and safety, work comfort, and managerial control of the dairy shed.
The literature to date demonstrates that economic evaluations of AMS adoption have employed a range of methods. Although applied computer simulations and simple economic analysis is frequently used to compare AMS with CMS. The findings from these economic assessments have often been varied and largely depend on the assumptions made in the analysis such as herd milk production, milking labour costs and life of equipment. There has also been no attempt to explore how AMS can co-exist with CMS. Parsons (1988) conducted an initial assessment of AMS prior to its existence on commercial farms. A simulation model was employed to assess the costs and benefits of changing from CMS to AMS. Years after, Parsons went on to further undertake simulation models that assessed different management strategies for AMS for a range of real farms (Cooper and Parsons, 1998, 1999). An important finding from these analyses is that the economic results from an AMS vary widely from farm to farm. Other studies include Rotz et al. (2001, 2003) and also country-level models simulating typical farms for up to ten years over four countries (Wauters and Mathijs, 2004).

In more recent papers, regression models are being used to model the relationship between the dependent variable and predictor values. Castro et al. (2012) used a multiple linear regression data analysis method to estimate the efficiency of AMS units on dairy farms in Spain. The system capacity was analysed through variables including number of cows, milk yield, milkings per cow per day, actual milking time, rejected milking time, cleaning time, and machine downtime. This was used to determine the number of cows milked per AMS unit to obtain the optimal values of milkings per cow and milk production. Sauer and Zilberman (2012) collected a dataset from Northern Europe that allowed them to trace the empirical dynamics of technology choices being made at the individual farm-level as most empirical adoption studies use cross-sectional data at one point. Econometric modelling is used to model the effects of risk, social interaction and past innovation experiences through a sequential implementation structure of the adoption decision. Their results show that risk has an important influence on adoption decisions and reductions in risk over time will significantly increase the probability to adopt AMS. In addition, peer-group behaviour and technology density has a significant effect and so does previous innovation experiences.
Partial budgeting techniques were also used by various authors. Lightfoot and Mulvaney (2002) applied a partial budgeting approach to examine the relative cost effectiveness of four different systems (including rotary, swing-over, AMS and Ad-lib). The financial viability of AMS was not explored as the author’s believed that cost effectiveness remains the paramount issues for farmers. Similarly, Davies et al. (2010) used the partial budget method to compare changes between two systems, CMS and AMS. The use of partial budgeting techniques to evaluate milking system purchases is not ideal because it is not good at handling cash flows that vary between systems from one year to the next. For example, milk production may be expected to decrease as cows adapt to the AMS but then could increase later with more early lactating cows opting for more than two milkings per day.

Both Armstrong et al. (2010) and Alford et al. (Alford et al., 2010) undertook preliminary economic assessments of AMS in Australian dairy. Both papers have applied similar approaches of whole-farm analysis that involves biophysical and economic submodels that are developed from all prices and costs and biophysical data collected from a case study farm. The biophysical model includes animal energy requirements based on metabolisable energy accounting for production levels and the energy supplied by purchased feed. Herd dynamics resulting from changes in herd size are also modelled. The economic submodel applies discounted cash flow budgets over a 10 year period. The studies also incorporate risk analysis by applying stochastic budgeting with the inclusion of probability distributions for key variables such as milk prices, feed prices and yields for home grown feed. The general findings of both these studies are that AMS are more expensive than CMS of the same capacity but are influenced by the estimated labour savings and the value placed on labour. Their results are also consistent with ex ante analyses undertaken by Lightfoot and Mulvaney (Lightfoot and Mulvaney, 2002)

Engel and Hyde (2003) is the first to employ a real options approach to analysing the decision to replace an existing CMS with AMS. This study differs from other analysis as it focuses on the choice to replace a CMS instead of choosing to install one or the other. The approach is based on the premise that real options exist under three
conditions associated with a decision. These are: (a) the decision can be postponed by
the decision makers; (b) the outcome of the decision must be uncertain; and (c) there
must be sunk costs (irreversibility) associated with the decision. These conditions must
all exist concurrently for the decision maker to hold a real option. The authors consider
that AMS fulfils all these conditions as the decision maker is able to postpone a decision
until some uncertainty is resolved before investing in a technology that will result in a
permanent loss of capital.

There are also a significant amount of studies employing traditional capital budgeting
methods and simple arithmetic economic analysis for analysing investments, such as net
present value (NPV) analysis. Dijkhuizen et al. (1997) used a capital budgeting
framework to analyse the choice of a CMS or AMS. This analysis included a break-
even analysis and used point estimates for milk prices, feed costs, labour costs and other
variables. Hyde and Engel (2002) went on to extend this model by incorporating a
Monte Carlo simulation to estimate a distribution of break-even prices and applying it
on a dairy farm in the United States. It is important to note that these two studies looked
at investment into AMS at a given point in time (i.e. a green field site). The study did
not consider the replacement of a CMS with an AMS and also did not account for the
effects of variability in returns and sunk costs (irreversibility) associated with the
investment would have on the research findings. More recently, a study undertaken by
Molfino et al. (2015) uses a simple audit approach collecting data on labour and time
management to analyse labour efficiency on-farm.

Fisher (2004) undertook a survey of 22 AMS in Ontario and key factors observed
included milking labour time, repair and maintenance of the milking machinery, milk
production, number of cows, number of robots, and other miscellaneous production
data. Rodenburg (2008) also provides a simple economic analysis based on a snap shot
of current prices for equipment and cost of labour. Jago et al. (2006) evaluated the
financial performance of a newly constructed AMS system for a New Zealand dairy
farm scenario. This analysis calculated a number of financial indicators including gross
farm revenue, farm working expenses, and capital cost of the AMS. This was used to
calculate the Economic Farm Surplus (EFS = GFR – FEW – depreciation), operating
returns on assets, and cost of production. Finally, a study by Bijl et al. (2007) used real accounting data collected from 62 farms (31 using AMS and 31 using CMS) to undertake a case control study. The profitability of these systems were analysed by matching an AMS farm with a CMS farm during the same year and no models were used. Their study was interesting as it found no difference in the profit margin between CMS and AMS. This was due to CMS having larger revenues but AMS having smaller costs.

Finally, much of the literature on AMS technology has also focussed on non-economic costs and benefits such as the impacts on cow welfare, animal health and milk quality etc. Meskens et al. (2001) provides a useful literature review on these factors.

2.4 Key research question
The key research question to be investigated in this thesis is if AMS technology adopted in Australia’s pasture based systems with voluntary cow traffic is competitive, in terms of profit, returns to capital, risk and non-pecuniary net benefits, when compared to Australian dairy farmers using conventional milking systems. This proposition will be tested by assessing the biophysical and economic performance of two dairy farm case studies, a Gippsland farm using ‘single box AMS’ and a Tasmanian farm using the ‘automatic milking rotary’. These two dairy farm case studies were chosen because they are deemed to have successfully integrated AMS into their whole farm system and are realising the benefits that are available from AMS. The case studies represent the use of the AMS technology at a steady state. For each case study, its biophysical and economic performance for an individual year was compared with the performance of other farmers in the region using conventional milking systems in the same year, where possible, and also over a hypothetical run of years with ranges of prices and seasonal conditions. Risk and uncertainty is also investigated in detail by running scenarios that represent long term typical prices, costs and rainfall.

In the next chapter, the method used in the analysis is set out, the case study approach used, explanation of the biophysical modelling of the feeding systems and the economic analysis, as well as the assumptions, are described.
General Method

3.1 INTRODUCTION
The purpose of this chapter is to describe the method that was used to analyse the two case study farms, particularly as it relates to the modelling of the biophysical and economic performance of the farms. The modelling work undertaken was whole farm budgets using a spreadsheet and @Risk (Palisade 2007).

3.2 ADVISORY COMMITTEE
The advisory committee to the study included Sydney University’s Future Dairy team which involved farm representatives, scientists and industry experts. The advisory committee provided significant input to help ensure that the parameters, scenarios and assumptions in the economic modelling of the case studies were as accurate as possible.

3.3 CASE STUDIES
As discussed in the literature review, the case study approach to whole farm analysis is well-established and was adopted for this research. The case study approach was used to examine the economic performance of two dairy farm businesses that have adopted two different forms of automatic milking systems. The case studies are based on real farms and therefore are defined by the natural resources, existing infrastructure and biophysical performance of the existing system. To ensure that the findings of the study can be generalised to theory, and in limited ways to other cases, the unique human components of the farm system (risk aversion, stage in life, goals and skills) were ‘abstracted’ out in the modelling exercise which has the assumption that management gets it right. This helps to remove the variability in different operator’s ability to implement and manage change to aspects of the farming system.

3.4 BIOPHYSICAL MODELLING OF FEEDING SYSTEMS
The modelling of the production system for both case studies was based on metabolisable energy (ME) requirements and supply for grazing ruminants classified across a number of categories. To calculate the ME requirements of the existing farm system, physical data was collected on:
Herd structure – stock classes, sales and purchases, and estimates of liveweight.

Monthly milk production, protein and fat composition.

Approximate distances walked to and from the dairy.

The whole farm budget accounted for all ME requirements for all grazing ruminants for maintenance, grazing, walking activity, growth of younger cows, pregnancy/foetal growth, lactation, and ME needs due to changes in body condition in early and late lactation. The calculation of these energy requirements are detailed in Standing Committee on Agriculture and Resource Management (Subcommittee et al., 1990) and CSIRO (2007).

Pasture growth rates on dairy farms are unknown and calculating the ‘true’ pasture growth rates is a difficult exercise. In the science discipline, growth is measured by observing the change in pasture mass between successive instantaneous measurements, summed over time as appropriate (Hodgonson 1979). This is known as pasture accumulation or herbage accumulation measured in DM/ha/day. This type of data is not readily available and so a common practice is to calculate pasture consumption by using livestock ME requirements and the estimated amount of ME made up by supplements and hay, and the residual ME coming from pasture consumption. To calculate the amount of energy derived from supplementary feeding, it is assumed in the analysis that all mature cows received the same amount of grain and hay, regardless of when they calved.

Details about the approach and assumptions for undertaking an economic evaluation and risk analysis of the case studies under a range of possible scenarios are set out in the following sections.

3.5 ECONOMIC ANALYSIS

In this thesis, the profitability and risks of two case study farms with different AMS technologies was investigated by defining and analysing the performance of the farm system under different scenarios over a number of years. The profitability and risks have been assessed at a stage where the businesses are considered to be operating at a
‘steady state’. For this analysis, this state is considered to be the stage when the new automatic milking system has been successfully integrated into the operations of the whole farm system and the costs and benefits of the technology are being realised. These case studies are compared to the performance of dairy farmers operating in the same region and State but using conventional milking systems.

To understand the economic performance of the case study farms, the three financial statements of annual profit and loss, annual net cash flow and net worth or balance sheet were analysed in detail. These statements along with a stock trading schedule, tax schedule, herd production figures and calculation of pasture consumption were combined in a whole farm spreadsheet model to build a picture of how each farm performed in the recent past.

To appropriately consider risk in an economic analysis, it is necessary to scrutinise the impact of changes to systems through applying it to sound technical representations of the business or parts of it. Stochastic or risk budgeting needs to be incorporated to enable choices to be compared in terms of mean and variance of distributions of possible outcomes.

3.5.1 Defining the existing farm system and performance

Using this whole farm model, a number of performance measurements are required to enable measurement of growth in wealth (change in equity), liquidity (net cash flow) and efficiency (return on assets managed). Based on Malcolm et al. (2005), the method used in this paper to analyse production data and business profitability is presented in Table 3.1.

Each of the business efficiency measures can be defined as follows:

Gross margin is the gross income resulting from the productive activity minus the variable costs incurred in generating that activity through the course of a production period. The gross margin represents the total available money to cover the overhead costs and achieve an operating profit. For this case study, the gross margin is formed by
the sales of animal products and the livestock trading profit (sales of animals produced, deaths, replacement costs and the difference between the values of the animals as they change categories through the analysed year).

Table 3.1: Calculating business efficiency

<table>
<thead>
<tr>
<th>Business Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production = Price per unit of output x Quantity of units + Inventory change = Gross Farm Income</td>
</tr>
<tr>
<td>Gross farm income – Variable costs = Gross Margin</td>
</tr>
<tr>
<td>Gross Margin – Overhead costs – Depreciation = EBIT (Earnings before Interest and Tax)</td>
</tr>
<tr>
<td>EBIT – Interest and Lease costs = Net Farm Income</td>
</tr>
<tr>
<td>Net Farm Income – Tax – Consumption above operators’ allowance = Growth (Increase in Equity)</td>
</tr>
</tbody>
</table>

To estimate the livestock trading profit, it is necessary to develop a livestock trading schedule which contains critical information about the flock or herd according to the animals’ categories at the start and at the end of the production year. The livestock trading schedule includes information such as numbers of animals according to their category, monetary value of each type, number of births, deaths, purchases and sales.

Variable costs are those costs which vary as the output of the activity varies. Any animal activity includes feed, husbandry, animal health, and sales/marketing costs.

Earnings before interest and taxes (EBIT) represent the return of the capital used in the business before paying interests and taxes. EBIT, which is also called operating profit, is defined as the total gross margin minus overhead costs and depreciation. Overhead costs are those costs that do not change when small changes in the level of production are made. Examples of overhead costs are permanent labour, administration, insurance, fees, vehicles and fuel. Depreciation is the cost associated with the obsolescence and loss of value of capital assets. There are several methods to depreciate capital items; the
straight-line method which assumes that an item is depreciated the same amount each year is used in this analysis.

Net farm income, also called net profit, is calculated as the operating profit minus interests and lease costs. After accounting for consumption and taxes paid, the remaining profit represents the increase in wealth, also called equity.

The growth in equity is also represented on the balance sheet. The balance sheet records the total value of the assets and liabilities of the business. Both assets and liabilities can be classified according to their liquidity: current, intermediate and fixed. The difference between the opening and closing values shows the growth in equity.

Finally, return on assets managed is the indicator of economic efficiency for evaluating new investments on farm (Makeham and Malcolm 1993). Return on assets indicates the overall earning of the total farm assets, irrespective of the capital structure of the business.

Given this study is concerned about the question of whether farms with well-developed AMS technologies can be as competitive as farms with conventional milking systems, additional changes to the farm system over time were not incorporated. Should these development scenarios be considered, a discounted cash flow analysis could be undertaken to compare these changes. This would require developing whole farm budgets over a long period (e.g. 10 years), to assess the different options. The benefits and costs, received or incurred in the future, would be discounted to adjust future net benefits from an investment to today’s dollars enabling a comparison between different ways of operating the farm. After this, the net present value (NPV) which is the sum of the discounted values of future income and costs, would be calculated to determine whether the investment or change to the farm earns more than the discount rate.

3.5.2 Sensitivity analysis
Sensitivity analysis was undertaken in the whole farm budgets to assess the effects of business risk. The key variables of milk price, grain price, milker hay feed price and
pasture consumption was analysed to understand the impact of its variability on the case studies operating profit.

A scenario analysis was conducted for the lowest 10% and 25% of outputs, as well as the highest 25% and 10% of outputs. This type of output scenario analysis generated an understanding of how a single variable, and importantly, combinations of variables drive operating profits at the lowest and highest scenarios.

Further, a tornado graph (used for deterministic sensitivity analysis) was presented to visually see the impact of a one standard deviation change of a key variable on the operation’s return on assets. Although, this only presents a ‘static’ picture where the level of one parameter is changed and the other components of the system are held constant.

3.5.3 Risk analysis
Risk analysis in whole farm budgets aim to incorporate, test and quantify the effects of business risk on a case study farm. When assessing risk to the case study farm, risk was dealt with as business risk and financial risk. Business risk refers to the risk independent of how a business is financed such as production risk, personal risk price risk and institutional risk. Financial risk refers to the risk to the liquidity and viability of the business, depending on the level of debt and equity (gearing). Financial risk also involves risks associated with credit such as when interest rates may rise unexpectedly.

The farm management methods for economic and risk assessments are taken from Makeham and Malcolm (1993). For this analysis, the Excel add-in @Risk (Corporation, 2007) is used through application of stochastic simulation techniques (Hadar and Russell, 1969, Hanoch and Levy, 1969). This type of model is similar to deterministic models in that it represents relationships between inputs and outputs of a system. The key difference is that the selected variables or relationships in the stochastic model include stochastic or random components, represented by probability distributions in order to reflect uncertainty of the system (Vose, 2008, Hardaker et al., 2004). In @Risk, Monte Carlo sampling is used to select values from a specified input distribution. A
single output that is a result of a set of random numbers drawn from the input distribution is called an iteration. Many iterations together allow for a distribution of the output variables of interest to be constructed.

**Monte Carlo sampling method**

A cumulative distribution function $F(x)$ is a function that gives the probability $P$ that the variable $X$ will be less than or equal to $x$. That is:

$$F(x) = P(X \leq x) \quad (3.1)$$

Where $F(x)$ represents a range between zero and one. For example, in Figure 3.1, the cumulative distribution function demonstrates a cumulative probability $F(x)$ of 0.6 for a random variable $X$ less than or equal to $x$.

![Figure 3.1: Figure of the cumulative distribution function, showing the relationship between $x$ and $F(x)$.

Equation 3.1 can also be viewed in reverse; what is the value of $F(x)$ for a given value of $x$. This is represented in the inverse of the function:

$$G(F(x)) = x \quad (3.2)$$
Figure 3.2 shows the relationship between $F(x)$ and $G(x)$. The inverse function is used to generate values of $x$ from each distribution in a model.

By selecting a random number from uniformly distributed values $r$, between zero and one, a probability distribution can be generated. In theory, this provides equal opportunity for all values of $r$ between zero and one. The value $r$ is then put back into Equation 3.2 for $F(x)$:

$$G(r) = x$$ \hspace{1cm} (3.3)

Samples are chosen randomly across the distribution and with a sufficient number of iterations, the Monte Carlo simulation will recreate the distribution when convergence is approached. For highly skewed distributions, a large number of iterations are required to avoid under or over sampling certain parts of the distribution. The Latin hypercube sampling method can help to overcome this problem (Vose, 2008, Hardaker et al., 2004).

In the farming business, it is important to recognise that risk and uncertainty is inherently a part of its operating environment. Undertaking sensitivity analysis is therefore important to identify the key variables that need be closely monitored to
enable operational and tactical decisions to be made, with an understanding of the impact on key measures of performance.

There are a number of techniques that can be used to incorporate and estimate risk. For example, using optimistic and pessimistic estimates of future uncertain variables and calculating the returns; changing a number of key variables and assigning probabilities on the scenario occurring; and assigning probability distributions to uncertain variables based on historical data and expected future data which can be used in conjunction with simulation techniques to assess a range of likely results.

3.5.4 Assumptions used in the economic analysis

**Labour**
In the economic analysis, labour and management costs were included based on industry award conditions of employment and market wage rates and discussions with the project steering committee. The total number of hours spent on the case study dairies were collected from the operator. In the analysis, this was used to compare with farmers across the Gippsland and Tasmania region that have conventional milking systems that are based on common industry relationships between size of operation and hours and standards of labour and management required.

The dollar cost of labour and management are presented in each of the case study chapters and reflect the type of labour required to operate a more complex AMS farm system.

**Interest and inflation**
The distributions for prices were adjusted for inflation using the consumer price index (CPI) for all groups retrieved from the Australian Bureau of Statistics website. The interest rate applied for loans was charged at a nominal rate of 7% per annum.

**Tax**
It was assumed that the marginal tax rate was charged at 15% in the marginal dollar.
Depreciation and salvage values
The straight line method for depreciation was used for the equipment with the salvage value being 10% of the original value at the end of its depreciable life. The number of years which new capital and infrastructure were depreciated for each case study is listed in the case study chapters.

3.5.4.1 Assumptions used in the economic analysis for Case Study 1 - Gippsland
In order to take into account the risk and uncertainty for key input variables, probability distributions were developed for milk price, grain price, hay price and pasture utilisation taking into account environmental conditions and management options.

Milk price
The international supply and demand and exchange rates are the key determinants of milk prices in Victoria. For case study 1, milk prices were retrieved from the Dairy Industry Farm Monitor Program (DIFMP) for the Gippsland region over the course of 9 years between 2006-07 and 2014-15, each year consisting of approximately 25 dairy farms (refer to Figure 3.3).

![Figure 3.3: Average yearly milk prices received per kilogram of milk solids in Gippsland in 2011-12 dollars (Dairy Industry Farm Monitor Project)](image-url)
While each farmers’ milk price is determined by the composition of milk that is produced, the data points of prices across the Gippsland region each year for milk prices (adjusted to 2011-12 dollars) was used as the basis for developing a probability distribution for milk price. Using the software @Risk (Palisade 2007) to fit a distribution over the dataset, a BetaGeneral distribution function was fitted, the mean was $5.65/kgMS and standard deviation $0.92/kgMS (Figure 3.4). No correlation was used between milk price and any other input. For this distribution, a minimum price can be determined ($3.00/kgMS) from the fitting process, while the maximum price remains unbounded and prices as high as $7.14/kgMS (in 2011-12 dollars) could be experienced in 5 of 100 years.

Figure 3.4: Milk price distribution in 2011-12 dollars

Table 3.2: Key percentiles for milk price

<table>
<thead>
<tr>
<th>Milk Price</th>
<th>$ per kg protein + fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>2% Lowest 2 years in 100</td>
<td>3.81</td>
</tr>
<tr>
<td>5% Lowest 5 years in 100</td>
<td>4.10</td>
</tr>
<tr>
<td>25% Lowest 25 years in 100</td>
<td>4.97</td>
</tr>
<tr>
<td>50% Most Common</td>
<td>5.6</td>
</tr>
<tr>
<td>75% Highest 25 years in 100</td>
<td>6.34</td>
</tr>
<tr>
<td>95% Highest 5 years in 100</td>
<td>7.14</td>
</tr>
</tbody>
</table>
Assumptions:

- A BetaGeneral distribution was used for this curve.
- The distribution had a mean milk price of $5.65/kgMS, standard deviation $0.92/kgMS and minimum price $3.00/kgMS.
- The milk price was based on that for an export-oriented factory.

Concentrates

The price of concentrates collected in the DIFMP includes whole and crushed grains, mixes, minerals, buffers, vitamins and pellets. It does not include by-products such as citrus and almond pulp. The concentrate prices used reflect the prices of grain mixers across the Gippsland region. Using @Risk, it was identified that the RiskGamma distribution function was suited with a mean of $387/tDM and standard deviation $72/tDM. This includes DIFMP data from 2006-07 to 2014-15, excluding 2007-08 where concentrate prices were significantly inflated by prolonged dry conditions.

Figure 3.5 Grain prices in 2011-12 dollars
Table 3.3: Key percentiles for grain price

<table>
<thead>
<tr>
<th>Grain Price</th>
<th>$/t air dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>2% Lowest 2 years in 100</td>
<td>273</td>
</tr>
<tr>
<td>5% Lowest 5 years in 100</td>
<td>289</td>
</tr>
<tr>
<td>25% Lowest 25 years in 100</td>
<td>335</td>
</tr>
<tr>
<td>50% Most Common</td>
<td>377</td>
</tr>
<tr>
<td>75% Highest 25 years in 100</td>
<td>427</td>
</tr>
<tr>
<td>95% Highest 5 years in 100</td>
<td>520</td>
</tr>
</tbody>
</table>

Assumptions:
- Grain was assumed to have an average MJ of ME per kg DM of 13.
- A Lognormal distribution was used for this curve.
- No correlation was included between grain prices and any other input.

Hay price

Hay price is influenced by both grain and water availability. In case study 1, the amount of metabolisable energy obtained from hay (through the outblock) represented only 2 per cent of whole farm energy requirements and is therefore not a major part of the feed system. For the purposes of modelling, hay is purchased when there is a gap in energy requirements and sold when there are excess energy requirements for the number of livestock being held.

The hay prices were collected from farms participating in the DIFMP between 2006-07 to 2014-15, excluding 2007-08 where hay prices were also significantly inflated by prolonged dry conditions.
Figure 3.6: Hay price in 2011-12 dollars

Table 3.4: Key percentiles for hay price

<table>
<thead>
<tr>
<th>Hay price</th>
<th>$/t air dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>2% Lowest 2 years in 100</td>
<td>97</td>
</tr>
<tr>
<td>5% Lowest 5 years in 100</td>
<td>117</td>
</tr>
<tr>
<td>25% Lowest 25 years in 100</td>
<td>178</td>
</tr>
<tr>
<td>50% Most Common</td>
<td>229</td>
</tr>
<tr>
<td>75% Highest 25 years in 100</td>
<td>282</td>
</tr>
<tr>
<td>95% Highest 5 years in 100</td>
<td>360</td>
</tr>
</tbody>
</table>

Assumptions:
- A Weibull distribution was used.
- Correlation between hay price and pasture consumption of -35% was used.

Pasture consumption
Pasture utilisation is affected by a range of factors including the type of grazing animal, water and nutrient dynamics, animal physiology and production and a range of options for pasture management, irrigation and fertiliser application (Johnson et al., 2008).

Grazed pasture consumption was estimated by using the method of back calculation. It needs to be noted that this calculation method could have a number of sources of error including incorrect estimation of liveweight, amounts of fodder and concentrates fed,
ME concentration of fodder and concentrate, ME concentration of pasture, wastage of feed and associative effects between feeds when they are digested by the animal. This is why it is best to compare pasture consumption on the same farm over time using the same method of estimation.

It is important to note that the long-term ME supply from pasture includes both the milking area and non-milking area (outblock) where the ME requirements of dry stock are also considered in the whole farm system.

![Figure 3.7: Metabolisable Energy supply from pasture](image)

Table 3.5: Key percentile yields for pasture consumption on milking area and outblock

<table>
<thead>
<tr>
<th>Pasture Consumption</th>
<th>t DM/ha consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2% Lowest 2 years in 100</td>
<td>4.3</td>
</tr>
<tr>
<td>5% Lowest 5 years in 100</td>
<td>4.4</td>
</tr>
<tr>
<td>25% Worst 25 years in 100</td>
<td>5.0</td>
</tr>
<tr>
<td>50% Most Common</td>
<td>5.6</td>
</tr>
<tr>
<td>75% Highest 25 years in 100</td>
<td>6.3</td>
</tr>
<tr>
<td>95% Highest 5 years in 100</td>
<td>7.6</td>
</tr>
<tr>
<td>100% Highest 2 years in 100</td>
<td>13.5</td>
</tr>
</tbody>
</table>

Assumptions:
- A RiskExtValue distribution was used.
Where excess ME is produced, additional hay is conserved and sold. It is valued at the price of hay in that year minus cost of conservation ($120/t).

Where insufficient ME is produced, additional milker quality hay is purchased and fed out.

Correlation between pasture consumption and hay price of -35% was used.

The average long-term pasture consumption for just the milking area is 8.6 tDM/ha.

3.5.4.2 Assumptions used in the economic analysis for Case Study 2 – Tasmania

**Milk price**

The milk price for Tasmania was collected from Dairy Australia from data from the 1991/92 to 2014/15 year. The price data was provided from internal Dairy Australia personnel.

![Figure 3.8: Milk price in 2015-16 dollars](image)

**Table 3.6: Key percentiles for milk price**

<table>
<thead>
<tr>
<th>Milk Price</th>
<th>$ per kg protein + fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>Lowest 2 years in 100</td>
</tr>
<tr>
<td>5%</td>
<td>Lowest 5 years in 100</td>
</tr>
<tr>
<td>25%</td>
<td>Lowest 25 years in 100</td>
</tr>
<tr>
<td>50%</td>
<td>Most Common</td>
</tr>
<tr>
<td>75%</td>
<td>Highest 25 years in 100</td>
</tr>
<tr>
<td>95%</td>
<td>Highest 5 years in 100</td>
</tr>
<tr>
<td>100%</td>
<td>Highest 2 years in 100</td>
</tr>
</tbody>
</table>
Assumptions:
- No correlation was included between milk price and any other input.
- A beta-general curve was used for this distribution
- The milk price was based on that for an export-oriented factory.

**Grain prices**
Wheat prices were provided by Dairy Australia which collects the data from a private consultant, reflecting major port prices for Tasmania. The price is for per tonne of dry matter as delivered and the feed wheat moisture content cannot exceed 12.5% which is a standard across industry.

![Wheat prices in 2015-16 dollars](image)

**Figure 3.9: Wheat prices in 2015-16 dollars**

<table>
<thead>
<tr>
<th>Wheat Price</th>
<th>$/t delivered</th>
</tr>
</thead>
<tbody>
<tr>
<td>2% Lowest 2 years in 100</td>
<td>252</td>
</tr>
<tr>
<td>5% Lowest 5 years in 100</td>
<td>270</td>
</tr>
<tr>
<td>25% Lowest 25 years in 100</td>
<td>323</td>
</tr>
<tr>
<td>50% Most Common</td>
<td>374</td>
</tr>
<tr>
<td>75% Highest 25 years in 100</td>
<td>441</td>
</tr>
<tr>
<td>95% Highest 5 years in 100</td>
<td>571</td>
</tr>
<tr>
<td>100% Highest 2 years in 100</td>
<td>642</td>
</tr>
</tbody>
</table>

Assumptions:
- A Lognormal distribution was used.
No correlation was included between wheat prices and any other input.

**Hay**

The data collected for hay was the price of lucerne. This reflected high quality hay and the data was sourced from the Herald and Weekly Times hay prices (large squares and rolls).

![Figure 3.10: Hay price in 2015-16 dollars](image)

**Table 3.8: Key percentiles for hay price.**

<table>
<thead>
<tr>
<th>Hay price</th>
<th>$/t air dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>2% Lowest 2 years in 100</td>
<td>252</td>
</tr>
<tr>
<td>5% Lowest 5 years in 100</td>
<td>267</td>
</tr>
<tr>
<td>25% Lowest 25 years in 100</td>
<td>303</td>
</tr>
<tr>
<td>50% Most Common</td>
<td>326</td>
</tr>
<tr>
<td>75% Highest 25 years in 100</td>
<td>347</td>
</tr>
<tr>
<td>95% Highest 5 years in 100</td>
<td>374</td>
</tr>
</tbody>
</table>
3.6 SUMMARY OF APPROACH TO THE RESEARCH

As similarly noted by Sinnett (2004), the relevant theories of agricultural economics, capital, labour, finance and management about investment in new technology generally accord well with the experiences of dairy farmers in pursuing profit and growth. There have been no studies about AMS technology that has tried, under the framework of farm-system theory, to draw together the technical, logistics, management and human detail of dairy farm systems. Empirical analysis bringing together this whole dimension will allow investigation of the complexities and less obvious costs that are not well captured in established theory and literature. This will help to capture the ultimate extent to which adoption of AMS technology become reality.

To examine the economic performance and understand the potential of AMS technology in Australia’s pasture-based system, this research uses in depth case studies for two types of automatic milking systems that are commercially operating in both Victoria and Tasmania. The analysis of each case study was conducted in a way to ensure that it is able to meet the four tests of logic for assessing case studies (Yin 1994). These are:

1. Construct validity - numerous information sources were used to construct the case study. This includes data obtained from the farmer, farm records, production data and the steering committee.
2. Internal validity – results were constantly presented to the case study farmer and the steering committee to ensure that the assumptions made were reasonable and ‘passed the test of common sense’.
3. External validity – where possible the data was abstracted to remove extreme anomalies specific to each farm case study and to ensure that a more representative farm was modeled.
4. Reliability – the analysis and modelling spreadsheets are well documented and draws on existing modelling methods that are well founded in literature.

In the next chapter, the analysis of the economic performance of the automatic milking system in Gippsland are presented, while similar analyses for the automatic milking rotary system in Tasmania are documented in Chapter 5.
3 Case study 1 – Gippsland automatic milking system

3.1 INTRODUCTION
A case study farm analysis was used to assess the economic performance of adopting novel milking technology, namely, an automatic milking system (Mcwilliams et al., 1998). This case study farm in Gippsland was chosen because it was a well-managed, owner operated farm, had good records, had a representative herd size and was a typical dryland enterprise with no more than 40% purchased supplements. Physical and financial information for the 2011-12 financial year was collected by interviewing the farm owner and using the farmer’s Dairy Industry Farm Monitor Project (DIFMP) data to analyse the AMS farm operation. This data was used to build the whole farm model of the business.

Interviews with the farm owner established that the 2011-12 financial year was a reasonable representative year of the farm operating in a steady state. This is 3 years after adoption of the AMS, where the new automatic milking technology had been successfully implemented and the benefits of the AMS are being realised. The aim of the case study was to examine the economic and financial feasibility of a novel technology (AMS milking) compared with conventional methods of milking in the Gippsland region. It should be noted that this study does not endeavour to determine the costs of the technology adoption or any underperformance that might be encountered in the initial months/years of adoption (whilst the herd becomes established and the operators gain experience).

3.2 CASE STUDY FARM DESCRIPTION

4.2.1 Location, land and history
The case study farm was located in Hallora, approximately 110km east from Melbourne. The owner purchased the 135 ha block of land in 1996 as an undeveloped farm which had a 10-unit walk through dairy. In 1998, the farmer invested in extensive upgrades and installed a 40-unit rotary dairy with improved laneways, larger cow yards, new milk
vats, an automatic feed system and cup removers which could milk over 300 cows. In 2011-12, the farmer milked 280 Holsteins through the rotary dairy.

After operating the rotary dairy for about 10 years, the farmer contemplated milking more cows. Major goals of the farmer were to increase flexibility and not employ any additional labour. Further, a satisfactory work and life balance was an important consideration in any expansion. In 2008, the 68 ha neighbouring property was purchased and an automatic milking system (Mcwilliams et al., 1998) was established on this new property. This farm operated independently alongside the farmers existing dairy operation. The farm area devoted to the AMS farm herd was 102 ha, of which 68 ha was owned by the farmer and 34 ha was leased on a 12-monthly basis. Of this area, 65 ha was available for grazing by the milking herd only and the 34 ha leased outblock was used for grazing dry cows and young stock.

The purchased neighbouring property already had an existing 20-unit swingover herringbone dairy. However, the farm owner decided to install the Lely A3 AMS as using the existing dairy would require increased labour. The Lely A3 AMS is a model of AMS robot released by Lely in 2005.

The sections to follow in this report pertain to the AMS business. The conventional business will not be considered in the analysis, however may be referred to in the discussion sections where the conventional business may have complemented the AMS operation. In Figure 4.1 Figure is a representation of both farm businesses; the focus in this analysis is on the AMS business represented on the right-hand-side of the Figure.
Figure 4.1: Schematic representation of the conventional and AMS farm business

Soil
The farm consisted of clay loam type soil with low pH and high phosphorus levels. The AMS farm area is characterised by:

- Landform: Rolling low hills
- Geology: Tertiary (early) sediments, pre basalt; and
- Dominant soils: Acidic yellow dermosols.

The fertiliser application rates per hectare for the 2011-12 year are presented in Table 4.1:

Table 4.1: Fertiliser application rates for the AMS farm (2011-12)

<table>
<thead>
<tr>
<th>Type</th>
<th>Nitrogen (N)</th>
<th>Phosphorus (P)</th>
<th>Potassium (K)</th>
<th>Sulphur (S)</th>
<th>Tonnes Applied per hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime (%)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>50</td>
</tr>
<tr>
<td>Chicken manure (%)</td>
<td>3.7</td>
<td>1.7</td>
<td>1.6</td>
<td>0.1</td>
<td>160</td>
</tr>
<tr>
<td>Total (kg)/ha</td>
<td>592</td>
<td>272</td>
<td>256</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>
4.2.2 Infrastructure and plant
Reconfigurations and upgrades to the farm layout were needed to customise the farm for AMS operation. The major plant and equipment procured included 2 tractors, sowing equipment, feed out equipment, excavator, material for laneway improvement, glycol chiller and three AMS milking robot units which included individual cow electronic transponder equipment.

A feed pad was also constructed to reduce wastage when feeding hay and silage, and was available to the cows prior to milking.

4.2.3 Labour
This family owned and predominantly family operated AMS business required 0.7 full time equivalent (FTE) labour units (where 1 labour unit refers to 50 hours of labour per week). The owner (in this case the farm manager) accounted for approximately 25 hours per week, other family members contributed about 6 hours per week and there was 4 hours per week of employed casual labour.

The imputed labour cost for the owner was $40,000 and was calculated based on a farm manager salary of $80,000 per annum. The imputed labour cost for family labour was calculated on a farm-hand salary of $50,000, and amounted to $6,000. The cost of the employed farm-hand labour was calculated in a similar way and equated to $4,000 per annum. Contractors were used for silage production, some spraying, seeding, hay production, tractor servicing, pregnancy testing and veterinary work. These costs were included in the figures used for the analysis of the farm.

For both case studies, industry standard salary figures are used and the differences in both case studies reflect factors including the herd size, complexity of farm system, and role responsibilities etc.

4.2.4 Pasture
Most of the milking area was sown to perennial ryegrass pastures. When these pastures began to thin, they are over-sown with ryegrass. Depending on the renovation cycle, a
paddock would be over-sown with annual, hybrid, or perennial ryegrass. Of the 102 ha of grazing area, 65 ha was milking area and 32.5 ha was also used for cutting silage and hay in most years.

The farm manager had chosen to operate the AMS with a 3-way grazing management system to help gain more regular and predictable cow traffic and improved grazing management, compared to two-way grazing (Lyons and Kerrisk, 2012). A 3-way grazing system gives cows three pasture allocations within each 24-hour period rather than the standard two allocations that would normally be provided in a twice-a-day conventional milk harvesting system. The 3-way grazing system could involve three fresh breaks of pasture a day, or two pasture breaks and a feedpad allocation (with a loafing area) depending on the pasture availability at different times of the year.

There are a number of potential benefits from adopting this type of grazing system compared with traditional systems such as increased average milk production, increased milking frequency, reduced milking intervals, reduced variation in milking intervals and improved utilisation of the AMS unit. For this farm, 3-way grazing was the preferred management strategy to create the target levels of milking frequency by motivating the cows to move regularly and voluntarily around the farm.

The proportion of the daily pasture allocations made available in each of the three paddocks/areas are able to be varied in order to shift the timing of cow traffic in an attempt to flatten distribute milkings across the day and thereby minimise times of congested cow traffic at the dairy. Such strategies are also used to increase the number of milkings that might occur during less popular periods. An example of pasture allocation adopted on the case study farm is given below. It should be noted that this was not held constant during the data collection period but was modified by the farm manager to suit seasonal conditions, work routines, and to accommodate normal management practices.

- Section A available to all cows exiting the dairy between 11:30am – 7:30pm;
- Section B available to all cows exiting the dairy between 5:00am – 11:30am; and
Section C available to all cows exiting the dairy between 7:30pm – 5:00am.

4.2.5 Livestock

To set up a ‘steady state’ farm system for modelling purposes, milk production and the herd structure were kept constant from year-to-year. In 2011-12, the milking herd comprised of 100% Holsteins for the AMS herd and the average live weight of a mature Holstein was estimated to be 640 kg. A concentrated Spring calving was used. The herd commenced calving on 1st August and each year there was a small proportion of carryover cows. The average lactation length was 305 days for both first calvers and mature milkers. In a typical year, the number of heifer calves reared was about 25% of the milking herd. This information was used to generate the following below to describe the herd structure and movement of cows to maintain a steady-state herd:

- 40 heifers and 130 mature cows calved in spring each year.
- The death rates were: calves 3%, cows and heifers 2%.
- The age group cull rates were: 5-6 year olds 25%, 6-7 years old 100%.
- There were 3 bulls, with 1 replaced each year.

In 2011-12, the milking herd consisted of 170 cows milked for the majority of the lactation. This equated to a stocking rate of around 2.6 cows per hectare on the milking area. The herd structure for the case study farm for the 2011-12 year is presented in Table 4.2. The livestock trading for maintaining a steady herd is presented in Table 4.3.

Table 4.2: Herd structure for case study (2011-12)

<table>
<thead>
<tr>
<th>Stock class</th>
<th>Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiparous cows</td>
<td>130</td>
</tr>
<tr>
<td>Primiparous cows</td>
<td>40</td>
</tr>
<tr>
<td>Cull Cows</td>
<td>45</td>
</tr>
<tr>
<td>Calves sold</td>
<td>124</td>
</tr>
<tr>
<td>Cow Purchases</td>
<td>6</td>
</tr>
<tr>
<td>Cow Deaths</td>
<td>2</td>
</tr>
<tr>
<td>End Milkers</td>
<td>170</td>
</tr>
<tr>
<td>Calves (0-1y/o)</td>
<td>41</td>
</tr>
<tr>
<td>Heifers (1-2y/o)</td>
<td>41</td>
</tr>
<tr>
<td>Bulls – start season</td>
<td>3</td>
</tr>
<tr>
<td>Bulls – end season</td>
<td>3</td>
</tr>
</tbody>
</table>
### Table 4.3: Livestock trading

<table>
<thead>
<tr>
<th>Item</th>
<th>No.</th>
<th>$/head</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Opening Number:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 year old heifers</td>
<td>41</td>
<td>550</td>
<td>22,550</td>
</tr>
<tr>
<td>Stock Class</td>
<td>40</td>
<td>1,100</td>
<td>44,000</td>
</tr>
<tr>
<td>1st lactation cows (heifers)</td>
<td>32</td>
<td>1,100</td>
<td>35,200</td>
</tr>
<tr>
<td>2 year old Breeding cows</td>
<td>32</td>
<td>1,100</td>
<td>35,200</td>
</tr>
<tr>
<td>3 year old Breeding cows</td>
<td>33</td>
<td>1,100</td>
<td>36,300</td>
</tr>
<tr>
<td>4 year old Breeding cows</td>
<td>33</td>
<td>1,100</td>
<td>36,300</td>
</tr>
<tr>
<td>5 year old Breeding cows</td>
<td>3</td>
<td>900</td>
<td>2,700</td>
</tr>
<tr>
<td><strong>Purchases:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mature cows</td>
<td>6</td>
<td>1,920</td>
<td>11,520</td>
</tr>
<tr>
<td>Bulls</td>
<td>1</td>
<td>1,500</td>
<td>1,500</td>
</tr>
<tr>
<td><strong>Births:</strong></td>
<td>170</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sales:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cull cows</td>
<td>45</td>
<td>700</td>
<td>31,500</td>
</tr>
<tr>
<td>Calves</td>
<td>124</td>
<td>50</td>
<td>6,138</td>
</tr>
<tr>
<td>Bulls</td>
<td>1</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td><strong>Deaths</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calves</td>
<td>5</td>
<td>40</td>
<td>200</td>
</tr>
<tr>
<td>Cows</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heifers</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Closing number:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 year old heifers</td>
<td>41</td>
<td>550</td>
<td>22,550</td>
</tr>
<tr>
<td>2 yo Milkers &amp; dry cows</td>
<td>41</td>
<td>1,100</td>
<td>45,100</td>
</tr>
<tr>
<td>3 yo Milkers &amp; dry cows</td>
<td>40</td>
<td>1,100</td>
<td>44,000</td>
</tr>
<tr>
<td>4 yo Milkers &amp; dry cows</td>
<td>32</td>
<td>1,100</td>
<td>35,200</td>
</tr>
<tr>
<td>5 yo Milkers &amp; dry cows</td>
<td>32</td>
<td>1,100</td>
<td>35,200</td>
</tr>
<tr>
<td>6 yo Milkers &amp; dry cows</td>
<td>25</td>
<td>1,100</td>
<td>27,500</td>
</tr>
<tr>
<td>Bulls</td>
<td>3</td>
<td>900</td>
<td>2,700</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>391</td>
<td></td>
<td>212,250</td>
</tr>
<tr>
<td>Non-cash profit/loss</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash from Sales</td>
<td>37,138</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stock Trading Profit/Loss</td>
<td>37,138</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 4.2.6 Milk production

On the AMS farm, cows produced an average of 7,344 L of milk per cow in the 2011-12 year, and 532 kg per cow of milk solids. This amounted to 90,427 kilograms of milk solids (kgMS) for the farm system. The production data for the case study farm in 2011-12 is presented in Error! Reference source not found.
Table 4.4: Production data for case study farm in 2011-12

<table>
<thead>
<tr>
<th></th>
<th>Case study actual data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total milk production (L) #</td>
<td>1,248,402</td>
</tr>
<tr>
<td>Total milk fat production (kg)</td>
<td>49,761</td>
</tr>
<tr>
<td>Total milk protein production (kg)</td>
<td>40,667</td>
</tr>
<tr>
<td>Milk fat</td>
<td>3.99%</td>
</tr>
<tr>
<td>Milk protein</td>
<td>3.26%</td>
</tr>
<tr>
<td>Average milk production per cow (L/cow)</td>
<td>7,344</td>
</tr>
<tr>
<td>Average milk fat production per cow (kg/cow)</td>
<td>293</td>
</tr>
<tr>
<td>Average milk protein production per cow (kg/cow)</td>
<td>239</td>
</tr>
<tr>
<td>Stocking rate (kg liveweight/ha)</td>
<td>1,664^</td>
</tr>
</tbody>
</table>

#Total Factory Milk – Does not include saleable milk fed to calves  
^ calculated based on estimated liveweight of culled cows

Figure 4.2 shows that the production curves for milk protein and fat follow a similar pattern to the overall milk production, with seasonal variation in output. The protein-to-fat ratio was generally highest in the middle of spring.

(*BF = butterfat; and Pro= protein)  
Figure 4.2: Total monthly milk production for the case study farm in 2011-12

4.2.7 Feed/diet

Milking cows
In the 2011-12 year, the first calvers and mature milkers grazed the milking area for approximately 305 days as a lactating herd, and 20 days as a dry herd. The herd also
spent 40 days when dry on the non-milking leased area. The annual ME supplied from supplementary feeds and pastures varied across the season. Within this, each stock class and the times the cows calve determined the distinct ME requirements for each month, and the changes throughout the year.

The estimated sources of metabolisable energy for the whole farm is presented in Figure 4.3. This is also represented as tonnes dry matter (DM) on a per cow basis in Figure 4.3.

In 2011-12, approximately 60 per cent of stock ME requirements were met by grazed pasture. In modelling the farm system, it was assumed that the opening and closing feed inventories for the farm were zero. This means that all feed produced on farm or purchased was used during the year and any excess fodder produced was sold at market rates.

![Figure 4.3: Estimated sources of whole farm metabolisable energy (John et al.)](image-url)
Pasture Consumption

Apparent pasture consumption in the milking area was estimated based on actual milk production and associated energy requirements (using livestock ME required and ME from purchased feed). The total energy for all stock was 13,343,429 MJ ME. This was made up of 4,949,000 MJ ME from supplements and the remaining 8,395,429 MJ ME from pasture.

Estimated annual pasture consumption from the 65 ha milking area was approximately 551 tDM (or 8.5 tDM/h). In addition to this, 44 tDM of hay was conserved from the milking area. This meant that the milking area provided around 52 per cent of the ME consumed by the entire herd (milking herd, young and dry stock, and bulls) with a total energy requirement of 12,393,618 MJ ME. The total fodder consumed per year for the milking area was 595 tDM (grazed pasture and conserved hay) equating to 9.1 tDM/ha/yr.

After including the 32.5 ha of non-milking leased land to the 65 ha of milking area (bringing the total usable area to 97.5 ha), the total ME from ‘home-grown’ feed increased to 66 per cent of the energy consumed by the entire herd. The total pasture consumed per year for the total grazing area was 682 tDM equating to 7.9 tDM/ha/yr.
This indicates that less pasture was consumed from the outblock area (non-milking area). The amounts of different feed consumed are shown on Table 4.5 and the energy required on-farm is presented in Table 4.6.

Table 4.5: Energy and feed types utilised on-farm, 2011-12

<table>
<thead>
<tr>
<th>2011-12</th>
<th>2011-12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Milking area = 65ha</td>
</tr>
<tr>
<td>Energy from home grown feed</td>
<td>52%</td>
</tr>
<tr>
<td>Energy from purchased feed</td>
<td>48%</td>
</tr>
<tr>
<td>Amount of Feed Consumed (t DM/cow)</td>
<td>6.5</td>
</tr>
<tr>
<td>Pasture + home grown silage (t DM/cow)</td>
<td>4.0</td>
</tr>
<tr>
<td>Grain (t DM/cow)</td>
<td>2.06</td>
</tr>
<tr>
<td>Purchased Silage + straw (t DM/cow)</td>
<td>0.25</td>
</tr>
<tr>
<td>Pasture Consumption (t DM per hectare)</td>
<td>9.1</td>
</tr>
</tbody>
</table>

* assumes ME of pasture = 11.0 MJ/kg DM

Table 4.6. Energy requirements for the farm herd

<table>
<thead>
<tr>
<th>Stock class</th>
<th>Requirement (MJ ME)</th>
<th>% of total on farm ME requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calves</td>
<td>325,124</td>
<td>3%</td>
</tr>
<tr>
<td>Heifers 24-36 months (1st lactation)</td>
<td>2,407,034</td>
<td>19%</td>
</tr>
<tr>
<td>Heifers 24-36 months (dry)*</td>
<td>248,310</td>
<td>2%</td>
</tr>
<tr>
<td>Mature cows (&gt;2 lactations)</td>
<td>8,480,525</td>
<td>68%</td>
</tr>
<tr>
<td>Mature cows (dry)*</td>
<td>167,265</td>
<td>1%</td>
</tr>
<tr>
<td>Yearlings (1-2 years)</td>
<td>694,280</td>
<td>6%</td>
</tr>
<tr>
<td>Bulls</td>
<td>71,080</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td><strong>12,393,618</strong></td>
<td></td>
</tr>
</tbody>
</table>

* assumes dry period of 60 days

The average ME concentration of perennial pasture across the year was estimated at 11 MJ/kg DM (Cohen and Doyle, 2000). This figure was used to back-calculate the amount of pasture consumed. The estimated pasture consumed should not be used as an estimation of pasture grown as it does not take into account wastage or unutilized pasture. It is important to note that this is only an estimate and that pasture utilization levels are also influenced by factors including rainfall, herd size, grazing management and fertiliser application.
For the months from around May to July, the total ME requirements of the herd declines as the milking herd is progressively dried off. Following an approximately 60 day dry period, the herds ME requirements increases as the cows calve and recommence lactation. This coincides with the typical seasonal pasture growth flush that occurs during Spring when pasture supply is generally higher than pasture demand which allows surplus pasture to be ‘shut up’ for later conservation as hay and/or silage. During November to December soil moisture generally declines, pasture growth slows, and conserved forages are fed to the herd to supplement the pasture that is available. This helps to maintain dry matter intake and milk production through the periods when pasture is limiting.

**Economic performance**

As noted, the biophysical and economic performance of the AMS farm is analysed in isolation to the entire business which includes the conventional 40-unit rotary. The economic performance of the farm for 2011-12 is summarised in Table 4.7. The economic performance results were calculated using actual data (prices, costs and volumes) collected from the farm.

In 2011-12, Gippsland farmers experienced a similar farmgate price of $5.71/kgMS compared to the long-term average of $5.64/kgMS. Further, lower feed costs and prolonged wet weather in parts of Gippsland also meant that the season started strong in terms of milk volume (currently Department of Economic Development, Jobs, Transport and Resources, 2011). When looking at modelled data of annual pasture consumption back to 1971, the 2011-12 year represented the highest annual pasture consumption year when all farms in the DIFMP for the Gippsland region recorded average annual rainfall. The above average rainfall, compared to long term average, meant the farm performed better than in a typical operating environment.

Despite the operational challenges associated with a very wet year, the case study farm recorded an annual return on assets of 7.23% from farming. The profit budget (Table 4.7), cash flow budget (Table 4.8), tax schedule (Table 4.9), and balance sheet (Table 4.10) are presented in Table 4.7.
Table 4.7: Profit budget for the case study farm in 2011-12.

<table>
<thead>
<tr>
<th>Gross Income</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk Receipts</td>
<td>$516,341</td>
</tr>
<tr>
<td>Stock Trading Profit/Loss</td>
<td>$37,138</td>
</tr>
<tr>
<td>Other income</td>
<td>$-</td>
</tr>
<tr>
<td><strong>Gross Farm Income</strong></td>
<td><strong>$553,479</strong></td>
</tr>
<tr>
<td>Less Total Variable Costs</td>
<td>$188,979</td>
</tr>
<tr>
<td><strong>Total Gross Margin</strong></td>
<td><strong>$364,500</strong></td>
</tr>
<tr>
<td>Less Total Cash Overhead Costs</td>
<td>$47,650</td>
</tr>
<tr>
<td>Less Operators Allowance</td>
<td>$40,000</td>
</tr>
<tr>
<td>Depreciation</td>
<td>$55,320</td>
</tr>
<tr>
<td><strong>Earnings before Interest and Tax (EBIT)</strong></td>
<td><strong>$221,530</strong></td>
</tr>
<tr>
<td>Less Interest and lease</td>
<td>$159,684</td>
</tr>
<tr>
<td><strong>Net Farm Income</strong></td>
<td><strong>$61,846</strong></td>
</tr>
<tr>
<td>Minus tax</td>
<td>$13,636</td>
</tr>
<tr>
<td><strong>Growth (increase in Equity)</strong></td>
<td><strong>$43,209</strong></td>
</tr>
</tbody>
</table>

Total Assets managed $3,062,730
Return on Assets (excl. cap apprec) 7.23%
Total assets owned (EQUITY) $315,368
Return on owner's equity (excl. cap apprec) 19.61%

NB. Land was valued at $19,853 per hectare ($8,083/acre)
^ Lease costs are included as a finance cost
Table 4.8: Cash flow budget for the case study farm in 2011-12

**Cash In**

<table>
<thead>
<tr>
<th>Cash In</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk Receipts</td>
<td>$516,341</td>
</tr>
<tr>
<td>Cash from Sales</td>
<td>$37,138</td>
</tr>
<tr>
<td>Other income</td>
<td>$-</td>
</tr>
<tr>
<td>Fodder sales</td>
<td></td>
</tr>
<tr>
<td><strong>Total Cash In</strong></td>
<td><strong>$553,479</strong></td>
</tr>
</tbody>
</table>

**Cash Out**

<table>
<thead>
<tr>
<th>Cash Out</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Costs-</td>
<td></td>
</tr>
<tr>
<td>Feed Costs</td>
<td>$155,017</td>
</tr>
<tr>
<td>Herd Costs</td>
<td>$17,576</td>
</tr>
<tr>
<td>Shed Costs</td>
<td>$16,386</td>
</tr>
<tr>
<td>Overhead Costs-</td>
<td></td>
</tr>
<tr>
<td>Repairs and Maintenance</td>
<td>$24,932</td>
</tr>
<tr>
<td>Administration</td>
<td>$12,718</td>
</tr>
<tr>
<td>Employed labour</td>
<td>$10,000</td>
</tr>
<tr>
<td>Leasing</td>
<td>$18,200</td>
</tr>
<tr>
<td>Estimated personal drawings</td>
<td>$45,000</td>
</tr>
<tr>
<td><strong>Total Cash Out</strong></td>
<td><strong>$299,829</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Net Cash Flow before Interest and Principle</th>
<th>$253,650</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest payments</td>
<td>$141,484</td>
</tr>
<tr>
<td>Principle Repayments</td>
<td>$43,923</td>
</tr>
<tr>
<td><strong>Net Cash Flow before tax</strong></td>
<td><strong>$68,243</strong></td>
</tr>
<tr>
<td>Tax payable</td>
<td>$(13,636)</td>
</tr>
<tr>
<td><strong>Net cash flow after tax</strong></td>
<td><strong>$54,607</strong></td>
</tr>
</tbody>
</table>

Table 4.9: Tax schedule for case study farm in 2011-12.

| Tax relevant income                   | $516,341  |
| less variable costs                  | $213,911  |
| less overhead costs (excluding operators allowance) | $68,038 |
| less investment into land deducted @10% per yr | $2,000  |
| less investment into plant and equipment deducted @ 20% per yr | $141,484 |
| less interest                         |          |
| **Total taxable income**              | **$90,908** |
| Marginal tax rate*                    | 15%      |
| **Tax payable**                       | **$13,636** |

*The rate chosen is to reflect the most likely average marginal rate.*
Table 4.10: Balance sheet for case study farm 2011-12.

<table>
<thead>
<tr>
<th>Start of year (opening)</th>
<th>End of year (closing)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Assets</strong></td>
<td><strong>Assets</strong></td>
</tr>
<tr>
<td>Owned land area value</td>
<td>$1,350,000</td>
</tr>
<tr>
<td>Total livestock value</td>
<td>$212,250</td>
</tr>
<tr>
<td>Plant and equipment</td>
<td>$771,200</td>
</tr>
<tr>
<td>Cash</td>
<td>$54,607</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$2,333,450</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Liabilities</strong></th>
<th><strong>Liabilities</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Loan</td>
<td>$2,021,200</td>
</tr>
<tr>
<td>Cash</td>
<td>$1,977,277</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$2,021,200</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Equity</strong></th>
<th><strong>Equity</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening equity (%)</td>
<td>13%</td>
</tr>
<tr>
<td>Closing equity (%)</td>
<td>15%</td>
</tr>
</tbody>
</table>

This balance sheet reflects only the AMS farm system. In reality, debt is being serviced from the farm owner’s entire business consisting of the 280 cow operation using the 40-unit rotary dairy and the AMS operation. This explains the low equity ratio that can be sustained for the AMS case study farm.

### 4.3 PERFORMANCE OF THE CASE STUDY SYSTEM UNDER A RANGE OF HISTORICAL PRICES, COSTS AND SEASONAL CONDITIONS

The economic and financial performance of the base farm system was also investigated under more typical conditions (refer to Table 4.11 for a summary).
Applying the long term average price paid for milk solids ($5.64/kg MS), and including commercial land lease rates, the case study farm would typically expect to achieve a return on total assets of 5.28%, excluding capital appreciation.

Table 4.11: Total gross income, operating profit (earnings before interest and tax, EBIT) and return to assets in 2011-12, and under long term average prices.

<table>
<thead>
<tr>
<th></th>
<th>2011-12 (Actual prices)</th>
<th>Mean outcome (long term average prices)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk Price ($/kgMS)</td>
<td>$5.71</td>
<td>$5.64</td>
</tr>
<tr>
<td>Milk Income</td>
<td>$516,341</td>
<td>$510,815</td>
</tr>
<tr>
<td>Feed Costs</td>
<td>$155,017</td>
<td>$209,304</td>
</tr>
<tr>
<td>Operating Profit (EBIT)</td>
<td>$221,530</td>
<td>$161,717</td>
</tr>
<tr>
<td>Return on Assets</td>
<td>7.23%</td>
<td>5.28%</td>
</tr>
</tbody>
</table>

4.3.1 Variability in performance of base farm system

The performance and risk associated with the case study farm system was also investigated under a range of possible futures for milk prices, feed wheat prices, hay prices and pasture consumption (capturing variability in rainfall experienced on the case study farm). This was carried out by using price and production distributions for these variables which were defined by historical records and industry expertise. For the case study, 10,000 iterations of annual operations were conducted with different costs, prices and levels of pasture production in each year. This combination of costs and prices selected each year generated a range of economic and financial results.

In farm business analysis, presenting these economic and financial results using a cumulative frequency distribution is effective for showing the ‘likelihood’, from 0 to 1 (y-axis), of different ‘outcomes’ occurring (x-axis). The y-axis can also be interpreted as a percentage chance of less or more than a particular outcome occurring.

Operating profit (Earnings Before Interest and Tax)

The cumulative frequency distribution for annual operating profit, using average prices and borrowing rates, is shown in Figure 4.5. This assumes that the farm system is managed in the same way continuously for the next 10 years, but experiences different prices, costs and pasture production between years based on the probability distributions. This provides an indication of the performance and risk associated with the base farm
system. From this scenario analysis, the mean annual operating profit for the current farm business was $161,760 per year. This result assumes that the case study farm business is in the steady state and the capital invested is performing at the expected fully operational level.

The results indicate that there is a large range in the possible outcomes for operating profit. However, in only 4 years out of 100 is the operating profit predicted to be less than $0. In 35 years out of 100, operating profit was greater than $200,000. In 60% of years (or 6 years in 10), operating profit should be between $81,157 and $243,332.

The analysis of the case study under long-term averages had the assumption that cow numbers and milk production per cow remained constant under all conditions. In practice, the farmer has a range of actions that he could employ to improve the profitability of the enterprise within each year under a range of poor and good prices or seasonal conditions.

Figure 4.5: Cumulative frequency distribution for the earnings before interest and tax (EBIT) of the case study farm system under long term average prices.
Return on assets managed and return on owner’s equity

Return on assets managed and return on owner’s equity also indicated that the farm, under long-term averages, was profitable. In 6 years out of 10, return to total assets was predicted to be between 2.65% and 7.94%, and below 0 in 4 out of 100 years (Figure 4.6). Return to owner’s equity (equity was assumed to be 14% at the start of year 1) is predicted to be between 1.60% and 10.30% in 6 years out of ten, and below 0 in 12 out of 100 years (Figure 4.7).

Figure 4.6: Cumulative frequency distribution for Return to Total Assets of the base farm system under long term average prices.
4.3.2 Exposure of the base farm system to various risks

Scenario/sensitivity analysis
To understand better the impact of different variable factors on the farm annual operating profit, the ‘scenario analysis’ function in @Risk was used. Refer to Table 4.12 for the results.
Table 4.12: Key inputs for earnings before interest and tax (EBIT) results from scenario analysis for the base farm system.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Milk Price ($/kg milk solids)</th>
<th>Grain Price ($/t air dry)</th>
<th>Milker hay feed Price ($/t air dry)</th>
<th>Pasture Consumed (t DM/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Simulation</td>
<td>5.59</td>
<td>387</td>
<td>232</td>
<td>5.72</td>
</tr>
<tr>
<td>Lowest 10%</td>
<td>4.56</td>
<td>430</td>
<td>266</td>
<td>-</td>
</tr>
<tr>
<td>Lowest 25%</td>
<td>4.71</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Highest 25%</td>
<td>6.60</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Highest 10%</td>
<td>7.17</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

NB. Values in parentheses represent the ratio of factor medians (subset to simulation) divided by the standard deviation of the simulation (RFMSD).

A scenario analysis was conducted for the lowest 10% and 25% of outputs, as well as the highest 25% and 10% of outputs. The numbers in the table represent the mean value of the criteria listed and those in the brackets show the ratio of factor means on standard deviation (RFMSD). This measure is useful for comparing the impact of different factors on the outputs of interest. As a guide, the higher the number the more significant the impact relative to other factors.

This can also be presented in a Tornado Graph which shows the actual change in output for a plus one standard deviation change in each input. In Figure 4.8, it is very clear that milk price is the most significant variable impacting on operating profits; a one standard deviation in the long term average milk price (92 cents increase) would add an additional 2.73% to the farmers return on assets. The key influential variables on return on assets are those that are outside of the farmers’ control.

Milk price
Milk price had a significant impact on the variation of the operating profit (earnings before interest, lease and tax) compared with any other input. During periods of higher operating profit, the RFMSD indicates that milk prices have a greater influence on operating profit than in periods of low profit.
Note: Dataset 1: Grain price ($/tDM); Dataset 2: Shortage/Surplus Hay (tDM); Dataset 6: Milk Price ($/KG MS); Dataset 8: Milker Hay Feed Price ($/tDM). The value shown on each bar is the coefficient value.

Figure 4.8: Contribution to variance of key inputs for the case study farm system under historical conditions.

Supplementary feed price
In the base farm system, supplementary feed price only affected operating profit substantially in the lowest 10% of feed supply periods. In part, this has to do with the probability distribution assigned to supplementary feeds used in the modelling. The distribution is skewed to the left to reflect the fact that supplementary feed prices have a greater chance of being substantially higher than the mean than being substantially lower than the mean.

In this case, supplementary feed costs had lower impact on operating profit than milk price. This is because during levels of low profitability, a combination of adverse factors such as increases in supplementary feed price and low pasture consumption is required to have a substantial impact. Milk price is the key driver of profitability in this base farm system.
**Pasture consumption**

In the analysis, the price of hay was correlated with pasture consumption to reflect the impact that seasonal conditions have on pasture consumption/availability and therefore hay prices. For example, during periods of high pasture availability, hay prices are likely to be lower. Interpretation therefore requires some care and this correlation should be better interpreted in terms of seasonal conditions.

For this farm system, the scenario analysis shows that to generate an operating profit in the top 10% of possible operating profitability, a high milk price is essential and to a lesser extent high pasture consumption in terms of tonnes of dry matter per hectare. In the model, the contribution that high pasture consumption has on EBIT is through the sale of excess metabolisable energy produced on farm as hay.

On the other hand, the sensitivity analysis also shows that during periods of low operating profit, factors including low milk price, high supplementary feed prices and high hay feed price combine to create unprofitable operating conditions. The amount of pasture consumed in these operating conditions have less of an impact.

**4.3.3 Debt**

The debt level of an agricultural enterprise has significant impacts on the viability of the business. This is particularly the case when making investment decisions that involve large amounts of capital investment. Basically, as debt increases (and equity falls) the interest repayments for the farm increase. To demonstrate the impact of debt on the cash flow of the business and on owner’s equity, 80% equity ($472,000 debt) and 65% equity ($825,000) were tested for the base farm system under long term average prices. Given the total value of plant and equipment is $771,200, scenario 1 would represent a situation where around 60% of the plant and equipment from the AMS adoption was borrowed. On the other hand, scenario 3 would represent a situation where adoption of AMS is fully funded through debt, with the farmer still owing 70% on the land. These equity scenarios are similar to the average equity levels observed across Victoria, with

In scenario 1 where the farm starts with 80% equity following investment into the AMS system, the return on owner’s equity is only below 0% in 12 of 100 years, assuming the farmer continues to farm in the same manner and the same level of debt is maintained. On average, the return on owner’s equity is 4.84%. In this scenario, net cash flow before tax is a comfortable $129,818. This will be sufficient for managing any short term adverse shocks to the farm and allows the farmer the option to pay down the debt quicker. In scenario 2, decreasing the starting equity level at 65% reduces the average return on owner’s equity to 4.35%.

In scenario 3, with a starting equity of 30% after investment into the AMS system, the return on owner’s equity was below 0% in 48 of 100 years, assuming the farmer continues to farm in the same manner and the same level of debt is maintained. The average return on owner’s equity becomes 1.11%. The net cash flow before tax is $22,765. This is because high interest payments significantly reduce annual net cash flows. This level of net cash flow before tax is critically low and would represent a highly risky position for the farmer in the event of a short-term adverse situation. Further, this may be coupled with greater difficulty in accessing finance in challenging years.

While the adoption of AMS technology allows the farmer to generate strong returns from capital employed, the challenges with financing such an investment with high levels of debt could lead to negative net cash flow situations where the owner would be losing capital by continuing to operate the farm business using the base system. Understanding the financial position of the farm business, before investing in any capital intensive equipment, is important for growing business wealth, as also is operating in a cashflow position where the farmer is better able to manage poor seasons (such as lower milk price, higher cost of feed and additional repair and maintenance costs).
4.4 COMPARISON WITH FARMS IN GIPPSLAND WITH CONVENTIONAL MILKING SYSTEMS

The data regarding the performance of dairy farms in Gippsland with conventional milking systems was extracted from the Dairy Industry Farm Monitor Project (DIFMP). The DIFMP provides profitability and productivity data for a range of farms across different Australian dairy regions. However, it is important to note that the participants were selected for the project in order to represent a distribution of farm sizes, herd sizes and geographical locations within each region. Therefore the results presented in the report do not represent population averages as the participant farms were not selected using random population sampling.

4.4.1 Comparison of performance for the 2011-12 year

Across the Gippsland region, the 2011-12 year was a wet year (as was the case for 2010/11) with the key challenges coming in the form of floods and managing wet soils. The annual rainfall for the region exceeded the long term average. In the 2011-12 DIFMP, some farms in the region experienced up to 160 per cent of, or 432mm more rainfall than, their long term average.

High rainfall experienced in the region over winter followed by spring where soils were water-logged across parts of the farm reduced the ability to harvest significant volumes of excess pasture and reduced opportunities to use fertilisers to generate more feed. This reduced the farm grazing area and pasture production. However, this meant that over the relatively cool summer period, soils remained moist and good quality forage was able to be grown and carried into autumn. Heavy follow up rainfall in late autumn and winter necessitated the use of fodder supplements two months earlier than usual.

In general, the impact of the wet conditions, combined with the need to feed lower quality home grown fodder and use more bought in concentrates in the early and the latter part of the year contributed to a poorer performance by Gippsland farms when compared to the year before.
Farm physicals

In this section is presented the key whole farm physical parameters for the case study farm compared with the Gippsland farms surveyed under the DIFMP in 2011-12 operating conventional milking systems (refer to Table 4.13). When examining the top 25% of farms in the DIFMP, ranked by return on assets under management, and comparing this with the middle band range (Q1-Q3), there are a number of distinguishing characteristics of the most profitable farms in the Gippsland region. These include:

- a greater stocking rate per hectare; 2.0 cows compared to 1.3 – 1.8 for the middle band; and
- greater milk production, in terms of kilograms of milk solids per cow, of 532kg compared to 485 – 535 range.

Despite the total useable area by the robotic dairy being half the size of the farms in Gippsland, there are some noticeable characteristics of the operation that has enabled it to generate a return on assets managed of 7.23%, above the average of the 4.4% across all farms surveyed in the 2011-12 year, and within the top 25% of farms, with an average return on assets of 7.5%, when ranked by return on assets under management. These characteristics include:

- high labour efficiency equating to 243 cows per full-time equivalent (FTE) compared to the average of 100 cows per FTE for the Gippsland average. This also meant high kilograms of milk solids per FTE of 129,181 kgMS/FTE compared to the Gippsland average of 50,244 kgMS/FTE. Figure 4.9 illustrates that the case study farm operates at a high level of labour efficiency when compared to the rest of Gippsland farms utilising conventional forms of milking (between 2006-2015);
- higher proportion of home grown feed as a percentage of ME consumed, 66% compared to the Gippsland average and top 25% average of 62% for both. Further, this is evident through the case study farmer achieving higher grazed pasture consumption per hectare across the milking area as well as the total useable area (9.1 tDM/ha/yr and 7.9 tDM/ha/yr, respectively) when compared to
the Gippsland average during this same year (7.1 tDM/ha/yr and 5.1 tDM/ha/yr, respectively);

- high volume of milk solids per cow (in kgMS/cow). This was only slightly above the average of the top 25% of farmers but around 6% higher than the Gippsland average; and

- annual rainfall was 13% higher than the Gippsland average for the 2011-12 year.

![Figure 4.9: Comparison of labour efficiency with rest of Gippsland](image)


**Figure 4.9: Comparison of labour efficiency with rest of Gippsland**

Figure 4.9 shows that the case study farm operates at a high level of labour efficiency when compared to the rest of Gippsland farms utilising conventional forms of milking (between 2006-2015). This figure is consistent with the findings undertaken by Molfino *et al.* (Molfino, 2015). In this study, Molfino *et al.* conducted a labour and time management audit on 5 commercial AMS farms across Australia over a 12 month period. The study found that labour efficiency ranged between 100 and 273 cows per FTE (where 1 labour unit referred to 50 hours per week).
Table 4.13. Farm physical parameters for Gippsland and case study farm 2011-12

<table>
<thead>
<tr>
<th>Farm physical parameters</th>
<th>Gippsland average</th>
<th>Q1 – Q3 range</th>
<th>Top 25% average (2011-12 year)</th>
<th>Case study farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual rainfall 2011-12</td>
<td>1,113</td>
<td>982 – 1,200</td>
<td>1,023</td>
<td>1,259</td>
</tr>
<tr>
<td>Water used (irrigation and rainfall) (mm/ha)</td>
<td>1,182</td>
<td>1,115 – 1,263</td>
<td>1,199</td>
<td>1,259</td>
</tr>
<tr>
<td>Total useable area (ha)</td>
<td>189</td>
<td>110 – 246</td>
<td>170</td>
<td>97.5</td>
</tr>
<tr>
<td>Milking cows per useable hectare</td>
<td>1.7</td>
<td>1.3 – 1.8</td>
<td>2.0</td>
<td>1.75</td>
</tr>
<tr>
<td>Milk sold (kg MS/ cow)</td>
<td>501</td>
<td>485 – 535</td>
<td>531</td>
<td>532</td>
</tr>
<tr>
<td>Milk sold (kg MS/ ha)</td>
<td>843</td>
<td>695 – 938</td>
<td>1,073</td>
<td>927</td>
</tr>
<tr>
<td>Home grown feed as % of ME consumed</td>
<td>62%</td>
<td>55% - 69%</td>
<td>62%</td>
<td>66%</td>
</tr>
<tr>
<td>Labour efficiency (milking cows / FTE)</td>
<td>100</td>
<td>80 – 115</td>
<td>112</td>
<td>243</td>
</tr>
<tr>
<td>Labour efficiency (kgMS/ FTE)</td>
<td>50,244</td>
<td>44,774 – 59,777</td>
<td>59,383</td>
<td>129,181</td>
</tr>
</tbody>
</table>

Source: DIFMP 2011-12

**Gross farm income**

In the Gippsland region for 2011-12, the variation in gross farm income per hectare between the surveyed farms ranged from $2,686 to $11,943 per hectare. The top 25% of farms averaged $6,370 per hectare, compared to the group average of $4,971 per hectare. The case study farm achieved a gross farm income of $5,677 per hectare.

**Milk solids production**

During 2011-12, the average milk solids sold per hectare was 843 kgMS per hectare, and 7,936,470 kgMS per farm. The average milk solids production of the top 25% of farms was at 1,073 kgMS per hectare and when comparing to the previous 2010/11 year, there does not appear to be any strong link between milk solids sold per hectare and milk solids sold per farm with either annual rainfall or the long-term average for individual farms. The AMS case study farm achieved 927 kgMS per hectare, still in the Q1-Q3 range but in the upper bound.

**Variable costs**

Generally, feed costs are the greatest cost in the dairy business representing around 46% of total costs in Gippsland farms (Victorian Department of Economic Development, 2016). This was exactly the case for the case study farm suggesting that the case study farm has not dramatically reduced the feed conversion efficiency (nor increased it) as a
result of operating with voluntary cow traffic and automatic milking. This is encouraging and supports the findings (Clark et al., 2016) who showed that pasture utilisation levels of an AMS farm were not different to similarly managed conventional milking farms. Refer to Table 4.14 for a summary of the case study farms’ variable and overhead costs compared to Gippsland averages.

**Overhead costs**

Overhead costs represent a significant component to farm businesses and include non-cash costs including imputed owner/operator and family labour and depreciation costs that need to be carefully included to provide a realistic assessment of performance. For the farms in Gippsland, there was a large range in overhead costs from $1,018 per hectare up to $2,638 per hectare; $132,689 to $571,827 per farm. The case study farm was towards the lower end at $1,282 per hectare ($118,038 per farm). The most significant overhead cost for the case study farm was the repairs and maintenance costs which account for over 45% of cash overheads. When looking at the associated costs of the AMS, the repairs and maintenance includes costs such as farm improvements, buildings, fences, yard, irrigation structures, lane tracks, plant and equipment.

Labour costs, including employed labour and imputed owner/operator and family labour is often the major overhead cost. For the Gippsland region, this represented 64% of overheads costs for the regional average, and 69% for the top 25% of farms. For the case study farm, labour costs were significantly lower at 40% due to the removal of physical labour required for milking.

The other non-cash cost, depreciation, is particularly important when investing in new capital assets as the replacement cost of the asset needs to be reflected in the true cost of the business. The straight line method for depreciation was used for the equipment. It was assumed that the salvage value at the end of the 15-year life was 10% of the original value for the robotic milking system. Despite the Australian Tax Office recommending depreciation of the AMS over 10 years, a useful life of 15 years was selected to reflect the operational life of the equipment. This is the appropriate approach for undertaking an economic assessment.
In the Gippsland region, the capital invested in the AMS meant the average depreciation for farms participating in the DIFMP equated to approximately $0.17/kgMS. For the case study farm, depreciation was significantly higher at $0.61/kgMS. There are three key reasons to explain this. First, for CMS a lower proportion of the capital value is included in the depreciation schedule as much of it is considered to be part of the land and improvements value whereas more of the capital is considered to be part of the mobile plant and equipment for an AMS farm. Second, the lower averages in all parts of Victoria reflect the fact that a significant proportion of dairy farms appear to have upgraded milking equipment around the time of industry deregulation in 2000. This is likely to be a result of financial assistance provided by the public and Australian consumer to help the industry adjust. This is reflected in data collected in the ABARES Australian Dairy Industry Survey (Australian Bureau of Agricultural and Resource Economics and Sciences, 2014). As a result, the depreciation value of these assets is either at the end or nearing the end of their depreciable life. Further, farmers have been investing in shed technology in an incremental manner, adopting automated technologies such as automatic cup removers, automatic drafting, and automated cleaning. This has postponed the need for large capital investments in an entirely new milking system. Finally, the depreciation costs experienced in the case study is due to the newly implemented automatic milking system. For this case study, this also included optional infrastructure development such as feedout equipment, laneway development, excavation and glycol chiller. However, it is important to note that the depreciation cost of a new conventional dairy for this scale of operation would also be comparable.

In Figure 4.10, data was collected for Gippsland surveyed farms from the DIFMP from 2016-07 to 2014-15. The scatter plot illustrates the greater levels of capital intensity generally associated with increases in herd size. However, when comparing the capital structure of the case study with the long term total capital structure of farms across Gippsland (between 2006 – 2015), the case study farm employs similar amounts of capital with farms of similar herd size.
Table 4.14: Variable and overhead costs for Gippsland and case study farm

<table>
<thead>
<tr>
<th>Farm costs ($/kgMS)</th>
<th>Gippsland average</th>
<th>Q1 to Q3 range</th>
<th>Top 25% average</th>
<th>Case study farm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herd costs $0.29</td>
<td>$0.21 – $0.37</td>
<td>$0.27</td>
<td>$0.19</td>
<td></td>
</tr>
<tr>
<td>Shed costs $0.18</td>
<td>$0.13 – $0.23</td>
<td>$0.16</td>
<td>$0.18</td>
<td></td>
</tr>
<tr>
<td>Purchased feed and agistment $1.34</td>
<td>$0.98 – $1.68</td>
<td>$1.35</td>
<td>$1.28</td>
<td></td>
</tr>
<tr>
<td>Home grown feed cost $0.78</td>
<td>$0.60 – $0.89</td>
<td>$0.71</td>
<td>$0.43</td>
<td></td>
</tr>
<tr>
<td><strong>Total variable costs ($/kgMS)</strong></td>
<td>$2.59</td>
<td>$2.16 – $2.80</td>
<td>$2.50</td>
<td>$2.08</td>
</tr>
<tr>
<td><strong>Overhead costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rates $0.05</td>
<td>$0.03 – $0.06</td>
<td>$0.03</td>
<td>$0.04</td>
<td></td>
</tr>
<tr>
<td>Registration and insurance $0.02</td>
<td>$0.01 – $0.03</td>
<td>$0.01</td>
<td>$0.01</td>
<td></td>
</tr>
<tr>
<td>Farm insurance $0.05</td>
<td>$0.03 – $0.07</td>
<td>$0.05</td>
<td>$0.02</td>
<td></td>
</tr>
<tr>
<td>Repairs and maintenance $0.32</td>
<td>$0.19 – $0.40</td>
<td>$0.19</td>
<td>$0.28</td>
<td></td>
</tr>
<tr>
<td>Bank charges $0.01</td>
<td>$0.00 – $0.01</td>
<td>$0.01</td>
<td>$0.02</td>
<td></td>
</tr>
<tr>
<td>Other overheads $0.10</td>
<td>$0.07 – $0.10</td>
<td>$0.09</td>
<td>$0.05</td>
<td></td>
</tr>
<tr>
<td>Employed labour cost $0.40</td>
<td>$0.15 – $0.54</td>
<td>$0.59</td>
<td>$0.11</td>
<td></td>
</tr>
<tr>
<td><strong>Total cash overheads</strong></td>
<td>$0.95</td>
<td>$0.73 – $1.14</td>
<td>$0.97</td>
<td>$0.53</td>
</tr>
<tr>
<td><strong>Depreciation</strong></td>
<td>$0.17</td>
<td>$0.11 – $0.22</td>
<td>$0.12</td>
<td>$0.61</td>
</tr>
<tr>
<td>Imputed owner/operator and family labour</td>
<td>$0.88</td>
<td>$0.55 – $1.03</td>
<td>$0.48</td>
<td>$0.44</td>
</tr>
<tr>
<td><strong>Total overhead costs ($/kgMS)</strong></td>
<td>$2.01</td>
<td>$1.55 – $2.13</td>
<td>$1.57</td>
<td>$1.31</td>
</tr>
<tr>
<td><strong>Total variable and overhead costs ($/kgMS)</strong></td>
<td>$4.59</td>
<td>$4.23 – $4.91</td>
<td>$4.07</td>
<td>$3.67</td>
</tr>
</tbody>
</table>

*Refer to glossary of terms.

Source: DIFMP 2006-07; DIFMP 2007-08; DIFMP 2008-09; DIFMP 2009-10; DIFMP 2010-11; DIFMP 2011-12; DIFMP 2012-13; DIFMP 2013-14; DIFMP 2014-15

Figure 4.10: Capital intensity of case study farm and farms across Gippsland

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It is important to note that while the case study farm exhibits similar levels of capital intensity with other farms of similar size, it still experiences significantly larger depreciation costs compared to the average depreciation across other farms in the Gippsland region. This can be explained by how the AMS is treated in the farm’s financial assessment. The AMS equipment was depreciated at a time and rate similar to other farm assets such as tractors with a salvage value (i.e., 15 years with a 10% salvage value). On the other hand, conventional milking systems in the DIFMP are depreciated over 30 years and for management purposes are treated as a sunk cost.

**Earnings before interest and tax**

In 2011-12, the economic performance of the case study farm was strong, achieving an EBIT of $2,272 per hectare. This is compared to the Gippsland average of $1,137 per hectare in the same year, and the average of $1,890 per hectare achieved by the top 25% of farms. Although, it is important to note that the top 25% in the previous 2010-11 year achieved an average EBIT of $2,575 per hectare, and $424,186 per farm. Despite milk production being slightly higher on most farms in the region, lower milk price and feed inventory loss in the 2011-12 year contributed to lower gross income. This was also accompanied by an increase in variable and overheads costs, which has decreased average EBIT. Refer to Table 4.15 for a breakdown of production costs.

**Return on assets managed and return on owner’s equity**

Return on assets is the EBIT expressed as a percentage of total assets and is a good indicator of the earning power of total assets, irrespective of the capital structure. On the other hand, return on owner’s equity is the net farm income (EBIT less interest and lease payments) expressed as a percentage of the owner’s equity. It is a measure of the owner’s rate of return on investment.

In 2011-12 year, the return on assets of farms in Gippsland ranged from -2.4% to 8.0%. The Gippsland average was 4.4% and the top 25% of farms achieved an average of 7.5% return on assets. The case study farm achieved 7.23% in the same year.
The case study farm demonstrated that for the 2011-12 year, it was able to generate a return on asset that outperforms the average Gippsland farm that employs conventional milking systems, and in fact, places the farm in the top 25% of high performing farms.

### 4.4.2 Variability in long-term farm performance compared to performance of Gippsland farms between 2006/07 and 2014/15

The long-term performance of the case study farm is compared to the performance of Gippsland farms between 2006/07 and 2014/15 surveyed under the DIFMP. Figure 4.11 and Figure 4.12 illustrate these long-term performances respectively. These graphs are overlaid in Figure 4.13 to compare the frequency and variance in performance that is likely to be achieved in the long-term.

![Figure 4.11: Long-term performance of case study farm](image-url)
When looking at the potential performance of the case study farm over a run of many years, the case study farm appears able to operate efficiently from an economic perspective, with a mean return to total assets of 5.28% excluding capital appreciation. The performance of the case study farm over a range of long-term scenarios becomes
very interesting when compared to the returns experienced on Gippsland farms over the period 2006/07 to 2014/15 (refer to Figure 4.13). Most notably, the return profile exhibited on the case study shows a slightly higher return exhibited in the long-term for less risk compared with farms in the DIFMP. Key observations:

- The mean return on assets experienced on the case study farm is marginally higher at 5.28% compared to the long-term average in Gippsland of approximately 4.5%. However, the key difference is the likelihood of achieving this level of return. The case study farm is expected to achieve a return of between 2.65% and 7.94% (excl. capital appreciation) in 6 of 10 years; farms in the wider Gippsland area are likely to achieve a return in this same range in just under 5 of 10 years.

- The range on the case study farm is also much more confined with a minimum of -4.49% and a max of 14.7%, compared to farms across Gippsland with a range of -14.1% and 43.6%. This is reflected in the larger standard deviation in long-term return on assets across Gippsland. Importantly, the case study farm is located in one of the more reliable rainfall areas of Gippsland and is therefore less variable regardless of the system.

Further, the average farm income, costs and profit per kilogram of milk solids as well as other physical data are compared between the long-term average for Gippsland and the performance of the case study farm under historical conditions (refer Table 4.15 and Table 4.16). In-depth data is also available at Table 4.17, Table 4.18, and Table 4.19.
Table 4.15: Historical data for Gippsland in comparison – Average farm income, costs and profit per kilogram of milk solids

<table>
<thead>
<tr>
<th></th>
<th>Long-term average for Gippsland (2006-07 to 2014-15)</th>
<th>Case study farm under historical conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross farm income</td>
<td>$6.70</td>
<td>$6.06</td>
</tr>
<tr>
<td><strong>Variable costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herd costs</td>
<td>$0.30</td>
<td>$0.19</td>
</tr>
<tr>
<td>Shed costs</td>
<td>$0.19</td>
<td>$0.18</td>
</tr>
<tr>
<td>Feed costs</td>
<td>$2.62</td>
<td>$2.31</td>
</tr>
<tr>
<td>Total variable costs</td>
<td>$3.13</td>
<td>$2.69</td>
</tr>
<tr>
<td><strong>Overhead costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash overhead costs</td>
<td>$0.98</td>
<td>$0.53</td>
</tr>
<tr>
<td>Non cash overhead costs</td>
<td>$1.17</td>
<td>$1.05</td>
</tr>
<tr>
<td>Total overhead costs</td>
<td>$2.14</td>
<td>$1.58</td>
</tr>
<tr>
<td><strong>Profit</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earnings before interest and tax</td>
<td>$1.41</td>
<td>$1.79</td>
</tr>
<tr>
<td>Interest and lease charges</td>
<td>$0.71</td>
<td>$0.57</td>
</tr>
<tr>
<td>Net farm income</td>
<td>$0.70</td>
<td>$1.22</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Return on assets</td>
<td>4.3%</td>
<td>5.28%</td>
</tr>
<tr>
<td>Return on equity</td>
<td>4.5%</td>
<td>5.93%</td>
</tr>
<tr>
<td>Liabilities per cow</td>
<td>$3,293</td>
<td>$11,631</td>
</tr>
<tr>
<td>Equity</td>
<td>71%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Note: dollar values are the nominal values converted to 2014/15 dollar equivalents by the consumer price index (CPI) to allow for inflation.

Table 4.16: Historical data for Gippsland – Physical information

<table>
<thead>
<tr>
<th></th>
<th>Long-term average for Gippsland (2006-07 to 2014-15)</th>
<th>Case study farm under historical conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milking cows</td>
<td>287</td>
<td>170</td>
</tr>
<tr>
<td>Milking area (ha)</td>
<td>154</td>
<td>65</td>
</tr>
<tr>
<td>Milk sold (kgMS/cow)</td>
<td>470</td>
<td>532</td>
</tr>
<tr>
<td>Estimated grazed pasture (tDM/ha)</td>
<td>7.1</td>
<td>9.1</td>
</tr>
<tr>
<td>Home grown feed as % of ME consumed</td>
<td>68%</td>
<td>66%</td>
</tr>
<tr>
<td>Concentrates imported tDM/cow</td>
<td>1.87</td>
<td>2.06</td>
</tr>
<tr>
<td>Cows milked/FTE</td>
<td>98</td>
<td>250</td>
</tr>
<tr>
<td>Labour productivity kgMS/FTE</td>
<td>46,164</td>
<td>129,182</td>
</tr>
</tbody>
</table>

There are a number observations that can be drawn from comparing these two data sets. Key observations:

- While gross farm income is approximately 10% lower than the long-term average, this reflects a significantly smaller than average herd size of 170
compared to 287 across Gippsland. Though, this small gap in gross income is offset by strong milk production performance from the case study farm system achieving 532 kgMS/cow compared to 470 kgMS/cow across Gippsland over the long-term. This is also evident with the farm importing slightly higher concentrates in tonnes of dry matter per cow.

- The variable costs of the case study farm business are substantially lower. This is reflected through lower herd costs and also lower feed costs per kilogram of milks solids. This is achieved through a higher pasture utilisation of 9.1 tDM/ha across a smaller milking area compared to 7.1 tDM/ha for Gippsland’s average. Further this level of utilisation is achieved over a smaller milking area of 65 ha in comparison to the Gippsland average of 154 ha.

- A significant benefit of the AMS technology is labour savings. This is evident in the significant reduction in cash overhead costs experienced in the case study farm business. The case overheads were $0.53/kgMS, approximately half the Gippsland long-term average of $0.98/kgMS. Not only is the reduction of employed staff a key contributor, labour productivity has improved substantially. The case study far, achieved labour productivity of 129,182 kgMS/FTE compared to the Gippsland average of 46,164 kgMS/FTE, almost tripling labour productivity.

- The combination of lower variable costs and overhead costs and higher milk production per cow are the major contributors to the case study farm achieving a higher earnings before interest and tax of $1.79/kgMS compared to the Gippsland long-term average of $1.41/kgMS.

- It is important to note the equity for the farm business is 15% compared to the Gippsland average of 71%. This is a result of the high liabilities per cow for the case study of $11,631/cow compared to the average of $3,293/cow. The is only possible because the debt is being serviced from the farm owner’s entire business consisting of the 280 cow operation using the 40-unit rotary dairy and the AMS operation.
Table 4.17: Historical data for Gippsland – farm income, variable costs, overhead costs and profit

<table>
<thead>
<tr>
<th>INCOME</th>
<th>VARIABLE COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOMINAL ($/Kg MS)</td>
<td>REAL ($/Kg MS)</td>
</tr>
<tr>
<td>$4.46</td>
<td>$4.48</td>
</tr>
<tr>
<td>$6.62</td>
<td>$7.76</td>
</tr>
<tr>
<td>$5.32</td>
<td>$6.16</td>
</tr>
<tr>
<td>$4.58</td>
<td>$4.92</td>
</tr>
<tr>
<td>$5.59</td>
<td>$6.06</td>
</tr>
<tr>
<td>$5.37</td>
<td>$5.75</td>
</tr>
<tr>
<td>$4.75</td>
<td>$4.97</td>
</tr>
<tr>
<td>$6.62</td>
<td>$7.33</td>
</tr>
<tr>
<td>$5.86</td>
<td>$6.51</td>
</tr>
</tbody>
</table>

Average: $5.97 $6.70 $0.30 $0.19 $2.62 $3.13

Note: ‘Real’ dollar values are the nominal values converted to 2014-15 dollar equivalents by the consumer price index (CPI) to allow for inflation.

Source: DIFMP 2014-15

Table 4.18: Historical data for Gippsland – Average farm physical information

<table>
<thead>
<tr>
<th>Total usable area</th>
<th>Milking area</th>
<th>Water used</th>
<th>Number of milking cows</th>
<th>Milk sold</th>
<th>Estimated grazed pasture*</th>
<th>Estimated conserved feed</th>
<th>Home grown feed as % of ME consumed</th>
<th>Concentrate price</th>
</tr>
</thead>
<tbody>
<tr>
<td>HA</td>
<td>MM/HA</td>
<td>HD</td>
<td>HD/HA</td>
<td>KG MS/COW</td>
<td>KG MS/HA</td>
<td>KG MS/DM</td>
<td>% OF ME</td>
<td></td>
</tr>
<tr>
<td>2006-07</td>
<td>191</td>
<td>187</td>
<td>668</td>
<td>282</td>
<td>1.4</td>
<td>405</td>
<td>579</td>
<td>5.6</td>
</tr>
<tr>
<td>2007-08</td>
<td>181</td>
<td>174</td>
<td>838</td>
<td>289</td>
<td>1.6</td>
<td>464</td>
<td>741</td>
<td>7.2</td>
</tr>
<tr>
<td>2008-09</td>
<td>182</td>
<td>172</td>
<td>814</td>
<td>276</td>
<td>1.6</td>
<td>483</td>
<td>803</td>
<td>7.2</td>
</tr>
<tr>
<td>2009-10</td>
<td>172</td>
<td>160</td>
<td>1022</td>
<td>268</td>
<td>1.7</td>
<td>472</td>
<td>792</td>
<td>7.6</td>
</tr>
<tr>
<td>2010-11</td>
<td>190</td>
<td>187</td>
<td>1,123</td>
<td>285</td>
<td>1.7</td>
<td>494</td>
<td>811</td>
<td>7.1</td>
</tr>
<tr>
<td>2011-12</td>
<td>189</td>
<td>126</td>
<td>1,182</td>
<td>291</td>
<td>1.7</td>
<td>501</td>
<td>843</td>
<td>7.4</td>
</tr>
<tr>
<td>2012-13</td>
<td>194</td>
<td>134</td>
<td>906</td>
<td>299</td>
<td>1.7</td>
<td>462</td>
<td>781</td>
<td>6.9</td>
</tr>
<tr>
<td>2013-14</td>
<td>186</td>
<td>126</td>
<td>1,044</td>
<td>264</td>
<td>1.8</td>
<td>468</td>
<td>805</td>
<td>7.6</td>
</tr>
<tr>
<td>2014-15</td>
<td>189</td>
<td>123</td>
<td>956</td>
<td>304</td>
<td>1.8</td>
<td>479</td>
<td>890</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Average: 186 154 950 287 1.7 470 786 7.1 1.0 68%

* From 2006/07 to 2010/11 estimated grazed pasture and conserved feed was calculated per usable area. From 2011/12 estimated grazed pasture and conserved feed was calculated per hectare of milking area.

Source: DIFMP 2014-15

4.5 CONCLUSION

The economic results presented above are based on a real case study, with distributions fitted for key variables that are largely beyond the farmers control such as milk and grain prices. When scrutinising the farm physical parameters, it is clear that the
performance of the farm system is above the Gippsland average for parameters such as kilograms of milk solids produced per cow and per hectare.

Table 4.19: Historical data for Gippsland - other performance indicators

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrates imported tDM/cow</td>
<td>2.06</td>
<td>1.83</td>
<td>1.7</td>
<td>2.0</td>
<td>1.8</td>
<td>2.0</td>
<td>1.9</td>
<td>1.8</td>
<td>1.9</td>
<td>1.87</td>
</tr>
<tr>
<td>Cows milked/FTE</td>
<td>250</td>
<td>68</td>
<td>102</td>
<td>96</td>
<td>95</td>
<td>97</td>
<td>100</td>
<td>99</td>
<td>104</td>
<td>98</td>
</tr>
<tr>
<td>Equity (%)</td>
<td>15%</td>
<td>76%</td>
<td>71%</td>
<td>78%</td>
<td>68%</td>
<td>74%</td>
<td>72%</td>
<td>67%</td>
<td>66%</td>
<td>71%</td>
</tr>
<tr>
<td>Labour productivity kgMS/FTE</td>
<td>129,182</td>
<td>27,359</td>
<td>47,435</td>
<td>46,149</td>
<td>44,537</td>
<td>48,138</td>
<td>50,244</td>
<td>46,047</td>
<td>48,617</td>
<td>46,164</td>
</tr>
</tbody>
</table>

Source: DIFMP 2014-15

The key variables that were important in this analysis was to capture the additional capital costs associated with a AMS over and above a conventional milking system, and the impacts across the system such as in labour efficiency, anticipated life of the system, difference in milk production per cow, annual repair and maintenance and other aspects.

After simulating the potential performance of the case study farm over a run of many possible scenarios, the case study farm appears able to operate efficiently from an economic perspective, with a mean return to total assets of 5.28% excluding capital appreciation. The long-term performance (in relation to return on total assets) achieved by the case study farm is, on average, marginally higher than that of Gippsland dairy farms operating traditional milking systems (between 2006/07 and 2014/15) which achieved on average 4.49%.

Analysis of this case study suggests that integrating AMS into this pasture-based system can be done so in an economically viable and competitive manner. This can be concluded following assessment of the profitability and risk aspects of the AMS operation. Nevertheless, the findings in this analysis requires careful interpretation given the specific resource endowments of the farm and to some extent managerial capability.
5 Case study 2 – Tasmania automatic milking rotary

5.1 THE AUTOMATIC MILKING ROTARY

5.1.2 Introduction
The method of the automatic milking rotary (AMR<sup>TM</sup> DeLaval, Tumba, Sweden) was designed and developed by DeLaval engineers in consultation with FutureDairy researchers, Dairy Australia and the University of Sydney. The initial concept development commenced in 2005 and the first prototype was built at DeLaval’s research facility in Sweden in 2008. The prototype was installed at Camden, NSW, in 2009 for testing under Australian conditions. Following testing and significant refinement, the AMR technology was installed on a commercial farm (Gala) in 2011 as the world’s first commercial pilot installation.

The concept of the AMR system was to enable herds greater than 240 cows (the average herd size at the time of concept development) to be milked with voluntary cow traffic with a capital cost that was more comparable to conventional milking systems than single box robots. The reason for the concept development was that the cost of the single box robots were expected to inhibit uptake of the technology in Australia where the average herd size is significantly larger than that in Europe, for which the single box robots had originally been developed. Given that single box robots can only milk between 6 and 10 cows per hour, the number of robots required per herd made the equipment less appealing for larger herds which would normally harness reduced capital costs (in relation to milk harvesting equipment at least) simply through economies of scale. The AMR is the world’s first high throughput automatic milking system that was designed to be capable of milking 50-90 cows per hour (subject to configuration of either two or four robotic arms and system management). As the equipment development and refinement progressed the decision was made (by DeLaval) to only commercialise the AMR with four pre-milking robotic arms. The equipment was designed to cope with both batch and voluntary milking which created a level of management flexibility that should appeal to a broader spectrum of farmers. Like all automatic milking systems, the AMR can conduct a number of milkings per day.
(depending on the entry speed of the cows, the speed and accuracy of the robotic arms and the milking speed of the cows amongst other things). How these milkings are harnessed by the operator is quite farm specific with some operators targeting less cows with more milkings/cow/day and others targeting more cows with less milkings/cow/day. The AMR is designed with a theoretical throughput potential of around 1500 milkings per day but this potential is reduced when cows are managed with voluntary cow traffic.

The primary reason that the AMR can conduct so many more milkings/hour (or per day; compared to single box robots) is created by the moving rotary platform that frees the robots up as soon as the cups have been attached to the cow minimising the “attention time” per cow and thereby increasing milking throughput. Once the cow has been milked and the milking cups removed, the cow continues to rotate around the platform towards the teat spray robot for post-milking sanitisation prior to exiting the platform. In comparison, in a single box robotic milking system, the robotic arm ‘stays with’ the cow throughout the entire milk harvesting process.

Anecdotally, it is understood that there are only twelve robotic rotary milking farms in operation around the world in 2015, three of which are located in Australia.

5.2 ASPECTS OF THE AMR AT THE GALA FARM

The milking stall
The AMR installed at the Gala farm is a 24-unit internal, herringbone rotary platform. This platform is designed such that the cow stands at a 30 degree angle with their heads facing out and their rumps facing in. The angle enables the five centrally located robots to approach the cows from the side (between the front and back leg).

The robotic arms in the AMR remain stationary whilst the rotary platform rotates the cow from the entry point through to the exit point in a stop-start fashion. Kolbach (2012) provides an explanation of the step-by-step pre-milking teat preparation and cup
attachment process that each cow is ‘subjected to’ within each milking session on the AMR.

Robotic devices
The robotic devices in the AMR imitate a milker by way of an ‘arm’ that cleans teats (with a cleaning and drying cup), and picks up and attaches the milking cups to the teats, applies teat spray at the completion of milking and rinses the milking cups between consecutive cows. The AMR has, five robots; two for teat preparation, two for cup attachment and one for teat disinfection after milking. The robots use 3D time of flight cameras to locate and attach the cups. The robots also can monitor real-time individual quarter milk yield, milk flow rates, blood concentration in the milk and milk conductivity.

Teat cleaning
The teat preparation module carries a fixed ‘teat-cup-like’ device. The teats are cleaned and stimulated while water circulates gently with air through the cup, the teats are then dried at the end of the circulation process by activating a vacuum in the cleaning device. The cleaning process also strips the foremilk from each teat which is diverted to the drain entirely independent of the milk lines to prevent any contamination.

The Gala farm has two robots dedicated to preparing the teats for milking.

Cup attachment
The cup attachment robots can collect two teat cups at a time. The first attaches the cups to the two rear teats whilst the second attaches cups to the two front teats (it can also attach the rear cups if the first cup attachment robot was unsuccessful for some reason).

Each of the teat washing and cup attachment robots effectively ‘tends to’ half an udder (either the rear or the front teats) reduces the ‘attention time’ per cow and thereby increases the throughput potential of the AMR.
Teat disinfection
The teat spray robot is located in the position closest to the point where the cow exits the AMR. It also uses a 3D time of flight camera to locate the individual teat for post-milking sanitation.

Control system and sensors
The AMR is equipped with sensors that help to control the milking process and monitor the milk quality of each cow. This function replaces the controlling and monitoring task of a human operator and therefore the observational sense of a human. The main task of the sensors is to monitor the technical functioning of the AMR such as cow identification, vacuum level monitoring, cow position sensing, teat cup attachment, start of the milk letdown process and monitoring of the milk harvesting process and milk properties (e.g., detection of abnormalities in milk flow rates, expected milk yield, blood presence and conductivity levels of the milk from each quarter).

Each cow can be identified by an electronic transponder (either ear tag of collar), which is recognised by the robots, smart gates, automatic feeders and computer system.

Further, the sensors collect the necessary data required to generate reports, alerts and detection alarms that allow the system to operate without direct human involvement. At Gala farm, the DelPro herd management software is used to manage many aspects of day-to-day decisions from the computer, including animal health (cow treatment and milking permissions), feeding (concentrate feed allocation), cow traffic (via ‘smart selection gates’) and diagnostics (mastitis detection index, feed consumption levels, variation in milk yield).

5.3 CASE STUDY FARM DESCRIPTION

5.3.1 Location, land and history
The case study farm is one of five dairy farms currently being operated since 1964 by the family, involving three generations since 1964. The family milks approximately 2000 cows across the five farms. The case study farm was developed as a greenfield site,
central north of Tasmania, where the Delaval AMR system was commissioned in 2011. The 270 hectare (ha) property consists of 200 ha of unirrigated effective milking area, 55 ha irrigated by centre pivot, and 15 hectares for buildings and infrastructure including a 600 megalitre farm dam.

Construction of the AMR commenced in March 2011 with the first calving at the farm occurring in August 2011. By the conclusion of the spring calving period there were 250 first calved heifers being milked manually through the AMR system. Robotic milking started in mid-February 2012 and cows were being brought to the dairy twice a day for batch milking prior to being transitioned to voluntary cow traffic in late-2012. By this time, the milking herd had been increased to 335 cows in the 2012-13 season with the view to milking approximately 550 cows in 2014-15 and 600 cows in the 2015-16 season.

The farm manager considers that the 2015-16 year represents a state in which the operation has reached a ‘steady state’ and during which the AMR was operating at full capacity for the given specifications and management approach of the system. As such, this analysis reflects what an AMR is capable of achieving given the operating environment in 2015-16.

From 2011, significant modification to the farm was undertaken to implement a farm management system that would enable the farmer to achieve efficient grazing and begin achieving the full labour saving and lifestyle benefits of automatic milking for large herds. Key modifications included developing the farm layout to achieve a 3-way grazing system to ensure that cows can present themselves for milking twice in a 24 hr period. Subsequently, this was modified to a four-way grazing system from August 2015 onwards (discussed in later sections). The dairy yard infrastructure included a series of pre-milking, post-milking, drafting and interchange yards with smart selection gates to direct cows to the dairy, various grazing areas, holding yard and feed pad depending on their individual settings in the herd management system and other factors like time of day, animal health management, mating etc. These modifications are explained in greater detail in the next section.
Dornauf dairies
4 farms (ha)

Gala farm
Automatic milking rotary (270 ha)

- St. Omer
  210 milkers
  64 ha irrigated property

- Weegena
  575 milkers
  250 ha partly irrigated

- Stevens Hill
  315 milkers
  123 ha dryland

- Harveys
  Dry stock farm
  188 ha dryland

- Milking area
  200 ha
  - Milking herd only
  - Perennial pasture

- Irrigated area
  55 ha
  - Irrigation by centre pivot

- Building and Infrastructure, and dam
  15 ha

Figure 5.1: Schematic representation of the conventional and AMS farm business

Soil
The case study farm is located on soils that range from red soils on basalt (ferosols) to heavy black clay loams, alluvial loams and lighter clay loams. This soil is generally deep, well-structured free draining and suitable for intensive cropping. The slopes are generally gentle and relatively free of stone.

5.3.2 Infrastructure and plant
While incorporating robots into the rotary parlour is the primary cost of an AMR, farmers adopting this entirely new system also have some options regarding other technology and infrastructure which can be incorporated into the dairy and/or farm system in order to maximise the benefits of automatic milking. Some of these options are driven by key functionality differences between the robotic rotary and the box stall AMS systems. These capability differences require different routine practices and
ultimately different choices to be made about the supporting infrastructure required. These differences include:

- The robotic rotary is unable to reattach any milking cups that are removed prematurely (i.e., before the completion of milking) since the cow is rotated past the robotic arms after teat cleaning and milking cup attachment.
- Milk from individual cows cannot be diverted; therefore, hospital and colostrum cows need to be managed separately and batch milked either through the AMR at designated times or through a separate facility.
- Automatic washes need to be manually scheduled and initiated by the farmers.
- Robotic rotaries do not have in-bail feeding.
- Some milk analyses (e.g., in-line somatic cell counter and herd navigator) (Mazeris, 2010) are not compatible with the AMR even though they can be available to some brands of single box robotic milking systems.

For the case study farm, a number of options were incorporated into the milk harvesting facility to allow targeted management systems to be implemented. These options included:

- Feed stations – the farmer installed 20 feed stations to enable grain-based concentrates to be allocated to individual cows (or groups of cows) based on production, stage of lactation, body condition and other parameters. The feed stations were accustomed with a feed storage and delivery system (silos and augers) allowing the farmer to feed individual cows different feedstuffs (in varied portions) thereby tailoring the protein and energy levels for cows in different stages of lactation and those in different physiological states. Whilst there is likely to be some benefits associated with in-bail feeding, this is not currently an option with the AMR and there are definitely some advantages of having the feed stations located separately to the milk harvesting process. At Gala, the feed stations are installed in the exit area of the dairy thereby providing a reward for cows and encouragement for them to walk off the AMR at the completion of milking. Their location also creates a cleaner environment in the dairy i.e., less dust and less risk of rodents (and the associated damage to wiring
etc) and encourages the cows to remain standing in a relatively clean area for a period of time after milking (with obvious udder health benefits).

- Single-sided herringbone – the farmer installed a used 15-bail single-sided herringbone facility to allow hospital and colostrum cows to be batch milked without interrupting the traffic and milkings of the main voluntary milking herd and to allow unsaleable milk to be diverted from the bulk milk vat. Having this facility gave the farmer flexibility to milk, observe and treat hospital and colostrum cows without the pressure of fitting around the main milking herd. The other advantages of this is that the risk of antibiotics entering the main vat is minimised, the facility provides a safe working environment for staff and more time to attend cows that require attention. This space also includes a treatment facility with a drop down platform (on the herringbone pit) to enable easy access for other husbandry practices such as vaccinations, artificial insemination, pregnancy testing etc.

- Priority access – the installation of a priority yard and laneway to allow selected cows to gain access to the front of the milking queue thereby reducing the time they wait to gain access to the milk harvesting equipment. Cows which might be given priority access include heifers in training (or those struggling with the system), cows which were incompletely milked at the previous attempt and cows whose milking interval is undesirably longer.

- Backing gate – the installation of a backing gate was deemed desirable during the early stages of the operation when cows were batch milked through the facility. Although it is not regularly used in the farms voluntary milking system, it has been useful for sweeping cows prior to system washing and maintenance, reducing the effective yard size during heifer training sessions, and used in conjunction with the priority access yard and laneway to allow access to a small group of priority cows without having to compete with the main milking herd which might be held behind the backing gate.

- Buffer vat and milk cooling – the buffer vat was installed to cater for the voluntary cow traffic system. This small, additional milk vat allows the robots to continue milking cows, even when the milk is being collected by the tanker and the main vat is being washed.
At the time of undertaking the case study analysis, it was estimated that the cost of establishing the milking rotary platform (excluding automation) cost the farmer approximately $1.75 million and that an additional $500,000 was required to fully automate the system for full voluntary cow traffic (the modifications listed above). It is important to note that the $1.75 million for the milking rotary platform includes the shed, yards (concrete and pipework), out of parlour feeders, feedpad, and effluent management system etc.

5.3.3 Labour
The family owned and operated Gala AMR farm business employed the equivalent of 2.4 full time labour units (where 1 labour unit refers to 50 hours labour per week). The owner (classified as the business manager) accounted for 50 hours per week; the owners’ partner contributes an additional 50 hours per week as a senior production manager (farm supervisor); and an additional senior farm hand employed on a casual basis contributing about 20 hours per week.

Following discussions with industry experts, the imputed labour cost of the farm manager operating a farm system of this complexity and size is estimated to be $120,000 per annum and the partner’s salary would be valued at $70,000 per annum. The additional senior farm hand being paid for 20 hours (0.4 FTE) at an annual salary of $50,000 would equate to approximately $20,000. Contractors were used for silage production, some spraying, seeding, hay production, tractor servicing, pregnancy testing and veterinary work. These costs were included in the figures used for the analysis of the farm.

In 2015-16, the labour efficiency of the farm was 250 cows per full-time equivalent (FTE). This is compared to other farms across Tasmania in the following sections.

5.3.4 Pasture
Most of the effective milking area was sown to perennial ryegrass. Since the commissioning of the AMR in 2011, the farm manager had operated the farm with a
three-way grazing management system managed by automatic gates to encourage the cows to flow from one paddock, through the dairy and into the next paddock/pasture allocation. This was for 200 ha of perennial pasture designated for the milking herd only, and was used until the 2014-15 season.

In the 2015-16 year from August 2015 onwards, the farm manager implemented a four-way grazing management system. The main reasons for shifting to this management approach was to reduce the size of the queue at the dairy (and subsequently the time spent on concrete at each visit) and to alleviate an ongoing issue with cows pre-empting the evening feed allocation and waiting in the post milking area for some hours leading up to an automated gate change time. Ultimately, this contributes to better voluntary cow movement and improved welfare for the cows. An unintentional benefit of the system was an associated 5 per cent increase in total milk production compared to the previous year. Data collected from the AMR system indicates that this has been primarily due to significantly increased milk production from the lower-performance cows (rather than an increase in average across the herd) and is probably associated with more equitable access to fresh pasture allocations and therefore higher quality feed and/or increased intakes.

The case study farms’ four-way grazing management pasture allocations were divided at unequal intervals (5am, 11.30am, 6pm and 9.30pm), partly because the four areas were different sizes but also to address the periods when queues were longest – typically in the middle of the day and early evening. The operators noticed a 25 per cent reduction in average queuing time and an improvement in the distribution of milkings with a more even spread throughout the day and night.

With this grazing system, the farm manager was able to achieve an average milking frequency of 2.3 milkings per cow per day and the AMR averaged 955 milkings per day. The cumulative average daily operating time of the AMR is 13 hours milking and 2 hours cleaning. The farmer indicated that the four-way grazing system has enabled the AMR to be operating at capacity (80 cows/hour with utilisation pushing further into the night).
5.3.5 Stock

Considering the business is operating at a steady state, a constant herd structure from year-to-year would reflect the system in the future. In 2015-16, the milking herd comprised 100 per cent New Zealand Friesians. The average live weight of each cow in the AMR herd was estimated to be between 570 and 580 kg.

The herd is calved with a split calving system was used with a third of the herd calving in autumn (through February and March) and two thirds calving in spring (through August and September). The average lactation length was 305 days for both first calvers and mature milkers. In a typical year, the number of heifer calves reared was about 25% of the milking herd. The following assumptions were used to describe the herd structure and movement of cows to maintain a steady-state herd:

- 125 heifers and 475 mature cows calved in each year.
- The death rates were: calves 2%, cows and heifers 1%
- The age group cull rates were: 6-7 years old 100%
- Approximately 160 are sold as value added heifers.

In 2015-16, the milking herd consisted of 600 cows milked for the majority of the lactation. This equated to a stocking rate of around 2.2 cows per hectare on the milking area. The herd structure and livestock trading schedule for the case study farm is presented in the Table 5.1.

5.3.6 Milk production

On the AMR farm, each cow produced an average of 8,250 litres of milk in the 2015-16 year peaking at 34 litres per day. This was equivalent to approximately 603 kg per cow of milk solids (320 kg fat and 280 kg protein). At 2.2 cows per hectare, this amounted to 1,340 kg milk solids (kgMS) per hectare, and 361,800 kgMS per farm. The production data for the case study farm in 2015-16 is presented in the Table 5.2.
Table 5.1: Stock trading schedule

<table>
<thead>
<tr>
<th>Item</th>
<th>No.</th>
<th>$/head</th>
<th>Value</th>
<th>Item</th>
<th>No.</th>
<th>$/head</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Opening Number:</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>Sales:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heifers 1 year old</td>
<td>291</td>
<td>1,000</td>
<td>291,000</td>
<td>Heifers</td>
<td>163</td>
<td>1,200</td>
<td>195,600</td>
</tr>
<tr>
<td>2 year old Breeding cows</td>
<td>125</td>
<td>1,800</td>
<td>225,000</td>
<td>Male calves</td>
<td>294</td>
<td>50</td>
<td>14,700</td>
</tr>
<tr>
<td>3 year old Breeding cows</td>
<td>121</td>
<td>1,800</td>
<td>217,800</td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 year old Breeding cows</td>
<td>119</td>
<td>1,600</td>
<td>190,400</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 year old Breeding cows</td>
<td>118</td>
<td>1,600</td>
<td>188,800</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 year old Breeding cows</td>
<td>117</td>
<td>1,600</td>
<td>187,200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulls</td>
<td>0</td>
<td>900</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>891</td>
<td></td>
<td>1,300,200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Purchases:</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>Deaths</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mature cows</td>
<td>0</td>
<td>1,920</td>
<td>0</td>
<td>Heifers 1 year old</td>
<td>291</td>
<td>1,000</td>
<td>291,000</td>
</tr>
<tr>
<td>Bulls</td>
<td>0</td>
<td>1,500</td>
<td>0</td>
<td>2 yo Milkers &amp; dry cows</td>
<td>125</td>
<td>1,800</td>
<td>225,000</td>
</tr>
<tr>
<td><strong>Births</strong></td>
<td>600</td>
<td></td>
<td></td>
<td>3 yo Milkers &amp; dry cows</td>
<td>121</td>
<td>1,800</td>
<td>217,800</td>
</tr>
<tr>
<td>Calves</td>
<td>300</td>
<td></td>
<td></td>
<td>4 yo Milkers &amp; dry cows</td>
<td>119</td>
<td>1,600</td>
<td>190,400</td>
</tr>
<tr>
<td>Males</td>
<td>300</td>
<td></td>
<td></td>
<td>5 yo Milkers &amp; dry cows</td>
<td>118</td>
<td>1,600</td>
<td>188,800</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6 yo Milkers &amp; dry cows</td>
<td>117</td>
<td>1,600</td>
<td>187,200</td>
</tr>
<tr>
<td>Bulls</td>
<td>0</td>
<td>900</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,491</td>
<td></td>
<td>1,300,200</td>
<td></td>
<td>1,491</td>
<td></td>
<td>1,626,500</td>
</tr>
</tbody>
</table>

Non-cash profit/loss   -  
Cash from Sales         326,300  
Stock Trading Profit/Loss 326,300

Table 5.2: Production data for case study farm in 2015-16.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total milk production (L)</td>
<td>4,950,000</td>
</tr>
<tr>
<td>Average milk production per cow (L/cow)</td>
<td>8,250</td>
</tr>
<tr>
<td>Average kilograms of milk solds per cow (kgMS/cow)</td>
<td>603</td>
</tr>
<tr>
<td>Stocking rate (kg liveweight/ha)</td>
<td>1,725</td>
</tr>
<tr>
<td>Average milk solids produced per ha (kg/ha)</td>
<td>1,340</td>
</tr>
</tbody>
</table>

5.3.7 Feed/diet

Milking cows

In the 2015-16 year, the first calvers and mature milkers grazed the milking area for approximately 305 days as a lactating herd, and 60 days as a dry herd (prior to calving). Approximately 300 calves and heifers to 12 months old were also agisted for
approximately 8 weeks before being joined at 15 months in the following season, and retained as 2 year old replacements or sold.

In 2015-16, approximately 51 per cent of stock metabolisable energy (ME) requirements were met by grazed pasture and silage made on-farm (collectively termed home-grown feed). Pasture is fed throughout the year and silage is made available to the cows at certain times of the year when pasture availability is lower than demand. The remaining 49 per cent was bought-in feed predominantly in the form of grain and other concentrates and is made available separately at the out of parlour feed stations and formulated to the individual cow’s needs through the Delpro herd management system. Each cow is fed approximately 2.25 tonnes of dry matter of concentrates. The farm is considered a high input farming system that is very much focussed on best practice grazing management to maximise the utilisation of home-grown feed.

**Pasture consumption**

Apparent pasture consumption in the milking area was estimated based on actual milk production and associated energy requirements (using livestock ME required and ME from purchased feed).

Estimated annual pasture consumption from the 200 hectares milking area was approximately 2,100 tDM (or 10.5 tDM/ha). This meant that the milking area provided around 46 per cent of the ME consumed by the entire herd (milking herd, young and dry stocks, and bulls). The total pasture consumed per year for the milking area was 2,364 tDM (grazed pasture and silage) equating to 11.82 tDM/ha/yr. Refer to Figure 5.2 for the estimated sources of ME brought into the farm and Figure 5.3 for the estimated home grown and purchased feed per cow.

In modelling the farm system, it was assumed that the opening and closing feed inventories for the farm were zero. This means that all feed produced on farm or purchased was used during the year and any excess fodder produced was sold at market rates.
5.3.8 Economic performance

The economic performance of the farm for 2015-16 is summarised in Table 5.3. The economic performance results were calculated using actual data (prices, costs and volumes) collected from the farm.

In 2015-16, the case study farm received a milk price almost identical to the long-term consumer price index (CPI) adjusted farmgate price of $5.61/kgMS. Under the
operational environment experienced in 2015-16, the farmer recorded an annual return on assets of 9.32%, excluding capital appreciation. Refer to the profit budget (Table 5.3), cash flow budget (Table 5.4), tax schedule (Table 5.5), and balance sheet (Table 5.6).

Table 5.3: Profit budget for the case study farm in 2015-16.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Income</td>
<td></td>
</tr>
<tr>
<td>Milk Receipts</td>
<td>$2,026,080</td>
</tr>
<tr>
<td>Stock Trading Profit/Loss</td>
<td>$326,300</td>
</tr>
<tr>
<td>Other income</td>
<td>$-</td>
</tr>
<tr>
<td><strong>Gross Farm Income</strong></td>
<td><strong>$2,352,380</strong></td>
</tr>
<tr>
<td>Less Total Variable Costs</td>
<td>$1,024,060</td>
</tr>
<tr>
<td><strong>Total Gross Margin</strong></td>
<td><strong>$1,328,320</strong></td>
</tr>
<tr>
<td>Less Total Cash Overhead Costs</td>
<td>$340,000</td>
</tr>
<tr>
<td>Less Operators Allowance</td>
<td>$120,000</td>
</tr>
<tr>
<td>Depreciation</td>
<td>$91,500</td>
</tr>
<tr>
<td><strong>Earnings before Interest and Tax (EBIT)</strong></td>
<td><strong>$776,820</strong></td>
</tr>
<tr>
<td>Less Interest and lease</td>
<td>$107,981</td>
</tr>
<tr>
<td><strong>Net Farm Income</strong></td>
<td><strong>$668,839</strong></td>
</tr>
<tr>
<td>Minus tax</td>
<td>$82,581</td>
</tr>
<tr>
<td><strong>Growth (increase in Equity)</strong></td>
<td><strong>$661,258</strong></td>
</tr>
<tr>
<td><strong>Total Assets managed</strong></td>
<td><strong>$8,098,700</strong></td>
</tr>
<tr>
<td><strong>Return on Assets (excluding capital appreciation)</strong></td>
<td><strong>9.59%</strong></td>
</tr>
<tr>
<td><strong>Total assets owned (EQUITY)</strong></td>
<td><strong>$6,892,420</strong></td>
</tr>
<tr>
<td><strong>Return on owner’s equity (excluding capital appreciation)</strong></td>
<td><strong>9.70%</strong></td>
</tr>
</tbody>
</table>

NB. Land was valued at $18,500 per hectare
Table 5.4: Cash flow budget for the case study farm in 2015-16.

**Cash In**

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk Receipts</td>
<td>$2,026,080</td>
</tr>
<tr>
<td>Cash from Sales</td>
<td>$326,300</td>
</tr>
<tr>
<td>Other income</td>
<td>$-</td>
</tr>
<tr>
<td>Fodder sales</td>
<td>$-</td>
</tr>
<tr>
<td><strong>Total Cash In</strong></td>
<td><strong>$2,352,380</strong></td>
</tr>
</tbody>
</table>

**Cash Out**

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Costs-</td>
<td></td>
</tr>
<tr>
<td>Feed Costs</td>
<td>$856,960</td>
</tr>
<tr>
<td>Herd Costs</td>
<td>$77,100</td>
</tr>
<tr>
<td>Shed Costs</td>
<td>$90,000</td>
</tr>
<tr>
<td>Overhead Costs-</td>
<td></td>
</tr>
<tr>
<td>Repairs and Maintenance</td>
<td>$120,000</td>
</tr>
<tr>
<td>Administration</td>
<td>$130,000</td>
</tr>
<tr>
<td>Employed labour</td>
<td>$90,000</td>
</tr>
<tr>
<td>Estimated personal drawings</td>
<td>$45,000</td>
</tr>
<tr>
<td>Lease</td>
<td>$-</td>
</tr>
<tr>
<td><strong>Total Cash Out</strong></td>
<td><strong>$1,409,060</strong></td>
</tr>
</tbody>
</table>

**Net Cash Flow before Interest and Principle**

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest Payments</td>
<td>$107,981</td>
</tr>
<tr>
<td>Principle Repayments</td>
<td>$32,100</td>
</tr>
<tr>
<td><strong>Net Cash Flow before tax</strong></td>
<td><strong>$803,239</strong></td>
</tr>
</tbody>
</table>

**Net cash flow after tax**

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tax payable</td>
<td>$(82,581)</td>
</tr>
<tr>
<td><strong>Net cash flow after tax</strong></td>
<td><strong>$720,659</strong></td>
</tr>
</tbody>
</table>

Table 5.5: Tax schedule for case study farm in 2015-16.

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tax relevant income</td>
<td>$2,026,080</td>
</tr>
<tr>
<td>less variable costs</td>
<td>$1,144,060</td>
</tr>
<tr>
<td>less overhead costs (excluding operators allowance)</td>
<td>$221,500</td>
</tr>
<tr>
<td>less investment into land deducted @ 10% per year</td>
<td>$2,000</td>
</tr>
<tr>
<td>less investment into plant and equipment deducted @ 20% per year</td>
<td>$107,981</td>
</tr>
<tr>
<td><strong>Total taxable income</strong></td>
<td><strong>$550,539</strong></td>
</tr>
<tr>
<td>Marginal tax rate*</td>
<td>15%</td>
</tr>
<tr>
<td><strong>Tax payable</strong></td>
<td><strong>$82,580.91</strong></td>
</tr>
</tbody>
</table>

*The rate chosen is to reflect the most likely average marginal rate.*
Table 5.6: Balance sheet for case study farm 2015-16.

<table>
<thead>
<tr>
<th></th>
<th>Start of year (opening)</th>
<th>End of year (closing)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Assets</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Owned land area value</td>
<td>$4,440,000</td>
<td>$4,440,000</td>
</tr>
<tr>
<td>Total livestock value</td>
<td>$1,300,200</td>
<td>$1,300,200</td>
</tr>
<tr>
<td>Plant and equipment</td>
<td>$2,450,000</td>
<td>$2,358,500</td>
</tr>
<tr>
<td>Cash</td>
<td>$</td>
<td>$720,659</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$8,190,200</td>
<td>$8,819,359</td>
</tr>
</tbody>
</table>

| Liabilities          |                         |                       |
| Loan                 | $1,542,580              | $1,510,480            |
| Cash                 |                          |                       |
| **Total**            | $1,542,580              | $1,510,480            |

**Equity** $6,647,620 $7,308,878

Closing equity $7,308,878
Opening equity $6,647,620
Growth in equity* $661,258

5.4 PERFORMANCE OF THE BASE FARM SYSTEM UNDER A RANGE OF HISTORICAL PRICES AND COSTS.

In the 2015-16 year, Tasmanian farmers experienced a lower average farmgate price of $5.60/kgMS when compared to $6.19/kgMS received in 2014-15. However, this was offset by slightly lower feed costs and rainfall returning closer to long-term averages. For this reason, the performance of the base farm system was also investigated under more typical conditions. Refer to Table 5.7 for a summary.
When applying the long term average price paid for milk solids ($5.61/kgMS), and including commercial land lease rates, the farm is able to achieve a return on assets excluding capital appreciation of 8.80%.

Table 5.7: Total gross income, operating profit (earnings before interest and tax, EBIT) and return to assets in 2015-16, and under long term average prices.

<table>
<thead>
<tr>
<th>2015-16 (Actual prices)</th>
<th>Mean outcome (long term average prices)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk Income $2,026,080</td>
<td>$2,030,017</td>
</tr>
<tr>
<td>Milk Price ($kgMS) $5.60</td>
<td>$5.61</td>
</tr>
<tr>
<td>Feed Costs $856,960</td>
<td>$924,951</td>
</tr>
<tr>
<td>Operating Profit (EBIT) $776,820</td>
<td>$712,763</td>
</tr>
<tr>
<td>Return on Assets 9.59%</td>
<td>8.80%</td>
</tr>
</tbody>
</table>

5.4.1 Variability in performance of base farm system
The performance and risk associated with the case study farm system was also investigated under a range of possible futures for milk prices, feed wheat prices and hay prices. This was carried out by using price and production distributions for these variables which were defined by historical records and industry expertise. For this case study, 10,000 iterations of annual operations were undertaken, with each year experiencing different costs and prices. This combination of costs and prices selected each year helped to generate a range, or spectrum of economic and financial results.

Operating profit (Earnings Before Interest and Tax)
The cumulative frequency distribution for annual operating profit, using average prices and commercial lease rates, is shown in Figure 5.4. This assumes that the farm system is managed in the same way continuously for the next 10 years, but experiences differences in prices and input costs between years based on the probability distributions. This provides an indication of the performance and risk associated with the base farm system. From this scenario analysis, the mean annual operating profit for the current farm business was $712,766 per year. This result reflects what the farmers describe as steady state and the capital invested is performing at the expected full capacity.

The results indicate that there is a large range in the possible outcomes for operating profit. However, in only 2 years out of 100 is the operating profit predicted to be less
than \$0. In 23 years out of 100, operating profit was greater than \$1,000,000. In the middle 60% of years (or 6 years in 10), operating profit is expected to be between \$388,000 and \$1,036,000.

The analysis of the case study under long-term averages assumed that cow numbers and milk production per cow remained constant under all conditions. In practice, the farmer has a range of actions that he could employ to improve the profitability of the enterprise within each year under a range of poor and good prices or seasonal conditions.

![Cumulative frequency distribution](image)

**Figure 5.4: Cumulative frequency distribution for the earnings before interest and tax (EBIT) of the case study farm system under long term average prices.**

**Returns on assets managed and return on owner’s equity**

Return on assets managed and return on owner’s equity also indicated that the farm, under long-term averages, was profitable. In 6 years out of 10, return to total assets was predicted to be between 4.81% and 12.83%, and below 0 in 2 out of 100 years (Figure 5.5). Return to owner’s equity (equity was assumed to be 81% at the start of year 1) is predicted to be between 4.06% and 13.45% in 6 years out of ten, and below 0 in 4 out of 100 years (Figure 5.6).
Figure 5.5: Cumulative frequency distribution for Return to Total Assets of the base farm system under long term average prices and commercial lease rates.

Figure 5.6: Cumulative frequency distribution for the Return to Owner’s Equity of the base farm system under long term average prices and commercial lease rates.
5.4.2 Exposure of the base farm system to various risks

Sensitivity analysis
A ‘scenario analysis’ function in @Risk was used to determine the impact of different variables on the farm’s annual operating profit. The results of the sensitivity analysis are presented in Table 5.8 showing the variables that have the highest impact on annual operating profit.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Milk Price ($/kg milk solids)</th>
<th>Grain Price ($ t air dry)</th>
<th>Milker hay feed Price ($ t air dry)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Simulation</td>
<td>5.59</td>
<td>387</td>
<td>232</td>
</tr>
<tr>
<td>Lowest 10%</td>
<td>4.21 (-1.50)</td>
<td>459 (0.88)</td>
<td>-</td>
</tr>
<tr>
<td>Lowest 25%</td>
<td>4.49 (-1.19)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Highest 25%</td>
<td>6.73 (1.24)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Highest 10%</td>
<td>7.11 (1.65)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

NB. Values in parentheses represent the ratio of factor medians divided by the standard deviation of the simulation (RFMSD).

A scenario analysis was undertaken for the lowest 10% and 25% of outputs, as well as the highest 10% and 25% of outputs. The numbers in the table represent the mean value of the criteria listed and those in the brackets show the ratio of factor means on standard deviation (RFMSD). This measure is useful for comparing the impact of different factors on the outputs of interest. As a guide, the higher the number the more significant the impact relative to other factors.

This can also be presented in a Tornado Graph which shows the actual change in output for a plus one standard deviation change in each input. In this graph, it is very clear that milk price is the most significant variable impacting on return on assets; a 91 cents (one standard deviation) on the long term average price of milk would add an additional 4.12% to the farmers return on assets. As identified in this tornado graph, the variables...
contributing to the variance in EBIT is no different to that experienced in conventional systems. The key influential variables on EBIT are those that are outside of the farmers’ control.

NB: The value shown on each bar is the coefficient value.

Figure 5.7: Contribution to variance of key inputs for the case study farm system under historical conditions

**Milk price**

Given the case study farm system is geared towards high output production per cow, fluctuations in milk price have a significant impact on the variation of operating profit compared with any other input. This sensitivity is emphasised in this farm system where the benefits of a high throughput AMR combined with a high input system generates exceptional production performance per cow (kgMS/cow).

**Supplementary feed price**

In the base farm system, supplementary feed price only affected operating profit substantially in the lowest 10% of periods. In part, this has to do with the probability distribution assigned to supplementary feeds used in the modelling. The distribution is skewed to the left to reflect the fact that supplementary feed prices have a greater
chance of being substantially higher than the mean than substantially lower than the mean.

In this case, supplementary feed costs had a lower impact on operating profit than milk price. This is because during levels of low profitability, a combination of adverse factors such as increases in supplementary feed price and low pasture consumption is required to register a substantial impact on operating profit. Milk price is the key driver of profitability in this base farm system.

**Hay price**

As evidenced in the tornado graph (Figure 5.7), hay price was not a major factor impacting on return on assets as it only represents a small portion of the cows’ diet in this farm system.

**5.4.3 Debt**

Refer to Figure 5.8 for a comparison of the net cash flow after tax under different debt scenarios.

In the current situation, the farm owner is operating at approximately 80% equity ratio (about $1m outstanding principal on the land and additional $0.5m for plant and equipment). Under these circumstances, the operator was achieving a return on equity of 9.70% into the long-term and a strong net cash flow after tax of $720,659.

To further demonstrate the impact of other equity and debt scenarios on the business’s cash flow and owner’s equity, equity levels of 65% ($2,907,940 debt) and 30% ($5,815,880 debt) were tested for the base farm system under long term average prices. When reducing equity levels to 65%, an additional $1.37 million of debt needs to be serviced. When comparing with the base case system, this would effectively mean the farmer is financing half of the AMR system through borrowings. The return on owner’s equity is reduced to 7.06%, the net cash flow after tax is reduced by approximately $100,000 to $628,434 on average due to higher interest and principle repayments. At this level of debt, the operation is in a strong position as net cash flow after tax is only less than zero in 1 of 100 years. In the other 99 of 100 years, the farmer has available
cash flow to re-invest into the business. This assumes that the farmer continues to farm in the same manner and the same level of debt is maintained.

Figure 5.8: Box and whisker plot for net cash flow after tax for the debt scenarios analysed

Note: the box and whisker plot shows the median and variability (interquartile range) of annual steady state net income for the debt scenarios analysed (respectively base case; 65% equity; and 30% equity)

In the final scenario where a starting equity of 30% is assumed, the operator needs to service $5.8 million of debt. In this case, the net cash flow after tax is below zero in about 11 of 100 years. This level of debt reduces net cash flow after tax to $394,093 on average. However, given the strong milk receipts received, it appears that the farmer is still able to generate positive nominal net gains in the owner’s wealth in the long-run. This means that even at 30% equity, the accrued benefits of running this system exceeds interest payments, and other additional operating costs associated with running the business.
It is important to note that this reflects simulation results on an annual basis, therefore not factoring in the increased risk associated with a number of consecutive poor years. A cumulative net cash flow analysis would be required to take this into account.

5.5 COMPARISON WITH FARMS IN TASMANIA WITH CONVENTIONAL MILKING SYSTEMS

5.5.1 Comparison of performance for the 2015-16 year
At the time of writing this thesis, the 2015-16 DIFMP report was yet to be released which would aid comparison of the case study farm to other farms across Tasmania for the same year. However, it is possible to compare the farm physicals of this case study farm system and cost structures with the recent 2013-14 and 2014-15 farms given that any differences are likely to reflect tactical decisions rather than complex and significant system changes that are relevant for this thesis.

Comparing case study farm performance with 2014-15 data
To summarise these two seasons, dairy farm profitability declined in the 2014-15 year when compared with 2013-14, largely a result of lower milk price. While there was only a small change in the overall cost of production, expenditure on purchased feed and agistment costs increased particularly on those farms with high levels of feeding (concentrates per cow). By 2015-16, the farmgate milk price has declined to $5.60/kg MS (from an average of $6.19/kg MS in 2014-15).

From a production point of view, it is important to note that when comparing with the 2014-15 season, which experienced rainfall levels well below long-term averages, the current season (to June 2016) has performed stronger on average in relation to milk production. As a result, comparing the farm performance of the case study farm in 2015-16 to the average farm performance of farms across Tasmania in 2014-15, particularly farm profitability measures, would lead to a slight overstatement of the case study farms’ relative performance.
**Farm physicals**

In this section key whole farm physical parameters for the case study farm compared to other Tasmanian farms operating conventional milking systems surveyed under the 2014-15 DIFMP are presented.

When comparing the performance of the top 25% of farms in the Tasmania DIFMP for the 2014-15 year to the middle band range (Q1 – Q3), there are a number of distinguishing characteristics of the most profitable farms. These include:

- High annual rainfall and irrigation use;
- High kilograms of milk solids produced per cow and per hectare: 486 kgMS/cow compared to the Tasmanian average of 447 kgMS/cow;
- High labour efficiency in terms of kilograms of milk solids produced per full-time equivalent: 69,887 kgMS/FTE compared to Tasmania’s average of 61,600 kgMS/FTE;
- Higher grazed pasture in terms of tonnes of dry matter (tDM) per milking hectare: 10.8 tDM/milking ha compared to Tasmania’s average of 9.3 tDM/milking ha;
- Higher nitrogen application of 237kg/ha compared with Tasmania’s average of 177 kg/ha.

Figure 5.9 shows that the case study farm operates at a high level of labour efficiency when compared to the industry dataset utilising conventional milking systems (between 2013-2015).
At face value, when comparing the case study farm to other farms across Tasmania, the farm is comparable in terms of its physical parameters including farm size and stocking rate per useable hectare (refer to Table 5.9), as well as the cost structures (refer to Table 5.10). However, it is noticeable that the case study farm system differs significantly from that of the average Tasmanian farmer as well as the top 25% of performers. The most notable system differences include:

- higher kg MS produced per cow of 603 kg MS (24% more) compared to the top 25% of performers producing at 486 kg MS per cow.
- higher kg MS produced per hectare of 1,419 kg MS (38% more) compared to the top 25% of performers at 1,032 kg MS per hectare.
- lower proportion of home grown feed as a percentage of ME consumed, 51% compared to the Tasmania average of 69% and top 25% of performers average of 70%.
- higher labour efficiency equating to 250 cows per FTE compared to the 146 cows/FTE achieved by the top 25% of performers. This translates to high kilograms of milk solids per FTE of 150,750 kg MS/FTE compared to the Tasmania average of 61,600 kg MS/FTE. Figure 5.9 illustrates the labour efficiency.
efficiency of the case study farm compared to the rest of Tasmanian farms utilising conventional milking systems (between 2013-15).

- higher pasture consumption in terms of tonnes of dry matter grazed and conserved per hectare per year. The case study farm achieved a pasture consumption of 11.82 tDM/ha/yr in 2015-16, compared to Tasmania’s average of 10 tDM/ha/yr in 2014-15 and 9.6 tDM/ha/yr in 2013-14.

**Table 5.9: Farm physical parameters for Tasmania farms in 2014-15 and case study farm in 2015-16**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total useable area (ha)</td>
<td>280</td>
<td>179 – 332</td>
<td>285</td>
<td>255</td>
</tr>
<tr>
<td>Milking cows per useable hectare</td>
<td>2.1</td>
<td>1.5 – 2.4</td>
<td>2.1</td>
<td>2.22</td>
</tr>
<tr>
<td>Milk sold (kg MS/ cow)</td>
<td>447</td>
<td>398 – 475</td>
<td>486</td>
<td>603</td>
</tr>
<tr>
<td>Milk sold (kg MS/ ha)</td>
<td>924</td>
<td>726 – 1,027</td>
<td>1,032</td>
<td>1,340</td>
</tr>
<tr>
<td>Home grown feed as % of ME consumed</td>
<td>69%</td>
<td>63% - 77%</td>
<td>70%</td>
<td>51%</td>
</tr>
<tr>
<td>Labour efficiency (milking cows / FTE)</td>
<td>140</td>
<td>111 – 158</td>
<td>146</td>
<td>250</td>
</tr>
<tr>
<td>Labour efficiency (kg MS/ FTE)</td>
<td>61,600</td>
<td>48,460 – 72,737</td>
<td>69,887</td>
<td>150,750</td>
</tr>
</tbody>
</table>

**Gross farm income**

In the Tasmania region for 2014-15, the variation in gross farm income between the surveyed farms ranged from $1,733 per cow to $5,088 per cow and a group average of $3,102 per cow. The top 25% of farms averaged $3,585 per cow. The case study farm achieved a gross farm income of $3,921 per cow in 2015-16. This is despite the much stronger prices achieved in the previous 2014-15 year.

**Milk solids production**

During the 2015-16 year, the average milk solids sold in Tasmania was 924 kgMS per hectare (245,649 kgMS per farm) with the top 25% of farms achieving 1,032 kgMS per hectare on average (274,904 kgMS per farm). The AMR case study farm achieved 1,340 kgMS per hectare (361,800 kgMS per farm); this was well beyond the Q1-Q3 range of the Tasmania’s production data.
Variable costs
The variable cost range for Tasmania in the 2014-15 year varied from $1,350 to $5,110 per hectare. However, the average was around $2,914 per hectare compared to the AMR case study farm experienced 30% higher variable costs at $3,792 per hectare. Generally, feed costs are the greatest cost in the dairy business representing around 54% of total costs in Tasmanian farms (Dairy Australia); this was exactly the case for the case study farm.

Overhead costs
As discussed in the Gippsland case study, overhead costs represent a significant cost to the farm business. In Tasmania, there was a large range in overhead costs (cash and non-cash) from $822 to $2,989 per hectare; and an average of $1,746 per hectare. The case study farm exhibited overhead costs of $2,074 per hectare with repairs and maintenance and labour costs representing the largest proportion of overhead costs at 37%.

For the case study farm, employed labour represented 16% of total overheads due to the removal of employed physical labour needed for a farm of this size. After including imputed labour costs, the overall labour costs of the case study farm amounted to 38% of total overheads. In contrast, it is evident that employed labour is by far the largest cost component accounting for an average of 41% of total overheads (cash and non-cash) for the average Tasmanian dairy farm surveyed under the DIFMP. This is also the case for the top 25% of high performing farms in Tasmania with employed labour representing approximately 38% of total cash overheads. This proportion increases to 60% when including the imputed owner and operator labour costs. The removal of physical labour required for milking has significantly altered the cost structure of the case study farm compared to the average Tasmanian dairy farm with a conventional milking system.

Repairs and maintenance costs as well as administration costs both separately represented approximately 21% of total cash overheads. The repairs and maintenance
costs of the case study farm is 26% higher at $444 per hectare compared to Tasmania’s average of $351 per hectare.

The other important non-cash overhead cost, depreciation, is important to analyse given the significant capital outlay of the investment as well as the type of investment. The straight line method for depreciation was used for the equipment with the salvage value being 10% of the original value at the end of its depreciable life. The remaining life of the various components of the farm system capital outlay was also adjusted as follows:

1. New conventional rotary parlour – 30 years;
2. Automation to AMR – 10 years; and

In the Tasmania region for 2014-15, the average depreciation for farms participating in the DIFMP equated to approximately $0.19/kgMS, down slightly from $0.21/kgMS in the 2013-14 year. For the case study farm, depreciation was slightly higher at $0.25 though significantly lower than that of Case Study 1 at $0.69/kgMS. This is largely due to the new rotary parlour which represents over three quarters of the cost of the AMR and is depreciated over 30 years. For this case study, this also included optional infrastructure development such as feedout equipment, laneway development, excavation and glycol chiller.

In the Figure, data was collected for Tasmanian surveyed farms from 2013-14 and 2014-15. The scatter plot illustrates the greater levels of capital intensity generally associated with increases in herd size. When comparing the capital structure of the case study with the long term total capital structure of farms across Tasmania, the case study farm has relatively higher levels of capital intensity when compared to farms of similar herd size.
Table 5.10 – Variable and overhead costs for Tasmania in 2014-15 and case study farm

<table>
<thead>
<tr>
<th>Farm costs ($/kgMS)</th>
<th>Tasmania average (2014-15)</th>
<th>Q1 to Q3 range</th>
<th>Top average</th>
<th>25% average</th>
<th>Case study farm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herd costs</td>
<td>$0.29</td>
<td>$0.22 - $0.34</td>
<td>$0.26</td>
<td>$0.21</td>
<td></td>
</tr>
<tr>
<td>Shed costs</td>
<td>$0.20</td>
<td>$0.14 - $0.23</td>
<td>$0.13</td>
<td>$0.25</td>
<td></td>
</tr>
<tr>
<td>Purchased feed and agistment</td>
<td>$1.74</td>
<td>$1.38 - $2.06</td>
<td>$1.72</td>
<td>$1.82</td>
<td></td>
</tr>
<tr>
<td>Home grown feed cost</td>
<td>$0.91</td>
<td>$0.71 - $1.00</td>
<td>$0.88</td>
<td>$0.74</td>
<td></td>
</tr>
<tr>
<td>Total variable costs ($/kgMS)</td>
<td>$3.13</td>
<td>$2.85 - $3.44</td>
<td>$2.98</td>
<td>$3.02</td>
<td></td>
</tr>
<tr>
<td><strong>Overhead costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rates</td>
<td>$0.04</td>
<td>$0.02 - $0.04</td>
<td>$0.03</td>
<td>$0.05</td>
<td></td>
</tr>
<tr>
<td>Registration and insurance</td>
<td>$0.02</td>
<td>$0.00 - $0.02</td>
<td>$0.01</td>
<td>$0.02</td>
<td></td>
</tr>
<tr>
<td>Farm insurance</td>
<td>$0.07</td>
<td>$0.03 - $0.09</td>
<td>$0.05</td>
<td>$0.07</td>
<td></td>
</tr>
<tr>
<td>Repairs and maintenance</td>
<td>$0.39</td>
<td>$0.28 - $0.46</td>
<td>$0.35</td>
<td>$0.33</td>
<td></td>
</tr>
<tr>
<td>Bank charges</td>
<td>$0.01</td>
<td>$0.00 - $0.01</td>
<td>$0.00</td>
<td>$0.00</td>
<td></td>
</tr>
<tr>
<td>Other overheads</td>
<td>$0.10</td>
<td>$0.05 - $0.12</td>
<td>$0.10</td>
<td>$0.21</td>
<td></td>
</tr>
<tr>
<td>Employed labour cost</td>
<td>$0.72</td>
<td>$0.45 - $0.81</td>
<td>$0.60</td>
<td>$0.06</td>
<td></td>
</tr>
<tr>
<td>Total cash overheads</td>
<td>$1.34</td>
<td>$1.09 - $1.62</td>
<td>$1.14</td>
<td>$0.74</td>
<td></td>
</tr>
<tr>
<td>Depreciation</td>
<td>$0.19</td>
<td>$0.09 - $0.21</td>
<td>$0.14</td>
<td>$0.25</td>
<td></td>
</tr>
<tr>
<td>Imputed owner/operator and family labour</td>
<td>$0.41</td>
<td>$0.19 - $0.57</td>
<td>$0.35</td>
<td>$0.53</td>
<td></td>
</tr>
<tr>
<td>Total overhead costs ($/kgMS)</td>
<td>$1.94</td>
<td>$1.60 - $2.19</td>
<td>$1.63</td>
<td>$1.54</td>
<td></td>
</tr>
<tr>
<td>Total variable and overhead costs</td>
<td>$5.07</td>
<td>$4.70 - $5.37</td>
<td>$4.62</td>
<td>$4.56</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.10: Total farm capital / number of cows per farm
**Earnings before interest and tax**

In 2015-16, the economic performance of the case study farm was stronger achieving an EBIT of $1,295 per cow with rainfall approximately at the long term average for the region. This is compared to the Tasmania average of $831 per cow in the previous year experiencing below long-term average rainfall, and with the top 25% of farmers averaging $1,351 per cow. Although, milk prices were significantly higher at $6.19/kgMS. Refer to Table 5.10 for a breakdown of production costs.

**Return on assets managed and return on owner’s equity**

In the 2014-15 year, the return on assets of farms in Tasmania ranged from 0.00% to 21.2% with an average of 7.8%. The top 25% of farms achieved an average of 13.1% return on assets. The case study farm achieved 9.59% in the 2015-16 year.

The case study farm demonstrated that for the 2015-16 year, it was able to generate a return on assets that is expected to be commensurate with the average performance for Tasmanian farmers in this year.

Return to owner’s equity (equity assumed to be 81% at 2015-16 based on financial data collected from the case study farm) was predicted to grow by 9.70% over the year and as a result increase the owner’s equity up to 83%.

**5.5.2 Variability in long-term farm performance compared to performance of Tasmanian farms surveyed under the Dairy Business of the Year Awards (between 2010 and 2015).**

The long-term performance of the case study farm is compared to the performance of Tasmanian farms between 2004/05 and 2014/15 surveyed under the DBOY. Figure 5.11 and Figure 5.12 illustrate these long-term performances respectively. These graphs are overlaid in Figure 5.13 to compare the frequency and variance in performance that is likely to be achieved in the long-term.
Figure 5.11: Long-term performance of Tasmania farms (2013-14 to 2014-15), Dairy Industry Farm Monitor Program

Figure 5.12: Long-term performance of Tasmania farms (2010-2015), Dairy Business of the Year Awards
Figure 5.13: Comparison of the long-term performance of the case study and Tasmanian farms (DIFMP)

Figure 5.14: Comparison of the long-term performance of the case study and Tasmanian farms (DBOY awards)
When looking at the potential performance of the case study farm over a run of many years, the case study farm appears able to perform strongly from an economic perspective, with a mean return to total assets of 8.80% excluding capital appreciation in comparison to returns experienced on Tasmanian farms over the period 2010 – 2015 (as surveyed under the Dairy Business of the Year Award). The long-term performance of the case study farm outperforms the average Tasmania farmer when compared to the 6 years of performance data from the DBOY Awards between 2010 and 2015. The standard deviation of the return on assets is similar. Key observations:

- The mean return on assets experienced on the case study farm is significantly higher at 8.80% compared to the long-term average in Tasmania (between 2010 and 2015) of 6.86%. The case study farm is expected to achieve this same level of return on assets in 63 of 100 years under its current system. The key difference is the likelihood of achieving a certain range of return around the middle 60% of years (or 6 in 10 years). In the middle 60% of years, the case study farm is expected to achieve a return of between 4.81% and 12.83% compared to the long-term average of Tasmanian farms of between 3.29% and 10.10% (excl. capital appreciation).
- The range of the case study farm is much more confined with a minimum of -7.14% and 21.42%, compared to farms across Tasmania with a range of -10.79% and 42.89%.

When comparing to the performance of Tasmanian farms in the 2013-14 and 2014-15 year (surveyed under the DIFMP), the case study farm’s performance is comparable to the performance of the previous seasons across Tasmania. Similar return on asset profiles was achieved for a similar level of risk. However, it must be noted that the 2013-14 and 2014-15 years experienced significantly higher milk prices at $6.87/kgMS and $6.19/kgMS, respectively.
Table 5.11: Recent data for Tasmania in comparison – Average farm income, costs and profit per kilogram of milk solids

<table>
<thead>
<tr>
<th></th>
<th>Two-year average for Tasmania (2013-14 and 2014-15)</th>
<th>Case study farm under historical conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Income (per kgMS)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross farm income</td>
<td>$7.25</td>
<td>$6.51</td>
</tr>
<tr>
<td><strong>Variable costs (per kgMS)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herd and shed costs</td>
<td>$0.50</td>
<td>$0.46</td>
</tr>
<tr>
<td>Feed costs</td>
<td>$2.58</td>
<td>$2.56</td>
</tr>
<tr>
<td>Total variable costs</td>
<td>$3.08</td>
<td>$3.02</td>
</tr>
<tr>
<td><strong>Overhead costs (per kgMS)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash overhead costs</td>
<td>$1.38</td>
<td>$0.74</td>
</tr>
<tr>
<td>Non cash overhead costs</td>
<td>$0.66</td>
<td>$0.78</td>
</tr>
<tr>
<td>Total overhead costs</td>
<td>$2.04</td>
<td>$1.54</td>
</tr>
<tr>
<td><strong>Profit (per kgMS)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earnings before interest and tax</td>
<td>$2.14</td>
<td>$1.97</td>
</tr>
<tr>
<td>Interest and lease charges</td>
<td>$0.45</td>
<td>$0.30</td>
</tr>
<tr>
<td>Net farm income</td>
<td>$1.69</td>
<td>$1.67</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Return on assets</td>
<td>6.69%</td>
<td>8.80%</td>
</tr>
<tr>
<td>Liabilities per cow</td>
<td>$2,744</td>
<td>$2,517</td>
</tr>
<tr>
<td>Equity</td>
<td>72%</td>
<td>83%</td>
</tr>
</tbody>
</table>

Note: dollar values are the nominal values converted to 2014/15 dollar equivalents by the consumer price index (CPI) to allow for inflation.

Table 5.12: Historical data for Tasmania – Physical information

<table>
<thead>
<tr>
<th></th>
<th>Long-term average for Tasmania (2006-07 to 2014-15)</th>
<th>Case study farm under historical conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milking cows</td>
<td>454</td>
<td>600</td>
</tr>
<tr>
<td>Milking area (ha)</td>
<td>209</td>
<td>200</td>
</tr>
<tr>
<td>Milk sold (kg MS/cow)</td>
<td>403</td>
<td>603</td>
</tr>
<tr>
<td>Estimated grazed pasture (t DM/ha)</td>
<td>9.1</td>
<td>11.82</td>
</tr>
<tr>
<td>Concentrates imported t DM/cow</td>
<td>1.03</td>
<td>2.25</td>
</tr>
<tr>
<td>Cows milked/FTE</td>
<td>113</td>
<td>250</td>
</tr>
<tr>
<td>Labour productivity kg MS/FTE</td>
<td>46,164</td>
<td>150,750</td>
</tr>
</tbody>
</table>


Given data limitations in the Tasmania region, the average farm income, costs and profit per kilogram of milk solids are obtained from the Dairy Industry Farm Monitor Project for the two years that it has been running; that is the 2013-14 and 2014-15 seasons.
(refer Table 5.11). Other physical data could be obtained from the Dairy Business of the Year Awards data set from the period of 2004-05 to 2014-15 (refer Table 5.12).

There are a number of observations that can be drawn from comparing these two data sets. Key observations:

- While feed costs are comparable, the farm physical data reveals that the case study farm is much more productive and efficient in producing feed on a cost per tonne of dry matter basis. This is compared in the below dot points.

- The cash overheads of the case study farm are approximately half that of the Tasmania average over the two years; respectively $0.74/kgMS compared to $1.38/kgMS. This is due to the significant reduction in physical labour required for the milking.

- Non-cash overheads are slightly higher than the average. This is a result of the higher imputed labour cost associated with the owner operator. Due to the high specification and skills required for the job, a salary of $120,000 was assigned for the owner operator. This is above the qualifications of an award-free business manager that sets policy, demonstrates extensive industry knowledge, technical skills and business management principles to perform a complex role.

- Another important non-cash overhead component is depreciation. When comparing to other farms surveyed in the DIFMP, the depreciation is similar to that of farmers using conventional systems in the region. The reason for this is that the new rotary milking system represents over three quarters of the cost of the AMR and is depreciated over 30 years.

- In relation to farm physical parameters, it is apparent that the case study farm is optimising feed production by maximising estimated pasture grazed at 11.82 t DM/ha compared to the region average of 9.1 t DM/ha over the long-term. Further, the farmer is also importing more concentrates to feed the cows with intake at 2.25 t DM/cow compared to 1.03 t DM/cow in the region. The farm is considered a high input system compared to farms across Tasmania over the long-run. This translates into 50% higher milking production per cow producing 603 kg MS per cow compared to the long-term average of 403 kg MS/cow.
• Labour productivity is higher than the long-term average by threefold. The high level of productivity is a result of a high production per cow system as well as the AMR reducing the amount of labour required for a 600 cow herd operation.

5.6 CONCLUSION

The economic performance of the AMR case study farm in its 2015-16 operating environment was analysed as well as its long-term economic performance under typical long-term conditions. The 2015-16 year was a particularly critical year for the farmers given the AMR was deemed to be operating at capacity and where the system has been refined to a stage where the benefits of AMR technology are being realised. At the surface, the base farm performed strongly in a year where milk prices are in line with long-term prices, generating operating profits and a positive annual net cash flow. While there is still no economic performance data of Tasmanian farms for the 2015-16 year, the case study farm registered a strong return on assets of 9.59%. This is impressive when compared to the average return on assets experienced by Tasmanian farmers of 9.5% in 2013-14 and 7.8% 2014-15, where milk prices were significantly higher at $6.87/kgMS and $6.19/kgMS respectively. When comparing the key farm physical parameters, it is clear that the benefits of the AMR technology represent an important element of this strong performance. This is most evident in the high labour efficiency, high grazed pasture per hectare, more targeted high input system and higher milk production per farm.

Under more typical conditions in the long-term, the case study farm is able to register an average return on assets of 8.80%. The key drivers of farm performance as with case study 1 remain as milk prices and grain prices. When exploring these conditions under alternative debt scenarios, it would appear that the case study farm is able to maintain robust cash flows under varying operating environments and in most cases has cash flow to re-invest into its business.

A key observation has been around the capital intensity of the farm calculated as total capital per farm divided by the number of cows per farm. It would appear that farms of similar herd size also employ similar amounts of capital on the farm. While the case
study farm employs marginally more capital for its herd size, it is able to improve its labour efficiency compared to other similar sized farms by more than double.
6 General discussion and conclusion

In the recent past, a significant body of information and knowledge has become available about the factors that affect the economic performance of AMS. Most of this information has been about dairy systems in the northern hemisphere and the determinants of success in European dairy systems are not directly comparable to the year round pasture-based systems prevalent in Australia. More recently, there has been an increase in the commercial adoption of AMS in Australia’s pasture-based system, development of the new automatic milking rotary (AMR), and also extensive research conducted through the Future Dairy project to develop management practices to support the use of AMS technology on pasture-based operations. As a result, there are now real examples of the experiences and performance of commercial businesses adopting AMS, as well as emerging evidence about operating with systems that represent best practice (particularly, voluntary milking). This study is the first to use a whole farm system approach for two case study dairy farms using AMS technology in Australia, and especially for the newly designed AMR developed in Australia.

In this thesis, the biophysical and economic analysis conducted for the two dairy farm case studies will contribute to new knowledge and information regarding the viability of AMS in Australia’s pasture-based systems when compared to conventional milking systems in the respective regions. The major finding of this investigation is that the two AMS farms studied in Gippsland and Tasmania are capable, under the current management, of operating competitively under the seasonal and economic conditions that have occurred in the past and are likely to occur in the future, when compared to farms using conventional milking systems in the same region and under the same conditions. Note: ‘operate competitively’ means ‘in the hands of the current managers, able to earn a range of annual returns to capital equal to the range of returns to capital earned by all the other dairy systems operating in Australia, and with similar risk profiles’. Note, also: while such a conclusion holds for the current managers of the case study farms, any manager of any system can fail to earn competitive returns on capital and fail to manage the risks: the key to these systems, as in all systems, is the skill of the management and the debt carried.
The Australian dairy industry is predominantly pasture-based relying on cows grazing throughout the year (Dairy Australia, 2016). This type of system is generally acknowledged to be the most cost efficient for producing milk (Horan et al., 2005), depending on the value of the land used. As such, the findings of this research are highly relevant to many Australian dairy farmers, given that the case studies demonstrate that AMS can be integrated successfully into Australia’s low cost pasture-based system in an economically competitive manner.

**Case study 1 – Gippsland AMS farm**

The first case study was for an AMS operation in Gippsland. The 2011-12 year represented a year that was 3 years post-adoption of the AMS. The case study business under the current management and managed in the way it is, is expected to achieve a return on total assets above the long-term average achieved by CMS dairy farm systems in Gippsland under a range of historical prices, costs and seasonal conditions. This assumed that the farm system was operating at a steady state and being managed in the same way into the future.

For 2011-12, the Gippsland case study farm generated a strong return on assets of 7.23%, well above the average of the 4.4% across farms surveyed in the same year using conventional milking systems. When comparing the key farm physical parameters, the benefits of the AMR technology represent an important element of this strong performance. This is evident in the high labour efficiency, the high proportion of home grown feed consumed, and a high volume of milk solids produced per cow.

Under the range of typical conditions in the long-term, the case study farm is likely to be able to generate a mean return on assets of over 5% with a standard deviation of 3%. This is marginally higher than the long-term average in Gippsland of approximately 4.5% with a standard deviation of around 4.4%. The business risks – seasons, prices – of dairying in the region are similar, regardless of the dairy system employed.
When discussing the results of the analysis with the farm manager, there are a number of key messages that help to support and enrich the findings of this case study farm. Key observations are:

- Quote “a good pasture manager becomes an average pasture manager in an AMS voluntary milking system”. This requires the operator to use new processes available under AMS to optimise pasture allocation.
- Key improvements in pasture allocation is required to drive system performance under AMS. Noticeable changes for this case study farm has been increasing home grown feed, reduced purchased feed, while maintaining relatively high concentrates in the cow diet.
- Improved data capture and synthesis has enabled for better understanding of rumination patterns, milk flow, cell counting, grazing patterns and more accurate pasture allocation. Precise pasture allocation is a fundamental driver of system success for this operation.

At the time of adoption, the farm manager revealed that the adoption phase was protracted given the limited information publicly available about how to manage AMS in pasture-based dairy farm systems. It is believed that today, the adaptation phase for AMS could be shortened to approximately 6 months as a result of drastic improvements in industry knowledge and experience of AMS in Australia.

**Case study 2 – Tasmania AMR farm**

The second case study was a dairy farm running an automatic milking rotary (AMR) system in Tasmania. The economic performance of this business was assessed by analysing data for the 2015-16 operating environment as well as analysing its long-term economic performance under the full range of potential long-term seasonal and economic conditions. The 2015-16 year was a particularly critical year for the farmers given the AMR was deemed to be operating at capacity and where the system has been refined to a stage where the benefits of AMR technology are likely to be (near) fully realised. The base farm performed strongly in a year where milk prices were in line with long-term prices of $5.61/kgMS, generating operating profits and a positive annual net cash flow. While comparable economic performance data of Tasmanian farms for the
2015-16 year is as yet unavailable, the case study farm registered a strong return on assets of 9.59%. This compares well with the average return on assets experienced by Tasmanian farmers of 9.5% in 2013-14 and 7.8% 2014-15, where milk prices were significantly higher at $6.87/kgMS and $6.19/kgMS respectively. When comparing the key farm physical parameters, the AMR technology and the information it provides to the decision-makers represent an important element of the economic performance. This is most evident in the high labour efficiency, high grazed pasture per hectare achieved and the precision high input system that is applied.

Under the full range of potential conditions in the long-term, the case study farm is likely to be able to register an average return on assets of 8.8% and standard deviation of 4.4%, similar to the long-term average performance in Tasmania of 8.7% with a standard deviation of 4.3%. When exploring these conditions under alternative debt scenarios, it would appear that the case study is able to maintain robust cash flows under varying operating environments and in most conditions has cash flow after debt servicing to re-invest.

A key observation has been around the capital intensity of the AMR farm calculated as total capital per farm divided by the number of cows per farm. It would appear that farms of similar herd size also employ similar amounts of capital on the farm. The case study farm has marginally more capital invested for the size of its herd but is able to significantly improve its labour efficiency compared to other similar sized farms. The significant reduction in physical labour required for milking meant that cash overheads for the case study farm was approximately half that of the long-term average for Tasmania.

The results of this investigation was discussed with the farm manager. The farm manager shared a number of insights that provide a more rounded understanding of the AMR operation. Key insights include:

- Quote: “the right farmers are beginning to adopt AMS for the right reasons for their system”.

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• Adopting a voluntary milking system requires the farm manager to place a strong focus on feeding accurately and achieve good pasture utilisation to drive system performance.

• Computer software to manage data collected through the AMS is providing opportunities for farm managers to improve system performance. The use of different reports help the manager to specify parameters and deviations that are critical for the farmers’ attention, at a cow-by-cow level. The farm manager referred to this as bringing in an ‘autonomous manager’ into the farm system.

When comparing the capital intensity of both farms to dairy farms across their respective regions using conventional milking systems, it was apparent that similar levels of capital intensity was used for farms of similar herd size. However, the Gippsland farm had significantly larger depreciation costs in comparison. This is because for a larger proportion of the total AMS equipment, depreciation is treated like depreciation for complex machinery, having a life of 15 years with a small salvage value, compared with a conventional milking system where a larger proportion of the total milking equipment is treated like non-complex machinery and depreciated over 30 years or included as improvements in overall land and buildings. Further, the low depreciation costs for a significant proportion of other comparable farms in the region can be explained somewhat by the industry upgrading milking equipment around the time of industry deregulation in 2000, with the milking equipment either at the end or nearing the end of its depreciable life. That is, as well as the nature of the capital, the relatively recent nature of the investments in the AMS and AMR systems would also contribute to higher depreciation costs than the average of other farms in the region. On the other hand, the depreciation costs experienced in the Tasmanian AMR system was only marginally higher than the regional average experienced in Tasmania. This is because the new rotary parlour, which represents over three quarters of the cost of the AMR, is depreciated over 30 years.

When comparing the physical and economic performance of both case study farms with data for farms with conventional milking systems in the same regions, there are
common success factors that contribute to the competitive economic performance of both case studies. These key factors included:

- Having higher kg MS produced per cow;
- Having higher labour efficiency in terms of number of cows per full-time equivalent;
- Achieving higher pasture utilisation in terms of estimated tonnes of dry matter grazed per hectare; and
- Achieving lower cash overheads as a result of labour savings.

The sensitivity analysis conducted for both farms suggest that, like all types of dairy systems, milk price and grain price remain the most critical variables affecting farm profitability. Variability in milk and grain prices affected the Tasmanian case study dairy farm more than the Gippsland farm, given the Tasmanian farm system is a high input system that is geared towards high output production per cow. This is important given AMS provides an opportunity to tailor concentrates fed with individual cow production and therefore improved return on investment in concentrates. However, this level of risk is comparable to other farms in Tasmania when compared to the long-term average performance for Tasmania.

It is important to note that for both case study dairy farms, the economic analysis conducted were only for the AMS component of the businesses. However, both case studies are part of a larger enterprise for the farm owners. The complementary effects between the non-AMS and AMS systems, while difficult to quantify and value, seemed to be numerous, varied and in sum, significant. Adding an AMS operation to a well-run CMS dairy system may well be a model for expansion for operators seeking to expand but constrained by quantity and quality of available labour, and an expansion option that does not add to business risk (and provided added financial risk is compatible). When interviewing the farm managers, a number of noticeable complementary factors of being part of a larger enterprise were raised. These include:

- Ability to select and swap cows that are more likely to adapt effectively to a voluntary milking system and the AMS;
- Ability to leverage cash flow off other operations during the process of adoption; and
- Ability to spread risk and therefore use the technology better to drive performance across the larger enterprise. For example, enabling labour to move between operations during different calving periods and therefore improving labour efficiency across farms.
- Greater flexibility with timing and labour tasks compared to adding another CMS farm.

While this is an economic analysis, the decision to adopt and integrate AMS into the dairy farms in the cases studied was also based to a considerable extent on a range of factors that are difficult to quantify and value. This needs to be considered on an individual basis. The most notable non-pecuniary benefits for AMS in pasture-based systems include:
- Flexible work routine;
- Reduced physical work load;
- More production information readily gathered and made available, with associated decision-making benefits and mental challenges and stimulus (for some);
- More time available to focus on farm management and business, and off-farm activities;
- Improved animal health and welfare; and
- Attractive for some young farmers.

In recent years, the knowledge around the adoption of AMS in Australia’s pasture-based dairy systems has increased markedly with the ‘practical operated experience’ of AMS farms being fine-tuned and operating competitively. The use of case studies and farm budgeting with sensitivity analyses of key criteria, prices and costs provided a transparent and simple method to assess the economic performance of two case study dairy farms in comparison to farmers using conventional milking systems in the same regions. Further, the advice of the steering committee was crucial to ensure that the way the technology is represented in the farm budgeting is as close to reality as possible.
Ultimately, the success of incorporating AMS into Australia’s pasture-based dairy systems will depend almost completely on the human element. Good managers can make almost any system work well and profitability. Fluctuations in prices, costs and seasonal conditions, and increasing competition will continue to place pressure on profit margins for operators of all dairy systems. Good management and decision making skills is fundamental to ensuring that introducing new technologies, such as AMS, are integrated into the whole farm system to make the best use of a given set of resources and circumstances, and realise the wide array of benefits technology has to offer some people in dairy.
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Author/s:
Taing, William

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