Economic Assessment of Automated Milking Systems in Minnesota

A Thesis
SUBMITTED TO THE FACULTY OF THE
UNIVERSITY OF MINNESOTA
BY

Zachary Uter

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

Dr. Joleen Hadrich

June 2023

Table Of Contents

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

The dairy industry is continuously evolving and one area that has evolved is the milking process. This change is an important factor in improving productivity and farm profitability (Bewley, 2010). The dairy industry initially utilized hand milking of the animals, transitioned to semi-automatic systems, and now automated milking systems are becoming the norm. Automated milking systems (AMS) were introduced in 1992 when the first commercial system was installed in the Netherlands. Since then, almost half of the new milking systems installed in Europe are robotic (Hyde & Engel, 2002). As of 2019, there are more than 35,000 AMS units in use around the world with a majority in Europe (Salfer et al., 2017). In 2011, about 500 United States dairy farms were using AMS. This nearly doubled by the end of 2017 when roughly 900 farms (approximately 2-3% of herds) were milking with AMS (Salfer & Endres, 2014; Leach, 2018). These innovations are an advantageous investment because the AMS units can milk continuously 24 hours per day, stopping only for maintenance and washing, and they have demonstrated benefits for dairy farmers and their families such as reduced labor, an increased amount of hours slept, and a more flexible lifestyle for dairy farmers and their families (Hansen, Bugge, & Skibrek, 2020).

The number of cows milked by one AMS unit typically ranges from 50-75 cows. Due to the large investment cost of AMS, these technologically advanced systems have size considerations. AMS is usually found on farms with 50 cows to 240 cows with only a few farms across the United States milking over 1,500 cows with AMS. Some Minnesota farmers have invested in AMS to fulfill many of the goals they have for the future of their dairy operations. There are a number of reasons why producers elect to install AMS, but often operators are focused on the primary issue of making their farm more competitive in a time where efficiency is key to success. Minnesota's dairy industry has changed dramatically over the past 15 years with licensed dairy farms milking 223 cows on average in 2022, up 128 cows from 2008 (United States Department of Agriculture, 2023b; United States Department of Agriculture, 2023c). This research studies farms that have transitioned from stall and parlor milking systems to AMS. The farms in this study also milk a similar number of cows as compared to the Minnesota average, ranging from 60 to 300 cows after the installation of AMS.

In this study, managerial characteristics and financial performance of stall and parlor milking systems are compared before and after the installation of AMS. Two different sources of data are used in the analysis. The first is a survey regarding farm managerial characteristics, and the second source provides financial data that was acquired from farm FINBIN records (www.finbin.umn.edu) or directly from the farmer. This study then analyzes the economics of installing AMS, using a net present value (NPV) analysis. Four different scenarios are compared based on the initial milking system the farm is transitioning from and the average number of cows per AMS unit. Characteristics used for the NPV analysis include survey responses, farm financial averages after the installation, predicted future agricultural trends, and assumed variables. The findings will be used to inform small- to average-sized dairy farms on whether investing in AMS is a profitable decision and emphasize costs that must be controlled if the decision is not in favor of AMS.

II. LITERATURE REVIEW

Numerous studies exist that have researched technology adoption in agriculture and specifically in the dairy industry. Previous work has examined the implementation of recombinant bovine somatotropin (rBST) (Foltz & Chang, 2002), breeding technology (Khanal & Gillespie, 2013), computer-based information systems, and much more (El-Osta & Morehart, 1999; Gezie, Mekonnen, Kidoido, & Mengistu, 2014; Abdullah & Samah, 2013; Bach & Cabrera, 2017; Quddus, 2013). Understanding technology adoption and its impacts on profitability is important as it not only informs producers but also shapes extension programs, policy, and future research

Gillespie et al. (2010) studied the adoption of rBST and the profitability of its use in the United States. Using data from the Agricultural and Resource Management (ARMS) survey, the study analyzed a farm's likelihood of adopting rBST using a probit model and the impacts rBST had on farm profit and productivity using an ordinary least squares model. Results indicated that certain characteristics drove the adoption of rBST which included the number of cows, region, age, and education, as well as complementary technologies on the farm. It was shown that rBST was adopted more often on larger farms which were more likely to be profitable although adoption drivers may also be driving profitability within the study. Smaller farms were less likely to adopt rBST because they may not have existing complementary technologies due to an increased management requirement and most small farms use low-input systems. El-Osta and Morehart (2000) used a diverse approach to study the production and competitiveness of dairy farms that used two broad types of technology, capital-intense and management-intense. Capital-intense technology (advanced milking parlors, genetically superior dairy cows, etc.) was associated with higher startup costs whereas management-intense technologies (record-keeping programs, rBST, improved feeding practices, etc.) were less expensive but required more human capital. Using a multinomial logit regression, El-Osta and Morehart (2000) found that the use of both types of technology are associated with decreased probability of a farmer being in a low milk production group. Management technology had a larger magnitude than capital-intense technology in determining whether a farmer would be in the top performance group.

There has also been a recent focus on the adoption of AMS in the dairy industry as small- and medium-sized dairy farms try to remain economically sustainable. Moyes et al. (2014) aimed to identify social factors influencing producer concerns about transitioning to AMS. Using data from a survey of small and medium-sized farms from the mid-Atlantic region of the United States, a logistic regression showed that farmers with higher levels of education and farms with larger herds were more likely to consider adopting AMS. The study also used a linear regression which showed that the leading factors when considering the transition to AMS were improvements in herd management and management of family time. Mathijs (2004) also captured social motivations through farm interviews conducted in Europe, and many farmers cited labor flexibility, improved social life, and improved health as reasons to invest in AMS. Floridi et al. (2013) used a Real Options approach to model and simulate a farmer's decision to replace a conventional milking system (CMS) with AMS and the timing of investments in Noord-Holland in the Netherlands. The results showed that the adoption of AMS was heavily influenced by current market conditions as well as policy uncertainty related to European

Union milk quotas. Farms that adopted AMS increased in acreage and herd size due to the decreased labor requirements.

Extensive research over the past 30 years has studied factors affecting the profitability of AMS farms in an attempt to inform farmers and impact policy. These technologically advanced systems are accompanied by high capital costs with the ability to increase the productivity of the cows and decrease the intensive labor needs when compared to CMS. The decision to adopt AMS is not independent, rather it interacts with a number of systems within the dairy operation. Therefore, the farmer must consider the cumulative effect of this decision in addition to the financial implications.

Many AMS profitability studies use simulations due to the lack of available farm-level data. Rotz, Coiner, and Soder (2003) simulated the implementation of AMS for farms ranging in size from 30 to 270 cows to examine long-term profitability. The highest returns were observed when AMS units were used at maximum milking capacity. When compared to CMS, the greatest return was observed using a single-stall AMS on a farm with 60 cows and an average production of 8,600kg (18,960 lbs). Hyde and Engel (2002) used a Monte Carlo simulation to estimate the breakeven purchase value of AMS under three different farm size scenarios. They found that the breakeven value for each farm size is greater than the costs associated with the AMS. Their sensitivity analysis showed that labor prices and the useful life of depreciable assets had a significant impact on breakeven values. Salfer et al. (2017) modeled profitability using partial budget simulations for three different size farms. A 120-cow and 240-cow AMS farm were found to be more profitable than CMS, but the 1,500-cow AMS farm was less profitable. Breakeven labor costs would need to be $27.02/hr for the 1,500-cow farm to compete with CMS assuming wage inflation of 1% per year. The economic life of AMS must also be 13 years or longer for the AMS to have a positive return. Another simulation study by Shortall et al. (2016) compared AMS and CMS profitability on pasture-based farms. Two different scenarios (70 cows and 140 cows) were evaluated for both AMS and CMS using a whole-farm budgetary simulation model. Although labor was reduced significantly for AMS, this system incurred higher interest expense, depreciation expense, and maintenance costs resulting in CMS being more profitable for both farm sizes.

Despite that many studies used simulations to analyze the impact of AMS, a few empirical studies had the capacity to use real farm data such as Bijl, Kooistra, and Hogeveen (2007) who examined the difference between AMS and CMS farm profitability using data from 62 dairy farms from the Netherlands. Each AMS farm was matched to a CMS farm that made an investment that same year to create treated and control groups. Results show that AMS was effective in decreasing labor expenses although they had lower revenues than their CMS counterparts. AMS farms had lower livestock and feeding costs, effectively netting out any margin between the two systems. Hansen, Herje, and Hova (2019) also studied the profitability difference between AMS and CMS farm profitability in Norway. Using kernel-matching and ordinary least squares, the results of the model conclude that AMS can be more profitable beyond 45 cows when compared to CMS. This shift comes from decreasing marginal costs coupled with higher revenues per cow which are a result of higher milk production on AMS farms.

Few studies have evaluated how dairy producers' management skillset impacts their ability to use AMS to generate additional profit on their farms. Some studies use management factors to determine productivity (Hagevoort, Douphrate, & Reyolds, 2013; Alvarez & Nuthall, 2006) but do not address the profitability of the farm. Other studies have addressed farmer welfare after the adoption of AMS (Huang, 2020; Tse, et al., 2018), which continues to be a question of interest. This research utilizes survey data pertaining to managerial choices made by farmers coupled with their farm's former financial data and connects it to the future profitability of AMS farms using NPV analysis. Many of the previous studies were conducted during the early adoption of AMS. Therefore, the studies relied on simulated data or matching techniques to determine the profitability of AMS compared to CMS rather than actual data generated on farms utilizing the technology. This study contributes to the profitability literature by using farm-level panel data from eight farms in Minnesota before and after the adoption of AMS, ranging from early adopters in 2011 to new installations in 2019.

III. DATA & METHODS

Data for this research were collected from eight Minnesota dairy farms that had transitioned to AMS and have been operating with AMS for at least three full calendar years. Financial data from three years prior to installation, at installation, and three years after installation of AMS were collected from the producer from one of two sources. Some farmers participated in the Minnesota Farm Business Management program (FBM) and contributed data to FINBIN, which was used as the main financial source. If the producer did not have FINBIN data or had incomplete data, the financial information was collected from financial statements provided by the producer, or the producer gave permission to access these financials through their agricultural lending institution or accountant.

When considering investing in AMS, dairy farmers must make the following decisions about herd size (increase, decrease, or remain the same), construction type (new or retrofit), changes to manure storage, and installation of other complementary technology, among other options. Once these decisions are made, then the farmer must determine the overall economic implications of the decision.

1. Survey

The survey used in this study was created through a combination of focus groups and factors that were considered in other research studies addressing the profitability of AMS. Seven different sections were created with multiple questions per section. These sections focused on investment costs, operational characteristics, and management characteristics and were created with multiple questions per section. The survey was then reviewed by the University of Minnesota's Institutional Review Board (IRB), and it was not considered to be human research and therefore did not require IRB oversight. Eight farms were surveyed, of which six were conducted in-person at the AMS facility, one was conducted via virtual meeting, and one was conducted over the phone. The survey elicited information that included the farm's initial milking system as well as the AMS installation date which was used to compare financial and farm characteristics before and after AMS. The previous milking system of a farm will be referred to as the initial farm type throughout the rest of this paper.

The survey consisted of seven sections: investment costs, decision-making, operation characteristics, labor management, milk production, reproduction management, and other AMS-related questions. These sections were used to collect background information about each farm and different management approaches. The investment section included any expenses for site preparation, lumber, concrete, electrical, plumbing, labor, etc. to accurately account for the total investment cost of the facility or buildings needed for installing AMS. The cost of the AMS unit (the cost of the unit and installation of the necessary components) was captured separately from the facility cost. The decision-making portion of the section included the year of AMS installation, reasons for investing in AMS, and other alternatives explored such as other CMS or exiting the industry. The operations characteristics section concentrated on the physical characteristics of the AMS facility which included the type of facility that is used, number of AMS units, brand of AMS, cows per AMS, location of the AMS, traffic type, and information about the previous milking system. The labor management portion captured information on the number of employees, time spent fetching cows, and the practices used within the AMS facility. The feeding characteristics section included the type of feed used in the AMS, frequency of feed pushing before and after AMS installation, and average feed fed in the AMS. The milk production section asked questions regarding current and past somatic cell counts, average box time, average number of milkings, and treated cow information. Reproduction characteristics focus on changes to the farm's breeding program and any features that were targeted to increase productivity with the AMS. The other category of the survey consisted of other technology adopted with the AMS, special funding for the AMS, as well as satisfaction with investments to date.

Profitability was compared before and after the installation of AMS for each farm type. This comparison was done using the average values from each initial farm type and the three years of data before and three years after installation. Due to the small sample size of this study, an analysis of the statistical significance of the differences was not completed.

One measure of profitability used in the comparison is the rate of return on assets (RROA), which is a long-term measure of profitability. The equation for the rate of return on assets is:

(1) $Rate\ of\ Return\ on\ Assets =$

$$\frac{Net\ Farm\ Income + Interest\ Expense - Opportunity\ Cost\ of\ Labor\ and\ Management}{Average\ Farm\ Assets}$$

and measures the return on all investments, or assets, of the farm if no debt financing was used, hence interest expense is added back to NFI. The opportunity cost of labor and management is deducted from NFI so as to not credit assets with additional earnings from unpaid wages. An opportunity cost of $55,000 was used for all farms in the study. RROA is expressed as a percentage that allows for easy comparison across many years for a farm and farm-to-farm comparisons even if they differ in size.

Another profitability measure used in the comparison of farm types is the operating profit margin ratio (OPMR). The OPMR is used as a short-term profitability measure and calculates profit as a percentage of the total revenue the farm brings in. The equation for OPMR is:

(2) $Operating\ Profit\ Margin\ Ratio =$

$$\frac{Net\ Farm\ Income + Interest\ Expense - Opportunity\ Cost\ of\ Labor\ and\ Management}{Total\ Revenue}$$

which uses the same factors in the numerator as RROA. By adding back interest expense and subtracting the opportunity cost of labor and management, OPMR focuses on yearly returns without regard to debt but still considers unpaid labor and management costs. Dividing by total revenue allows the farmer to interpret the ratio as a percentage of every dollar made in profit after paying operating expenses.

2. NPV Analysis

Not only will changing expenses and revenues need to be considered but several other factors such as interest rates and tax rates must be considered. Another important concern is the time value of money or the assumption that a dollar today is not worth the same as a dollar in the future. In order to analyze this decision with its many nuances, a net present value (NPV) analysis is performed. An NPV analysis, or discounted cash flow method, is a capital budgeting technique that allows for the comparison of different investment scenarios whose cash flows may differ over the life of the investment. NPV analysis uses many assumptions since it is a multiyear investment that must discount future cash flows generated by the investment to today's value (Kay, Edwards, & Duffy, Farm Management, 2008; Olson, 2011; Barry & Ellinger, 2012).

Investments with an NPV that is greater than zero should be considered since the return on the investment for the farm is greater than the cost of capital. If multiple investment options are positive, the investment with the highest NPV is preferred. If the NPV is equal to zero, then the farmer is indifferent to investing since it would not provide any additional return over the cost of capital. Investments with a negative NPV should not be made since the cost of capital outweighs the future revenues of the asset (Kay, Edwards, & Duffy, Farm Management, 2008; Olson, 2011; Barry & Ellinger, 2012). NPV is calculated as:

$$(3)\ NPV = -Investment_{t=0} + \frac{\sum_{t=1}^{T=n} Cash\ Inflows_t - Cash\ Outflows_t}{(1+WACC)^t},$$

where *Investment* is the investment cost to install AMS on the farm, *Cash Inflows*$_t$ are revenues generated from the new AMS at time t, *Cash Outflows*$_t$ are expenses including cash operating expense, loan payments, and fixed expenses from AMS at time t, and the weighted average cost of capital (WACC) is the discount rate. WACC represents the opportunity costs of investment for the farm and therefore takes the costs of equity, cost of debt, and marginal tax rate into account when discounting future value. The calculation for WACC is:

$$(4)\ WACC = \underbrace{\left(i_e + \frac{E}{A}\right)}_{Cost\ of\ Equity} + [\underbrace{\left(i_d + \frac{D}{A}\right) * (1 - Tax\ Rate)}_{After-Tax\ Cost\ of\ Debt}],$$

where i_e is the interest rate of equity, $\frac{E}{A}$ is the equity-to-asset ratio, i_d is the interest rate of debt, $\frac{D}{A}$ is the debt-to-asset ratio, and *Tax Rate* is the marginal tax rate of the farm. *Cost of Equity,* $\left(i_e + \frac{E}{A}\right)$, captures the opportunity cost of the investment based on the farm's equity position and prior returns to equity. *After-Tax Cost of Debt,* $\left(i_d + \frac{D}{A}\right) * (1 - Tax\ Rate)$, captures any tax deductions from the interest expense the farm will incur for the project based on the solvency position of the farm and the interest rate on the debt it acquires for funding (Barry & Ellinger, 2012).

Financial data, including solvency and profitability measures, were used as the base assumptions for the NPV analysis. These measures were collected from the farms surveyed which included three years prior to the installation year, the installation year, and three years after the installation of the AMS, totaling seven years of data. This data was obtained from the FINBIN database or from the producer if the farm did not participate in the FBM education program. In the FBM program, farm business management instructors work with farmers to help them meet their business goals. In return, these farms contribute their financial data to FINBIN (www.finbin.umn.edu), which is a farm financial database with contributions from 12 states. If the farm did not participate in FBM during the study period, financials were acquired from the farmer or the farmer's financial institution. This analysis relies on accrual-based statements to match revenues and expenses to when they are generated and recognized. Farms that provided cash profit/loss statements were converted to accrual income statements using the farm's corresponding balance sheets to match the accrual statements within FINBIN. Accrual-adjusted variables are used in the NPV analysis since they provide a more accurate estimate of profit than cash accounting (Kay, Edwards, & Duffy, Farm Management, 2008). Accrual revenues generated by the farm include income from milk sales, other cash revenue such as crop sales and government payments, and accrual adjustments of inventories and accounts receivable. Accrual expenses include cash operating expenses, accrual adjustments to prepaids/supplies and accounts payable, depreciation expenses, and interest expenses.

The survey and financial data contain the three key variables that were used in the NPV analysis: investment cost, cash and accrual revenues generated by the farm, and cash and accrual expenses recognized by the farm. All the financial variables used in the study, FINBIN and self-reported, were inflated to 2022 values using the Consumer Price Index from the Federal Reserve Bank of Minneapolis (Federal Reserve Bank of

Minneapolis, 2023). Market assumptions from the Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri were used to predict future trends in milk production, revenues, and expenses. The outlook within the FAPRI report estimated future agricultural trends from 2023-2032 and the NPV analysis in this study uses a 15-year investment period which ends in 2037. Therefore, values from the FAPRI report were extrapolated from 10 years to 15 years using Microsoft Excel® to estimate the last 5 years of the investment period. The trends were estimated as linear or logarithmic after 2025 and a trendline was used to calculate the expected future values from 2033-2037.

Four NPV scenarios were created to analyze new barn construction costs for farms converting from different types of CMS to AMS including (1) stalls to AMS with 60-69 cows per unit, (2) stalls to AMS with 70+ cows per unit, (3) parlor to AMS with 50-59 cows per unit, and (4) parlor to AMS with 60-69 cows per unit. Each of these scenarios considers two AMS units per farm. These scenarios were created using the empirical data collected through in-person survey data collection. It was assumed that these responses were representative of small- and medium-sized Minnesota dairy farms. This study emphasizes the managerial perspective for the NPV analysis and therefore uses accrual revenues and expenses to more accurately reflect the operations of a dairy farm.

IV. RESULTS

1. Survey Summary Statistics

Of the eight farms that were surveyed, five transitioned from a stall barn, meaning a stanchion or tie stall barn, to AMS and the remaining three converted from parlor setups

(Table 1)[1]. Each of the farms that were surveyed are still operating with their original AMS units and milking Holstein dairy cows. The earliest installation date within the survey farms was 2011. After installing AMS, the farms in the study indicated they no longer utilized their initial milking system. The maximum number of AMS units on a farm was four and the average cost of each unit was $195,760 in 2022 values. The average facility cost of $1,318,087 does not include the AMS units nor any additional project costs such as the addition of a manure lagoon.

Table 1. Operation Characteristics and Investment Costs

	Obs.	**Mean**	**Min**	**Max**
Installation Year	8	-	2011	2019
Initial Farm Type		-	-	-
Stalls	5	-	-	-
Parlor	3	-	-	-
Number of AMS Units	8	-	1	4
Facility Cost without AMS Units*	8	$ 1,318,087	-	-
AMS Unit Cost*	8	$ 195,760	-	-

Source: Study Survey
Note: * Indicates values were inflated to 2022 Values

The investment costs, as reported by the farmer, differed greatly when examining the initial farm type for the project and AMS unit expense (Table 2). On average, farms transitioning from stalls had facility costs almost three times as large as those from parlors even though the facilities and equipment within them were very similar to one another. Seven of the eight farms within the study were new builds, meaning that the facility that houses the freestalls and the AMS units was newly constructed. The difference in costs is unknown since farmers reported many of the same technologies

[1] Data sources for survey summary statistics are found in APPENDIX A: Data Sources

within their AMS barn including an automatic feed pusher, automated manure cleaning system, cross- or tunnel-ventilation systems, etc. AMS units were also more expensive for stall farms with an average cost of $211,590 in 2022 values compared to that of $169,377 for parlor farms.

Table 2. Average AMS Project Costs by Initial Farm Type

	Transitioning From	
	Stalls	**Parlor**
Facility Cost without AMS*	$ 1,779,149	$ 549,651
AMS Unit Cost*	$ 211,590	$ 169,377

Source: Study Survey
Note: * Values were inflated to 2022 values

Survey results regarding the operations characteristics of the study's farms after AMS installation are shown in Table 3. Of the eight farms in the study, only one farm was milking three times a day prior to AMS, but with AMS, these farms average 2.7 milkings per cow per day. Box time averages about 7.6 minutes for the study farms, which refers to the length of time spent in the AMS unit including prepping the cow and any post-treatment. The number of cows per AMS unit varied between the farms with half of them having between 60-69 cows per unit. All farms within the study utilized a free-flow barn design which allows cows to visit the AMS, feed bunk, and stalls at any time they choose. Fetching time, or the time spent rounding up cows that need to visit AMS, mirrors the distribution of cows per AMS unit with most of the farms spending between one and two hours a day fetching cows.

Table 3. AMS Operations Characteristics

	Obs.	Mean	Min.	Max.
Number of Milkings per day	8	2.7	2.5	2.8
AMS Box Time (min)	8	7.6	6.5	9.5
Feed Fed (lbs) in AMS per day	8	11.9	9.8	12.1
Cows per AMS Unit	**Obs.**	**Percentage**		
50-59	2	25.0%		
60-69	4	50.0%		
70+	2	25.0%		
Fetching Time				
Less than 1hr per day	1	12.5%		
1-2hrs per day	4	50.0%		
2-3hrs per day	3	37.5%		

Source: Study Survey

The survey also contained responses related to feed management and milk quality that may impact milk production and premiums received by the farm. Before installing AMS, farms pushed feed up 2.6 times a day on average. Feed push-ups stimulate the eating behavior of cows, encouraging them to consume more and therefore produce more milk (Collings, Weary, Chapinal, & Keyserlingk, 2011). Feed push-ups increased to an average of 17.1 times per day with the use of automated feed pushers on the farms. Another noteworthy observation from the survey included the change in somatic cell count (SCC) before and after installation (Figure 1). In dairy, SCC measures the number of white blood cells per milliliter of milk which is usually a health indicator for the farm and cows. Farmers typically receive premiums, or additional payment, for maintaining low SCCs. The ranges and sizes of the premium vary and are determined by the creamery where the dairy sells its milk. Before AMS, the farms studied had a wide range of SCCs, ranging from less than 100,000 to greater than 300,000 on average. After installing AMS, these farms saw an aggregation of SCCs towards the 100,000-299,999 range (Figure 1).

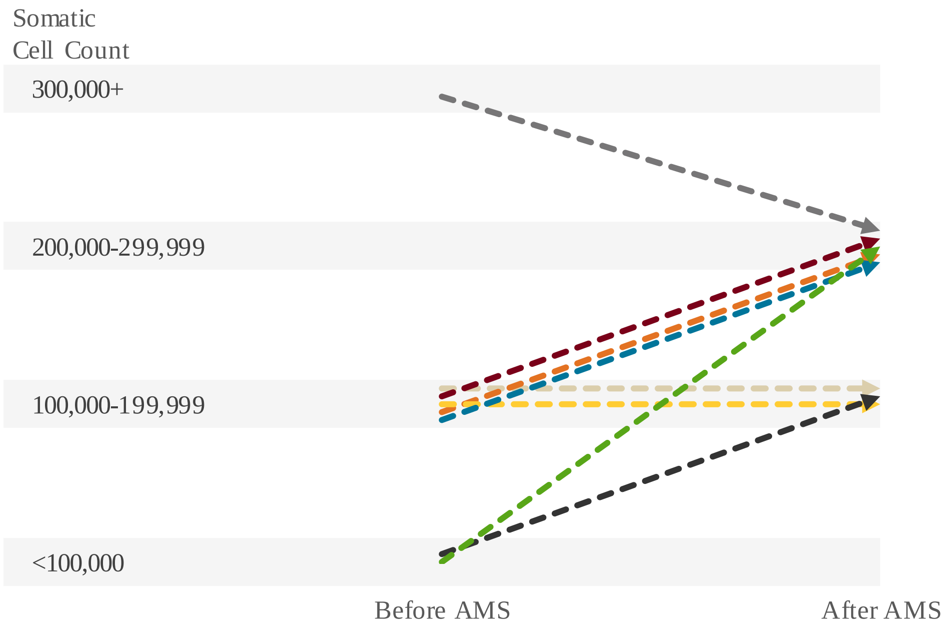

Figure 1. Average Somatic Cell Count (SCC) Before and After AMS Installation

Additional responses from the survey were used to make assumptions for the NPV analysis. There were very few observed differences between study farms, but bedding types differed across farms. Three different bedding types were used by the eight farms. Five of them used sand, two used straw, and one used lime. Succession planning was another question with varying responses. Only five of the farms responded that some type of transition plan was in place. Apart from the results previously mentioned, the farms used in this study had very similar management characteristics after installing AMS. All eight farms utilize activity tracking collars whereas only one farm had used them prior to AMS. Activity trackers are a complementary product of the AMS facility and allow for better health monitoring and heat detection. All but one of the farms have adapted their breeding program in some way to target features that they feel are more advantageous for AMS. Some features that these farms are focusing on include temperament, teat length, teat placement, and milking speed. Other similarities observed across all farms were operational characteristics such as traffic type and robot location. Each herd in this study utilized free-flow traffic, meaning cows have access to feed, water, and AMS units whenever they want without restriction. Six of the eight farms positioned their AMS units at the end of the facility and the remaining two farms had their units positioned at the side of the facility. Utilizing the study survey and the many management characteristics that the study farms had in common, it was assumed that these groupings based on the initial milking system would accurately reflect the average revenues and expenses recognized in the NPV analysis.

2. Summary Statistics from Financial Sources

There are more evident differences found within the financial sources of this study between farms transitioning from stalls and parlors before and after the installation of AMS. On average, stalls to AMS had fewer cows (Figure 2) and milk yield per cow (Figure 3) than parlors before and after the installation of AMS. Both farm types experienced increases in milk yield per cow of roughly 10% after installing AMS but parlor to AMS still produced more milk per cow.

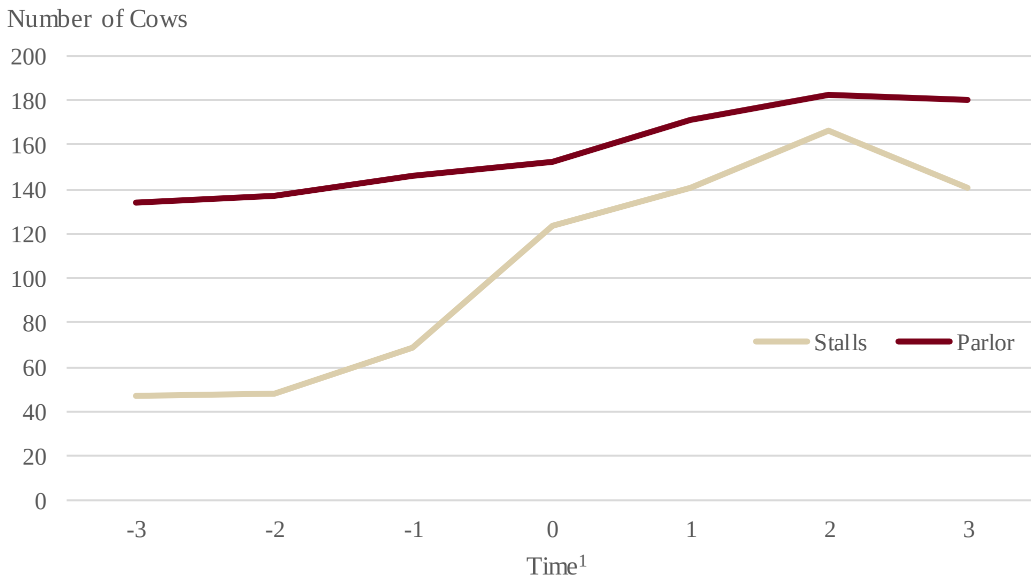

Figure 2. Average Number of Cows by Initial Farm Type

Sources: Data from FINBIN (Center for Farm Financial Management, 2023), financials of participating farms, or an agricultural professional supporting the farm.
Note: [1] Indicates time of AMS installation; -3=3 years before, 0=installation year, 3=3 years after

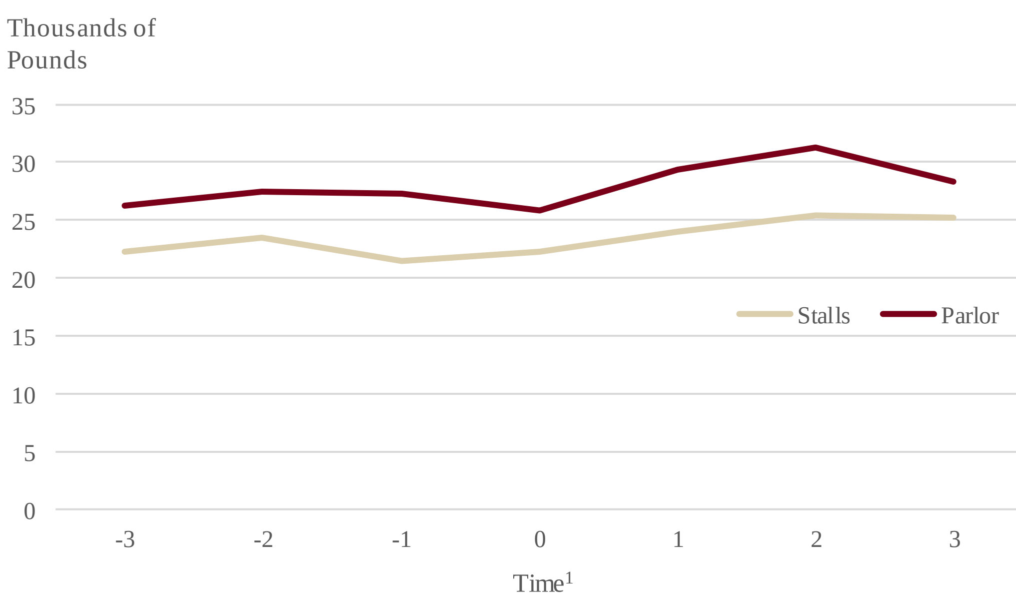

Figure 3. Average Production per Cow by Initial Farm Type

Sources: Data from FINBIN (Center for Farm Financial Management, 2023), financials of participating farms, or an agricultural professional supporting the farm.
Note: [1] Indicates time of AMS installation; -3=3 years before, 0=installation year, 3=3 years after

Farms transitioning from stalls to AMS and parlors to AMS had significant differences in revenues and profitability measures. Gross farm income increased by 57% for stalls to AMS while parlors to AMS observed a similar increase of 42% in revenue (Table 4). The net farm income (NFI) per cow decreased for stall to AMS from $2,191 before AMS to $628 after AMS. The opposite was observed for parlor to AMS with NFI per cow increasing almost $190 to $1,359. Farms transitioning from parlor to AMS had increases in both their rate of return on assets (RROA) and operating profit margin ratio (OPMR) as opposed to the decreases for stall to AMS in the same measures. Stall to AMS experienced a 1.7 percentage point decrease in average RROA from 5.9% to 4.2%. This ratio after installation is still in the "fair" range according to the Farm Financial Standards Council (FFSC) financial scorecard (Farm Financial Standards Council, 2022). Parlor to AMS saw an increase in RROA from -0.8% to 7.1%, moving from the "vulnerable" range into the "fair" range. As for OPMR, stall to AMS saw a dramatic decrease in the average from 15.0% to 7.7% moving from the edge of the "fair" range on the FFSC scorecard to the "vulnerable" range. Farms transitioning from parlors increased their average from -5.8% to 10.7% which does not move from the "vulnerable" range but nears closer to the "fair" range of 15%.

Both farm types experienced an increase in their interest expense ratio, which is the ratio of interest expense to total revenue generated. This increase is likely due to the financing costs associated with the project. Stall to AMS remained in FFSC's "fair" range (8.0% before, 8.1% after) whereas parlor to AMS moved from a "strong" ratio of 4.3% to a "fair" ratio of 5.4%.

The depreciation expense ratio also increased for both farm types after installing AMS. Similar to the interest expense ratio, the depreciation expense ratio is calculated by dividing the farm's depreciation by its revenue. The depreciation expense is expected to increase as AMS has a high cost of capital that will be depreciated each year. This added expense will be considered in the NPV calculation as it reduces the farm's tax liability. The stall to AMS depreciation ratio increased from 5.9%, a "fair" ratio, to 11.8% which is deemed "vulnerable." Parlor to AMS remained in the "fair" range moving from 4.5% to 7.2%.

Labor is typically a significant factor when choosing to install AMS and those changes are also outlined in Table 4. Although stall to AMS did not decrease the number of full-time employees on the farm, labor per hundredweight of milk increased from $1.10 to $2.01. On the other hand, the same labor measure decreased for parlor to AMS, but they decreased the number of full-time staff employed on the farm from 3.5 to 3.0.

Table 4. Average Farm and Financial Characteristics Before and After AMS Installation by Initial Farm Type

	Stalls		*Parlor*	
	Before Install	**After Install**	**Before Install**	**After Install**
Farm Characteristics				
Milking Cows	55	149	139	178
Milk Yield/Cow (lbs)	22,445	24,850	26,995	29,698
Full Time Employees+	2.4	2.5	3.5	3.0
Financial Characteristics				
Gross Farm Income* ($)	675,549	1,062,573	1,069,902	1,519,606
Operating Expense* ($)	470,335	824,759	942,432	1,054,830
Total Expense* ($)	555,040	968,977	1,043,520	1,277,638
NFI/Cow* ($)	2,191	628	190	1,359
Rate of Return on Assets (%)	5.9	4.2	(0.8)	7.1
Operating Profit Margin Ratio (%)	15.0	7.7	(5.8)	10.7
Interest Expense Ratio (%)	8.0	8.1	4.3	5.4
Depreciation Expense Ratio (%)	5.9	11.8	4.5	9.1
Labor/CWT* ($)	1.10	2.01	4.36	2.43
Repairs/CWT* ($)	1.58	0.87	1.27	1.04
Utility/CWT* ($)	0.90	0.64	0.85	0.57
Purchased Feed/CWT* ($)	7.67	7.45	6.44	10.50

Sources: Data from FINBIN (Center for Farm Financial Management, 2023), financials of participating farms, or an agricultural professional supporting the farm.
Note: * Indicates values were inflated to 2022 values (Federal Reserve Bank of Minneapolis, 2023). Variables with + were part of the study survey

3. NPV Scenarios

Four scenarios were examined over a 15-year investment period which include 1) stalls to AMS with 60-69 cows per unit or 65 cows per unit, (2) stalls to AMS with 70+ cows per unit or 75 cows per unit, (3) parlor to AMS with 50-59 cows per unit or 55 cows per unit, and (4) parlor to AMS with 60-69 cows per unit or 65 cows per unit, over a 15-year investment period. The NPV analysis was completed using the assumed investment costs assumptions from the survey, market assumptions from FAPRI (2023), other economic assumptions outlined in the next section, and average revenues and expenses per cow after AMS installation for each farm type with the corresponding cows per unit. The four NPV scenarios were calculated using two different revenue and expense expectations. Each of the four NPV scenarios were calculated using two different sets of predicted values. The first uses 15 years of projected values as estimated by FAPRI[2]. The second set of expectations uses the 2023 values as projected FAPRI and holds these values constant for the 15-year investment period. The base economic assumptions were held constant for both sets of NPV calculations. Results from the study are based on averages and were not tested for statistical significance due to the small sample size of the study.

4. Investment Costs and Financing

Investment costs were calculated using the average facility cost per cow after installation multiplied by the total number of cows in a facility with two AMS units valued at a market rate of $200,000 each (Leedstone, 2023; Farm Systems, 2023)[3]. Personal interviews were used to evaluate how farmers typically received financing for AMS projects. These interviews discovered that many of the loans are unique to the farm's financial position, projected cashflows after installing AMS, and relationship with their lender. Loan lengths varied from 7 years to 20 years depending on the equity position of the farm and the loan to the appraised value of the facility (Compeer Financial, 2023). Assuming a 15% down payment, the remaining 85% of the investment cost for this study was assumed to be financed through a 15-year loan with principal and interest payments captured in the NPV (Table 5). An interest rate of 5% was used for the loan calculation because it was approximately the average interest rate paid by farms during the installation periods (4.935% was the average). The investment was depreciated

[2] FAPRI values were extrapolated from 10 years to 15

[3] Sources of data used in the NPV analysis are found in APPENDIX A: Data Sources

using straight-line depreciation over 15 years with zero salvage value for both the AMS units and facility (Table 5). Although these assets will likely have a useful life longer than 15 years, depreciating the assets fully during this time period captures the tax benefits. Having a salvage value of zero fully captures the expense of the facility and AMS units that the farmer will have to replace sometime in the future. This investment will have very little resale value if the farmer would like to sell them while still operating so recognizing these expenses allows farmers to market their milk with more knowledge of the true cost when including the entirety of the investment.

Assumptions used for the calculation of the WACC, which is used to discount future values, are also included in Table 5. The cost of debt is equal to the interest rate of the loan used for the investment. The cost of equity was assumed to be equal to 8%, or the average return to the stock market. The debt-to-asset ratio and the equity-to-asset ratio were equal to the farm type average after installing AMS. The marginal tax rate fluctuated and was calculated based on the farm's project net farm income each year using the Internal Revenue Service brackets (2021). The average WACC using FAPRI market assumptions for the 15-year period for the four scenarios was 6.19% and dropped slightly to 6.11% when holding 2023 predicted values constant for the 15 years.

Table 5. Base Economic Assumptions for Each NPV Calculation

	Definition	Unit
Salvage Value		0
Depreciable life		15 years
Length of the Loan		15 years
Interest Rate		5%
Down Payment		15%
WACC Assumptions		
Cost of Debt	Assumed Loan Interest Rate	5%
Cost of Equity	Average Return to the Stock Market	8%
Debt-to-Asset Ratio	Avg. of Farms Used in the Study	
Equity-to-Asset Ratio	Avg. of Farms Used in the Study	
Marginal Tax Rate	Calculated Based on Farm Taxable Income	
WACC Average using FAPRI Estimations		6.19%
WACC Average using 2023 Values		6.11%

5. *Market Assumptions*

Assumptions of future trends in revenues and expenses were made using the *U.S. Agricultural Market Outlook* Report (Food and Agricultural Policy Research Institute, 2023). This report estimates trends over 10 years, from 2023-2032, for farm revenues, input prices, production totals for crop and livestock enterprises, and much more. Input prices, milk prices, milk production, and other farm revenues were used from this report and extrapolated using Microsoft Excel® to 15 years by estimating trends outlined by FAPRI. Figure 4 shows farm expenditures indexed to 100 with 2022 as the base year. Most expenses decrease from 2022 levels into 2023 except for wage rates and farm services. This decrease is due to prices returning to a more normal state after 2022 experienced shocks including the war in Ukraine, avian influenza, and harsh weather conditions. By 2026, many of these categories are predicted to recover to prior levels and continue to increase into the future. Extrapolated values in Figure 4 are denoted by dashed lines.

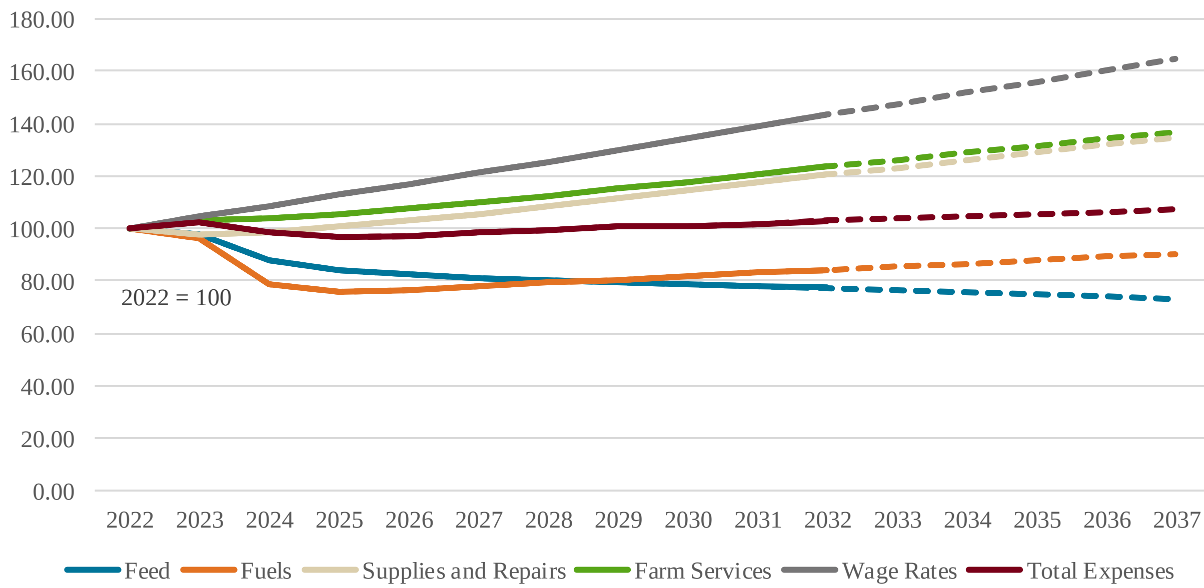

Figure 4. Farm Expense Price Indices, 2022-2037[1]

Source: Food and Agricultural Policy Research Institute, 2023
Note: [1] Trends from 2033-3037 are extrapolated from FAPRI trends and denoted by dashed lines

Farm revenues for the investment period were also extrapolated from 10 to 15 years using FAPRI estimates. The revenues are also indexed to a 100 with 2022 as a base year (Figure 5). Unlike farm expenses, farm revenues are not expected to increase greatly in the future. Government payments and value of inventory are assumed to decrease dramatically in the next few years with the value of inventory remaining at depressed levels (Food and Agricultural Policy Research Institute, 2023). Farmers experienced large government payments from ad hoc programs that are not expected to be at such high levels in the future. Crop prices are also expected to fall from record high levels in recent years (Food and Agricultural Policy Research Institute, 2023).

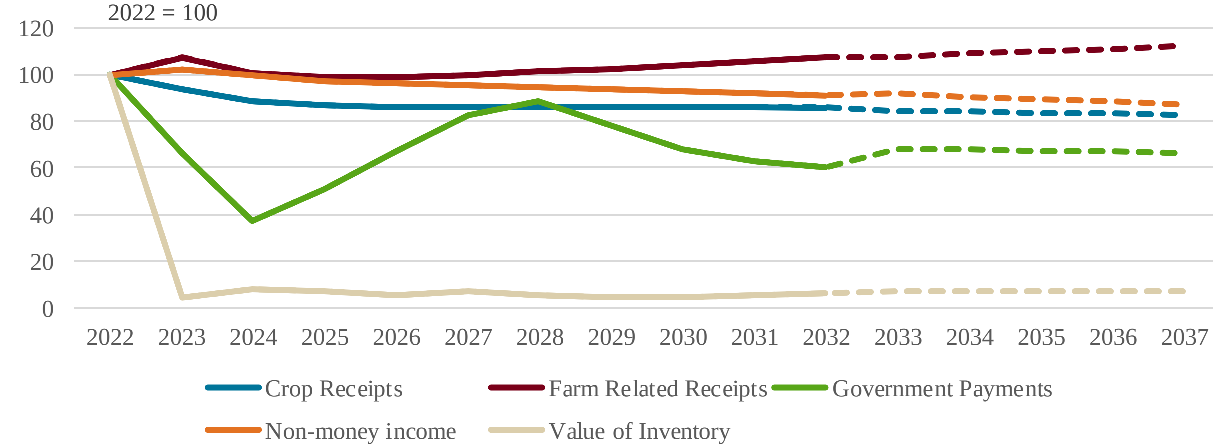

Figure 5. Farm Income Price Indices, 2022-2037[1]

Source: Food and Agricultural Policy Research Institute, 2023
Note: [1] Trends from 2033-3037 are extrapolated from FAPRI trends and denoted by dashed lines

Even as farm revenues are returning to pre-2020 trends, the largest revenue driver for this study is milk price and production. Milk production per cow is expected to grow at roughly 1% a year for the next 10 years (Food and Agricultural Policy Research Institute, 2023). This 1% increase per year was assumed to hold constant for the full investment period of 15 years. FAPRI also estimates that weakening consumer demand for dairy will decrease prices to the 2010-2019 average. Figure 6 shows the historical hundredweight price of Class III Milk for the Federal Milk Marketing Order (FMMO) 30[4] assuming 3.5% butterfat content and 2.99% protein. The average price in 2022 was $21.96/cwt which was the highest yearly average since 2014 (United States Department of Agriculture, 2023a). As of April 2023, the yearly average price is $18.45/cwt already demonstrating a decrease in prices estimated by FAPRI. These estimates were also extrapolated to estimate the remaining five years of the investment, from 2033-2037.

[4] States included in FMMO 30 include parts of North Dakota, South Dakota, Iowa, Illinois, Michigan, Wisconsin, and Minnesota.

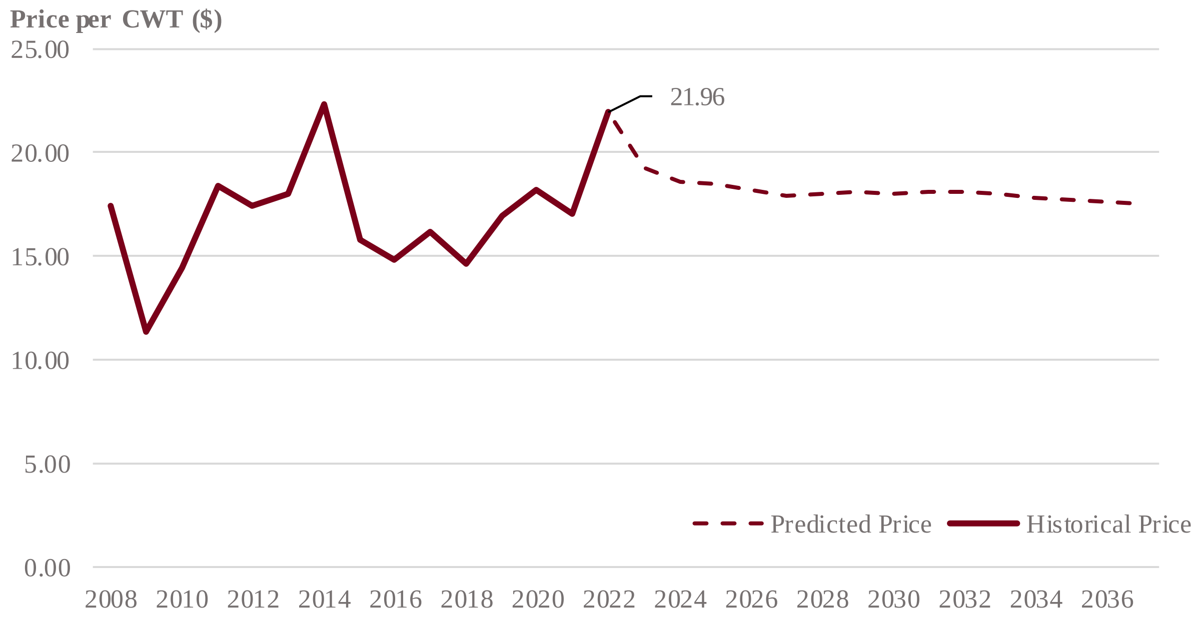

Figure 6. Historical Class III Milk Price[1] and Predicted Price, 2008-2037[2]

Source: United States Department of Agriculture, 2023 & Food and Agricultural Policy Research Institute, 2023
Note: [1] Average Class III Milk Price for the Upper Midwest Marking Area - Federal Milk Marketing Order 30. [2] Prices from 2033-3037 are extrapolated from FAPRI trends.

6. Initial Revenue and Expense Assumptions

Each NPV scenario utilizes a set of initial financial assumptions based on the average values of the corresponding farm type and the number of cows per AMS unit after installing AMS (Table 6). The values impacting the revenue generated by each farm are milk produced per cow and other non-milk revenue generated by the farm. These values are used as starting point in the NPV analysis and adjusted using the FAPRI estimates for the entirety of the investment period (Figure 5). Expenses were examined with special consideration given to purchased feed, hired labor, repairs, and fuel costs which were split from the remaining operating expenses. It was assumed that purchased feed cost was a better measure of change than the cost of total feed fed as farms would not be investing in both land and AMS at the same time. Just as revenues, these expenses were then used as starting points for the analysis and were adjusted using FAPRI estimates (Figure 4).

Table 6. Initial NPV Revenue and Expense Assumptions

	Stalls		Parlor	
Number of Cows per AMS Unit	60-69	70+	50-59	60-69
Inflows				
Milk Produced, Lbs/Cow	24,117	24,866	29,972	29,402
Milk Price/CWT[1]	-	-	-	-
Other Income, $/Cow	1,603.90	2,149.95	1,595.93	2,124.57
Outflows, $/Cow				
Purchased Feed	1,559.19	1,655.73	3,032.85	3,128.59
Fuel & Oil	80.48	131.40	116.27	187.50
Total Repairs	195.31	254.99	553.82	253.53
Hired Labor	390.59	362.03	853.03	685.65
Other Op. Expenses	2,726.06	3,559.38	1,070.71	1,781.36
Facility Cost	13,680.95	11,353.73	2,705.67	2,839.79
Depreciation	1,117.19	934.69	422.80	394.45
Principal Payments[2]	949.61	794.49	359.38	335.28
Interest Payments[2]	422.71	353.65	159.97	149.24

Note: [1] Milk price fluctuates depending on assumptions used in NPV. Refer to Figure 6 for FAPRI estimations of milk price through 2037. [2] Averaged over the 15 years investment period since values vary year over year.

7. NPV Outcomes

Results from four scenarios using 15 years of FAPRI values over the investment period are displayed in Table 7. The NPV for both farm size scenarios of stall to AMS are negative meaning that the revenues generated by installing AMS do not recover the investment cost and operating expenses associated with the project. Due to this negative value, farmers should not transition from stalls to AMS under these assumptions. However, both parlor to AMS scenarios have a positive NPV meaning that farms transitioning from parlors should make the investment. Parlor to AMS with 60-69 cows per AMS unit experiences a greater return and are therefore more profitable than the same initial farm type with 50-59 cows per unit.

Table 7. Net Present Value using FAPRI Estimates

	Stalls		**Parlor**	
Number of Cows per AMS Unit	60-69	70+	50-59	60-69
Accrual Cash Inflows, 15 years	11,955,331	15,216,911	11,988,669	14,869,147
Accrual Cash Outflows, 15 years	12,120,063	16,040,950	10,288,897	12,734,839
Accrual Cash After-Tax Net Cash Flows	-164,732	-508,581	1,804,415	2,249,685
Net Present Value	-443,168	-618,190	1,024,124	1,364,628

Table 8 displays the results of the NPV analysis holding the 2023 FAPRI values constant for the lifetime of the investment. The NPV of stalls to AMS improves with this set of predictions but is still negative for both scenarios. This is due to many factors but mainly occurs during the tenth period of the investment in 2032. Holding 2023 values constant for the life of the investment creates a large gap in predicted expenses and revenues from 2032 onward. Feed prices and fuel expenses are 26.4% and 14.4% higher, respectively, in this scenario compared to the previous scenario in which the forecasted values were used. Decreases in expenses for supplies and repairs, farm services, and wage rates coupled with higher milk prices and other income offset the increased feed and fuel expenses. Supplies and repairs are 19.1% lower in 2023, farm services are 16.9% lower, and wage rates are 27.2% lower than the FAPRI estimated values in 2032. These values continue to spread throughout the remainder of the investment period, in turn creating higher net farm income. After-tax net cashflows improved greatly but when discounted to present value, these positive cash flows do not overcome the initial investment in AMS for stalls. The parlor to AMS scenarios improves as well as they remain positive, and maintain the same investment logic as before, planning to milk 60-69 cows per robot for greater returns.

Table 8. Net Present Value using 2023 Values

	Stalls		**Parlor**	
Number of Cows per AMS Unit	60-69	70+	50-59	60-69
Accrual Cash Inflows, 15 years	12,767,042	16,260,185	12,796,702	15,881,682
Accrual Cash Outflows, 15 years	12,799,470	16,489,720	10,770,953	13,522,557
Accrual After-Tax Net Cash Flows	294,351	85,924	2,130,393	2,474,501
Net Present Value	-178,996	-346,865	1,193,933	1,482,625

8. Breakeven Analysis

The breakeven analysis finds the value such that the NPV is $0, that is the farm would breakeven on the investment. The breakeven milk price and interest rates for each of the scenarios are calculated holding the 2023 FAPRI values constant. Stalls to AMS with 60-69 cows per unit require a milk price of $20.81/cwt each year of the investment in order to achieve an NPV of $0 (Figure 7). The breakeven price for stalls to AMS with 70+ cows is 40 cents higher at $21.21/cwt. Historically, average yearly milk prices have only been higher than these breakeven prices twice in the last 15 years. As for parlors to AMS, they require $15.12/cwt and $14.49/cwt respectively for 50-59 cows and 60-69 cows. These prices frequently exceeded with only a few years falling below these breakevens.

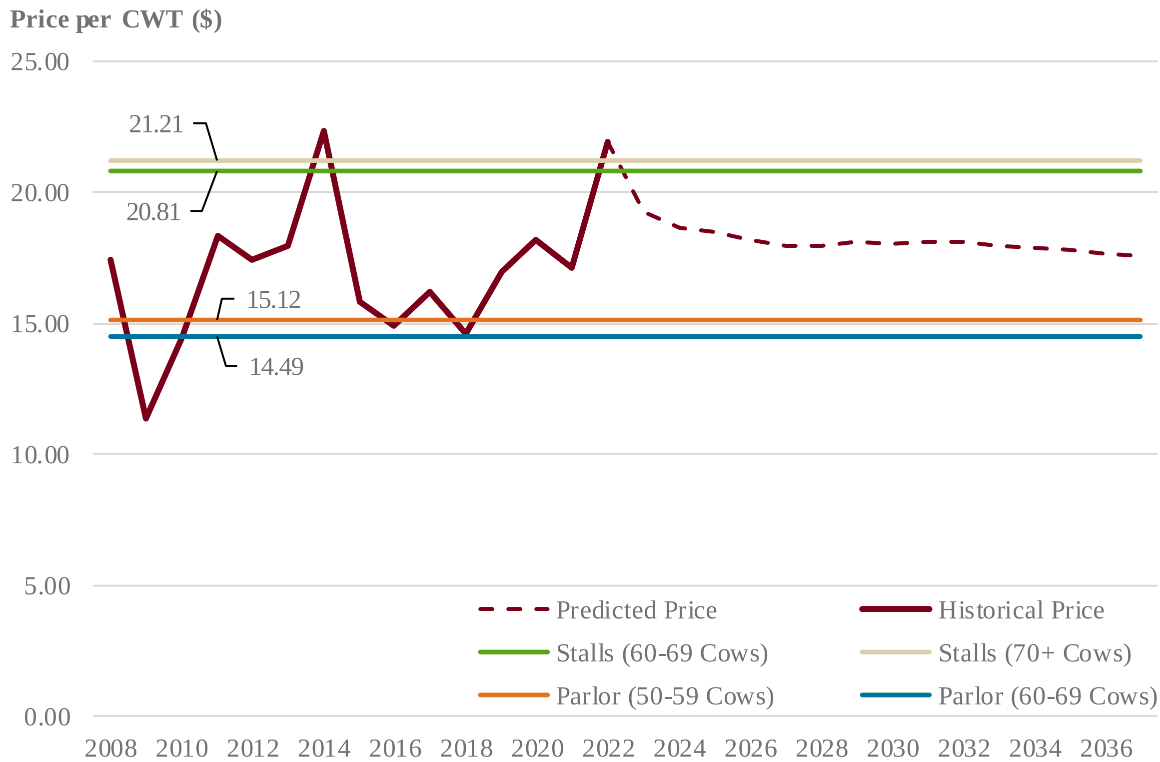

Figure 7. Average Class III Milk Price[1] and Estimated Breakeven Even Price, 2008-2037[2]

Source: United States Department of Agriculture, 2023 & Food and Agricultural Policy Research Institute, 2023
Note: [1] Average Class III Milk Price for the Upper Midwest Marking Area - Federal Milk Marketing Order 30. [2] Prices from 2033-3037 are extrapolated from FAPRI trends.

When adjusting historical milk prices for inflation to 2022 values, breakeven prices are met more frequently for the stall to AMS scenarios (Figure 8). These breakeven prices are still not met by the values predicted by FAPRI. Parlor to AMS breakeven prices have been met for each of the past 15 years and are predicted to remain that way for the entirety of the investment.

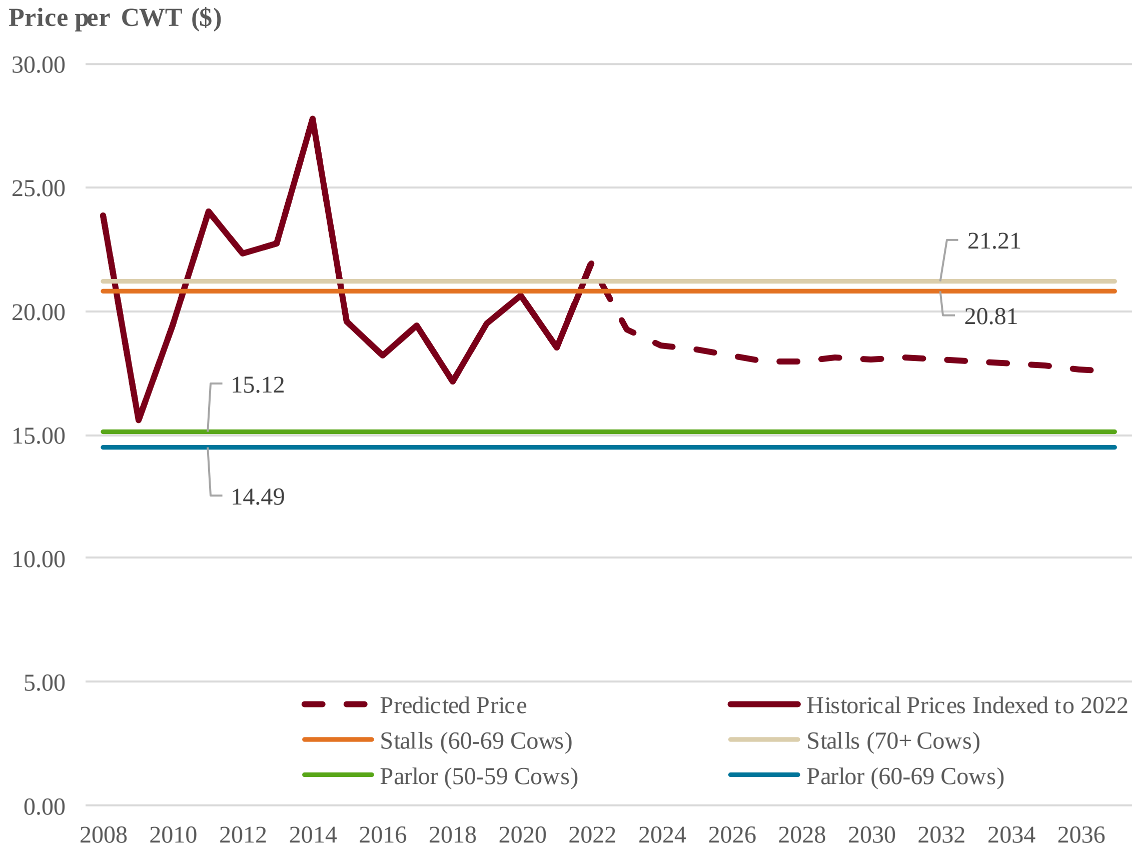

Figure 8. Average Class III Milk Price[1] Adjusted for Inflation[2] and Estimated Breakeven Prices, 2008-2037[3]

Source: United States Department of Agriculture, 2023 & Food and Agricultural Policy Research Institute, 2023
Note: [1]Average Class III Milk Price for the Upper Midwest Marking Area - Federal Milk Marketing Order 30. [2] Prices from 2008-2022 are inflated to 2022 values. [3] Prices from 2033-3037 are extrapolated from FAPRI trends.

Breakeven interest rates were also calculated for each of the NPV scenarios when holding 2023 values constant (Figure 9). Since the parlor to AMS scenarios had positive NPVs, the interest rate that would make the investment breakeven was significantly higher than the base rate of 5.0. These breakeven rates of 32.8% and 33.9% for 50-59 cows and 60-69 cows respectively and are not displayed in Figure 9 since they are well above the historic market rate. Stall to AMS both had interest rates lower than 5% with

60-69 cows having a breakeven rate of 3.7% and 70+ cows having a significantly lower rate of 1.5%. The lowest interest rate for real estate farm loans since 1970 was 4.0% in the third quarter of 2021.

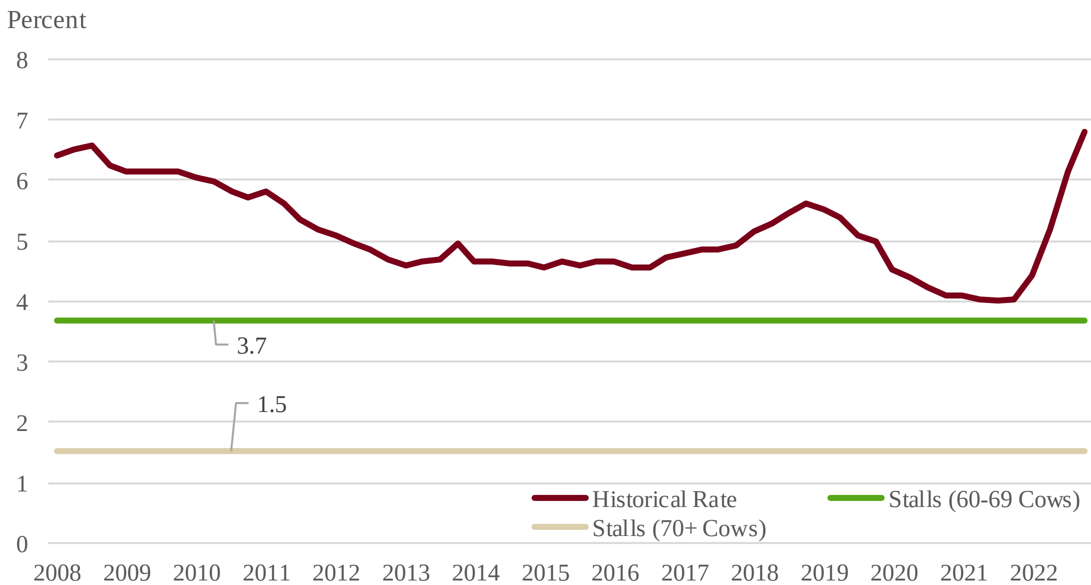

Figure 9. Interest Rates on Real Estate Farm Loans and Estimated Breakeven Rates, 1970-2022

Source: Federal Reserve Bank of Chicago, 2023

Additional breakeven values were calculated for each scenario, including yield, hired labor expense, purchased feed, other operating expenses, and investment cost per cow (Table 9). Stalls to AMS with 60-69 cows must increase yield per cow by 2.9% on top of the 10% increase after installation assumption to breakeven. These farms can also cut purchased feed per cow by 9.4% or other expenses by 5.2% to have an NPV of $0. The stalls to AMS with 70+ cows per AMS face even larger decreases to achieve breakeven. Decreasing operating expenses per cow by 7.6%, purchased feed per cow by 17.0%, or hired labor per cow by 73% produces a breakeven NPV. Increasing milk production by 5.4% would also achieve this but that is in addition to the added production when transitioning to AMS. Facility costs per cow must decrease by 10.8% and 24.3% for 60-69 cows and 70+ cows per unit respectively for an NPV of 0. This may be more feasible for stall to AMS farms to control since the stall farms in this study had much higher facility costs per cow than their parlor counterparts.

Table 9. Breakeven Values by Initial Farm Type using 2023 Values

	Stalls		**Parlor**	
Cows per AMS unit	60-69 Cows	70+ Cows	50-59 Cows	60-69 Cows
Yield per Cow, lbs	24,819	26,219	23,015	22,353
Hired Labor per Cow, $	252.95	97.85	2,213.99	2,066.66
Purchased Feed per Cow, $	1,412.51	1,374.21	4,483.16	4,600.29
Other Expense Operating per Cow[1], $	2,585.58	3,289.75	2,459.78	3,190.90
Facility Cost per Cow, $	12,203.21	8,594.33	17,028.86	17,459.48

Note: [1] Does not include Purchased Feed, Fuel & Oil, Repairs, and Hired Labor Expense

9. Sensitivity Analyses

The NPV analyses conducted for this study are conditional on underlying assumptions made within each model. To evaluate which factors have the greatest impact on the NPVs of the scenarios, a sensitivity analysis is conducted. A sensitivity analysis changes one factor of the NPV to determine the impact it has on the NPV. The new NPV that is calculated is then compared to the base NPV, or the NPV found holding 2023 values constant (Table 8), and the difference is reported. Both pessimistic and optimistic situations are considered because prices are equally as likely to increase as they are to decrease. Table 10 examines five variables used in the NPV analysis including purchased feed cost per cow, hired labor cost per cow, other expenses per cow, facility cost per cow, and down payment to determine how changes to these variables affect each of the four scenarios. In this sensitivity analysis, different expense variables are increased by 10% while holding all other factors constant, which is a pessimistic approach. The down payment percentage is modified from 14% to 20% for the sensitivity analysis. A 10% increase in other expenses per cow has the greatest impact on stalls to AMS, decreasing the NPV by -$353,167 and -$476,126 for 60-69 and 70+ cows respectively. Increasing investment cost per cow by 10% and purchased feed per cow by 10% also have large negative impacts on the NPV of each stall farm. Parlors to AMS experience the largest decrease in NPV when purchased feed per cow is increasing by 10% but both scenarios still have a NPV greater than $960,000. The second largest decrease experienced by parlor to AMS farms occurs when increasing other expenses per cow are increased by 10% but once again, the NPV of these scenarios is overwhelmingly positive. Increasing the down payment by 5% had minimal changes in the NPV of all scenarios. Similarly, increasing hired labor costs by 10% for each scenario was not as impactful as other expenses and purchased feed.

Table 10. Pessimistic Scenarios, Increasing Cost-Sensitivity Analysis using 2023 Values

Purchased Feed Costs, $/cow	**Base**	**+10%**	**Base NPV**	**NPV with Change**	**Difference**
Stalls (60-69 Cows)	1,559.19	1,715.11	-178,996	-371,462	-192,466
Stalls (70+ Cows)	1,655.73	1,821.30	-346,865	-557,053	-210,188
Parlor (50-59 Cows)	3,032.85	3,336.13	1,193,933	960,953	-232,980
Parlor (60-69 Cows)	3,128.59	3,441.45	1,482,625	1,191,174	-291,451
Hired Labor Cost, $/cow	**Base**	**+10%**	**Base NPV**	**NPV with Change**	**Difference**
Stalls (60-69 Cows)	390.59	429.65	-178,996	-229,873	-50,878
Stalls (70+ Cows)	362.03	398.23	-346,865	-395,733	-48,868
Parlor (50-59 Cows)	853.03	938.34	1,193,933	1,124,663	-69,270
Parlor (60-69 Cows)	685.65	754.21	1,482,625	1,415,309	-67,316
Other Expenses[1], $/cow	**Base**	**+10%**	**Base NPV**	**NPV with Change**	**Difference**
Stalls (60-69 Cows)	2,726.06	2,998.67	-178,996	-532,162	-353,167
Stalls (70+ Cows)	3,559.38	3,915.32	-346,865	-822,991	-476,126
Parlor (50-59 Cows)	1,070.71	1,177.79	1,193,933	1,108,502	-85,431
Parlor (60-69 Cows)	1,781.36	1,959.50	1,482,625	1,309,666	-172,959
Facility Cost, $/cow	**Base**	**+10%**	**Base NPV**	**NPV with Change**	**Difference**
Stalls (60-69 Cows)	13,680.95	15,049.05	-178,996	-347,139	-168,143
Stalls (70+ Cows)	11,353.73	12,489.10	-346,865	-492,644	-145,779
Parlor (50-59 Cows)	2,705.67	2,976.24	1,193,933	1,173,016	-20,917
Parlor (60-69 Cows)	2,839.79	3,123.77	1,482,625	1,455,961	-26,664
Down Payment, %	**Base**	**Change**	**Base NPV**	**NPV with Change**	**Difference**
Stalls (60-69 Cows)	15.00	20.00	-178,996	-181,612	-2,616
Stalls (70+ Cows)	15.00	20.00	-346,865	-361,617	-14,751
Parlor (50-59 Cows)	15.00	20.00	1,193,933	1,189,052	-4,881
Parlor (60-69 Cows)	15.00	20.00	1,482,625	1,477,585	-5,040

Note: [1] Does not include Purchased Feed, Fuel & Oil, Repairs, and Hired Labor Expense

A sensitivity analysis was also performed with increasing interest rates. The current rate for agricultural real estate loans as of the fourth quarter of 2022 is 6.8% (Federal Reserve Bank of Chicago, 2023). The base scenario, using 2023 constant values, assumes an interest rate of 5.0%. Table 11 presents each scenario with interest rates increasing by 0.5 percentage points up to 7.5%. Once again, stall farms are more severely affected by increasing interest due to higher facility costs per cow. Both parlor to AMS scenarios experience little change in NPV as interest rates increase to 7.5%, only an average decrease of roughly $150,000 but maintain values above $1,000,000.

Table 11. Pessimistic Scenarios, NPV with Increasing Interest Rates using 2023 Values

Stalls (60-69 Cows)	**Base**	**Change**	**Base NPV**	**NPV with Change**	**Difference**
	5.0	5.5	-178,996	-243,972	-64,977
	5.0	6.0	-178,996	-307,186	-128,190
	5.0	6.5	-178,996	-369,968	-190,972
	5.0	7.0	-178,996	-430,262	-251,267
	5.0	7.5	-178,996	-489,134	-310,138
Stalls (70+ Cows)	**Base**	**Change**	**Base NPV**	**NPV with Change**	**Difference**
	5.0	5.5	-346,865	-399,018	-52,152
	5.0	6.0	-346,865	-451,291	-104,425
	5.0	6.5	-346,865	-503,870	-157,004
	5.0	7.0	-346,865	-556,754	-209,888
	5.0	7.5	-346,865	-609,799	-262,934
Parlor (50-59 Cows)	**Base**	**Change**	**Base NPV**	**NPV with Change**	**Difference**
	5.0	5.5	1,193,933	1,169,217	-24,717
	5.0	6.0	1,193,933	1,144,078	-49,855
	5.0	6.5	1,193,933	1,119,625	-74,308
	5.0	7.0	1,193,933	1,095,332	-98,601
	5.0	7.5	1,193,933	1,069,748	-124,185
Parlor (60-69 Cows)	**Base**	**Change**	**Base NPV**	**NPV with Change**	**Difference**
	5.0	5.5	1,482,625	1,446,790	-35,835
	5.0	6.0	1,482,625	1,412,484	-70,141
	5.0	6.5	1,482,625	1,378,645	-103,980
	5.0	7.0	1,482,625	1,344,297	-138,328
	5.0	7.5	1,482,625	1,309,371	-173,254

Table 12 is an optimistic approach to the stall to AMS NPV scenarios and assumes that some expenses generated by farms in the study may be overstated or that lending assumptions become more favorable in the future. Parlor to AMS scenarios were not considered for this decreasing cost sensitivity analysis since the base NPV scenarios were positive. The decreasing feed purchased per cow has the greatest influence on stalls to AMS with 60-69 cows, increasing the NPV by almost $190,000 and creating a positive NPV of $10,986. Reduction in hired labor cost per cow and investment cost per cow also have large effects on the 60-69 cow scenario but these NPVs are still negative. Of these favorable parameter changes, stall to AMS with 70+ cows still never reaches a positive NPV value. Investment cost per cow, other expenses per cow, and purchased feed cost per cow generate the highest NPV differences, similar to 60-69 cows

Table 12. Optimistic Scenarios, NPV with Decreasing Costs for Stalls using 2023 Values

Purchased Feed Costs, $/cow	**Base**	**-10%**	**Base NPV**	**NPV with Change**	**Difference**
Stalls (60-69 Cows)	1,559.19	1,403.27	-178,996	10,986	189,982
Stalls (70+ Cows)	1,655.73	1,490.16	-346,865	-141,290	205,575
Hired Labor Cost, $/cow	**Base**	**-10%**	**Base NPV**	**NPV with Change**	**Difference**
Stalls (60-69 Cows)	390.59	351.54	-178,996	-127,609	51,387
Stalls (70+ Cows)	362.03	325.82	-346,865	-298,710	48,155
Other Expenses, $/cow	**Base**	**-5%**	**Base NPV**	**NPV with Change**	**Difference**
Stalls (60-69 Cows)	2,726.06	2,589.76	-178,996	-5,192	173,804
Stalls (70+ Cows)	3,559.38	3,381.41	-346,865	-116,399	230,467
Investment Cost, $/cow	**Base**	**-10%**	**Base NPV**	**NPV with Change**	**Difference**
Stalls (60-69 Cows)	13,680.95	12,312.86	-178,996	-13,074	165,921
Stalls (70+ Cows)	11,353.73	10,218.35	-346,865	-95,503	251,363
Down Payment, %	**Base**	**Change**	**Base NPV**	**NPV with Change**	**Difference**
Stalls (60-69 Cows)	15.00	10.00	-178,996	-176,586	2,410
Stalls (70+ Cows)	15.00	10.00	-346,865	-332,371	14,494
Interest Rate, %	**Base**	**Change**	**Base NPV**	**NPV with Change**	**Difference**
Stalls (60-69 Cows)	5.00	4.00	-178,996	-44,052	134,944
Stalls (60-69 Cows)	5.00	4.50	-178,996	-111,849	67,147
Stalls (70+ Cows)	5.00	4.00	-346,865	-244,511	102,354
Stalls (70+ Cows)	5.00	4.50	-346,865	-295,516	51,350

V. DISCUSSION

The outcomes of these NPV analyses established that the initial farm type has a large impact on the profitability of AMS. Using FAPRI estimates for the investment period of 15 years as well as holding the 2023 estimates constant, farms transitioning from stalls to AMS do not generate enough revenue to cover investment costs, operating expenses, and fixed expenses. On the other hand, parlor to AMS experiences a positive NPV for each of the pessimistic sensitivity analyses. Stall to AMS suffered substantially with increasing costs and had only a single instance of a positive NPV when decreasing costs.

Although the NPV for both stall to AMS scenarios is negative, there are a few additional points to consider. This study has a unique perspective as it examined farms before and after installing AMS. Stall farms had an average of 55 cows before AMS and 149 cows after, a 171% increase compared to a 28% increase by parlor farms. Not only is transitioning from a stall barn to an automated milking facility a steep learning curve but increasing herd size by 171% puts managers in a new and challenging management situation. Management for parlor farms has some similarities to AMS management with cows living in freestalls. This study's time frame may not account for changes that stall farm management may have made after the initial three years of AMS use.

One of the greatest differences between the stall to AMS and parlor to AMS scenarios was the average cost of the facility per cow. Stall to AMS on average spent $12,517/cow compared to $2,773/cow by parlor to AMS, a difference of roughly 450%. A limitation of this study is that costs were self-reported by the farmer and may be approximated such that the true expense incurred by the farmer at the time of installation is not accurately represented. The facility costs differences may hold true as parlor farms may have an advantage over stall farms because of their previous management experience with cows in freestall housing. These farmers understand the costs associated with maintaining freestalls and may have been able to identify and possibly reject unnecessary costs that were proposed when constructing the AMS facility. If stall to

AMS facility costs per cow were equal to the average of parlor to AMS, stall to AMS with 60-69 cows per unit would have an NPV (holding 2023 values constant) of $1,043,132 and the NPV for 70+ cows per unit would be $669,611. Both stall to AMS scenarios would be accepted given facility costs were those of parlors because the NPV is greater than zero. The 60-69 cows per unit would be preferred over the 70+ cows per unit since its NPV is $373,521 higher. It is also possible that parlor farms under-reported the true costs of their facility. Using the average stall farm cost of $12,517/cow, the NPVs for parlor to AMS farms would be $407,366 and $544,641 for 50-59 cows and 60-69 cows respectively. Using either facility cost per cow, the NPVs for parlor farms are greater than zero, meaning that these farms should consider investing in AMS whereas stall farms require a lower cost per cow to meet that decision rule.

Purchased feed expenses per cow and other expenses per cow have considerable impacts on stall to AMS NPVs. Reducing purchased feed costs by 10% or more could be difficult as the quantity and quality of feed have implications for milk production and animal health. Some items within other expenses, however, may not have the same direct consequences on milk production and cow health and therefore may be easier to control. The other expenses category in the NPV analysis contains all expenses other than purchased feed, fuel and oil, repairs, and hired labor. This would include all farm enterprises, including seed, fertilizer, crop chemicals, supplies, breeding fees, veterinary expenses, miscellaneous, etc. Reducing spending slightly in these areas could lead to a major swing in the NPV for stalls to AMS. The 60-69 cows per unit scenario would require a decrease of 5.2% in other expenses per cow to have an NPV of $0. The 70+ cow per unit scenario requires a slightly larger decrease in other expenses per cow at 7.6%.

On the revenue side of the NPV analysis, the report by FAPRI estimates the milk prices based on FMMO area classes. The Class III milk price for FMMO 30, used as the milk price in this study, is the FMMO base price and does not include any additional component pricing or premiums received for milk quality or quantity. Farms included in the study were assumed to have a butterfat percentage of 3.5% and a protein percentage of 2.99%. Holsteins, which were the primary breed for farms in this study, produce a milk fat of over 4.0% (Salfer I., 2022) and protein greater than 3.2% on average. Additional component pricing and premiums are not considered but can increase the mailbox price received by the farmer, as can be seen by the January 2023 FMMO 30 Class III Price and Minnesota Mailbox Price with a positive difference of $2.38/cwt (United States Department of Agriculture, 2023d).

This analysis used information from eight Minnesota dairy farms to complete a comprehensive capital budget analysis that considers management factors. A number of assumptions were made to complete the work, which may not fully capture macroeconomic conditions and market volatility. First, the estimates included in this analysis are inflation-adjusted but the magnitude of the investment costs is impacted by the market conditions for the year in which the investment was made which impacts the overall NPV estimates. Second, FAPRI estimates were projected using 2023 values as a constant for the NPV analysis and sensitivity analysis. Revenues and expenses may be overstated as FAPRI expects prices to return to pre-2020 levels by 2025 and follow the 2010-2019 trends. Unforeseen events can disrupt this trend as evidenced in the last few years with the war in Ukraine, the COVID-19 pandemic, and avian influenza disrupting the agricultural economy. Prices may fluctuate and trends may change in ways that further improve or deteriorate the NPV of these scenarios.

Overall, the results reveal that AMS is not a profitable choice for farms transitioning from stalls considering the discounted accrual cash flows, assumptions, and data provided in this study. Farms transitioning from parlors experience a positive NPV for scenarios using 15-year FAPRI estimations, holding 2023 values constant, and all pessimistic sensitivity analyses. The sensitivity analyses revealed which factors are key in considering the investment in AMS.

VI. CONCLUSION

This research analyzed the management choices and financial performance of eight Minnesota dairy farms before and after the installation of AMS. Results show that parlor to AMS farms experienced increases in profitability measures such as NFI/cow, rate of return on assets, and operating profit margin ratio revealing a significant improvement in profitability after installation. Stall to AMS farms encountered a slight decrease in the rate of return on assets and more substantial decreases in NFI/cow and operating profit margin ratio. These shifts leave stall to AMS farms in a more vulnerable state, but the data collected for this project only included three years after installation and may disregard a longer learning curve that stall farm management experiences.

In addition to the financial and managerial comparisons pre- and post-installation, this research assessed the NPV using survey using a combination of survey data, farm financial data, and forecasts. Results of the NPV analysis show that farms transitioning from parlors to AMS that plan on milking 50-59 and 60-69 cows per AMS unit have a positive NPV using FAPRI predicted values as well as holding 2023 values constant. The NPV of parlor to AMS was also positive for each pessimistic sensitivity analysis situation further demonstrating that parlor farms interested in transitioning to AMS should make the investment. However, farms transitioning from stalls to AMS did not attain a positive NPV using predicted values or 2023 values. The only situation where stalls to AMS had a positive NPV was if purchased feed decreased by 10%, and this positive NPV was only for the farm with 60-69 cows per unit. Stalls to AMS had an average facility cost 450% higher than parlor to AMS which impeded these farm scenarios from positive NPV values.

The results of the NPV scenarios for stalls to AMS were negative but the assumptions used within that analysis must be considered. Stall farms experienced a drastic increase in the number of cows when transitioning to AMS, more than doubling in the three years after installation of AMS. These increases may strain management as expenses shift and different techniques are necessary to manage cows in freestall housing. Parlor farms did not experience the same growth in herd size and may have a smaller learning curve when transitioning to AMS. Stall farm management must be prepared for the different costs associated with AMS and shift management styles in order to be profitable. The learning curve for management may be longer than three years, and therefore it is not captured in this study.

Despite the limitations of this study, there are a number of beneficial takeaways. Eight Minnesota dairy farms participated in this study, providing information about the management and operational characteristics of the farm and farm financials. This research was the first to consider management characteristics on AMS profitability. The in-person survey technique was a successful strategy for this type of research and opens the door for future research of the intersection of management decisions and profitability. This study also displayed the future success of installing AMS on Minnesota dairy farms. Farms with parlor milking systems have profitable outcomes from transitioning to AMS as shown by the positive NPV while stall to AMS farms should consider facility costs and future purchased feed costs before proceeding with investment decisions. A final limitation is that this research did not calculate the statistical differences in the financial standings before and after the installation of AMS nor did it calculate the statistical difference that management characteristics had on the profitability between the farms. Future work could emphasize how these characteristics impact farm profitability using a larger sample size so statistical significance inference can be examined. As the dairy industry continues to evolve, it is essential to understand factors impacting farm profitability and the impacts of advanced technology.

REFERENCES

Abdullah, F., & Samah, B. (2013). Factors impinging farmers' use of agriculture technology. *Asian Social Science, 9*(3), 120-124.

Alvarez, J., & Nuthall, P. (2006). Adoption of computer based information systems: The case of dairy farmers in Canterbury, NZ, and Florida, Uruguay. *Computers and Electronics in Agriculture, 50*(1), 48-60.

Bach, A., & Cabrera, V. (2017). Robotic milking: Feeding strategies and economic returns. *Journal of Dairy Science, 100*(9), 7720-7728.

Barry, P., & Ellinger, P. (2012). *Financial Management in Agriculture* (7th ed.). Upper Saddle River, New Jersey: Pearson Education, Inc. .

Bewley, J. (2010). Precision dairy farming: Advanced analysis solutions for future profitability. *The First North American Conference on Precision Dairy, 16.* Toronto.

Bijl, R., Kooistra, S., & Hogeveen, H. (2007). The profitability of automatic milking on Dutch dairy farms. *Journal of Dairy Science, 90*(1), 239-248.

Collings, L., Weary, D., Chapinal, N., & Keyserlingk, M. (2011). Temporal feed restriction and overstocking increase competition for feed by dairy cattle. *Journal of Dairy Science, 94*(11), 5480-5486.

Compeer Financial. (2023). Financing AMS Projects. (Z. Uter, Interviewer)

El-Osta, H., & Morehart, M. (1999). Technology adoption decisions in dairy production and the role of herd expansion. *Agricultural and Resource Economics Review, 28*(1), 84-95.

El-Osta, H., & Morehart, M. (2000). Technology adoption and its impact on production performance of dairy operations. *Review of Agricultural Economics, 22*(2), 477-498.

Farm Financial Standards Council. (2022, September 7). *Farm Financial Scorecard.* Retrieved from Center for Farm Financial Management: https://www.cffm.umn.edu/wp-content/uploads/2019/02/FarmFinanceScorecard.pdf

Farm Systems. (2023). Average AMS Cost. (Z. Uter, Interviewer)

Federal Reserve Bank of Chicago. (2023, May 11). *AgConditions*. Retrieved from Federal Reserve Bank of Chicago: https://www.chicagofed.org/research/data/ag-conditions/index

Federal Reserve Bank of Minneapolis. (2023). *Consumer Price Index, 1913-*. Retrieved from Minneapolis Fed: https://www.minneapolisfed.org/about-us/monetary-policy/inflation-calculator/consumer-price-index-1913-

Floridi, M., Bartolini, F., Peerlings, J., Polman, N., & Viaggi, D. (2013). Modeling the adoption of automatic milking systems in Noord-Holland. *Bio-based and Applied Economics, 2*(1), 73-90.

Foltz, J., & Chang, H.-H. (2002). The adoption and profitability of rbST on Connecticut dairy farms. *American Journal of Agricultural Economics, 84*(4), 1021-1032.

Food and Agricultural Policy Research Institute. (2023). *U.S. Agricultural Market Outlook*. University of Missouri, Columbia. Retrieved from https://fapri.missouri.edu/wp-content/uploads/2023/03/2023-Baseline-Outlook.pdf

Gezie, D., Mekonnen, H., Kidoido, M., & Mengistu, A. B. (2014). Factors influencing adoption of dairy technology on small holder dairy farmers in selected zones of Amhara and Oromia National Regional States, Ethiopia. *Discourse Journal of Agriculture and Food Sciences, 2*(5), 126-135.

Gillespie, J., Nehring, R., Hallahan, C., Sandretto, C., & Tauer, L. (2010). Adoption of recombinant bovine somatotropin and farm profitability: Does farm size matter? *AgBioForum, 13*(3), 251-262.

Hagevoort, R., Douphrate, D., & Reyolds, S. (2013). A review of health and safety leadership and managerial practices on modern dairy farms. *Journal of Agromedicine, 18*(3), 265-273.

Hansen, B., Bugge, C., & Skibrek, P. (2020). Automatic milking systems and farmer wellbeing–exploring the effects of automation and digitalization in dairy farming. *Journal of Rural Studies, 80*, 469-480.

Hansen, B., Herje, H., & Hova, J. (2019). Profitability on dairy farms with automatic milking systems compared to farms with conventional milking systems. *International Food and Agribusiness Management Review, 22*(2), 215-228.

Huang, F. (2020). *The Economics of Robotic Milking Systems in Dairy: Productivity and Profitability*. Dissertation, University of Guelph, Ontario.

Hyde, J., & Engel, P. (2002). Investing in a robotic milking system: A Monte Carlo simulation analysis. *Journal of Dairy Science, 85*(9), 2207-2214.

Internal Revenue Service. (2021, November 10). *IRS provides tax inflation adjustments for tax year 2022*. Retrieved from IRS: https://www.irs.gov/newsroom/irs-provides-tax-inflation-adjustments-for-tax-year-2022

Kay, R., Edwards, W., & Duffy, P. (2008). *Farm Management* (6th ed.). New York, New York: McGraw-Hill.

Kay, R., Edwards, W., & Duffy, P. (2008). *Farm Management* (6th ed.). New York, New York: McGraw-Hill.

Khanal, A., & Gillespie, J. (2013). Adoption and productivity of breeding technologies: Evidence from US dairy farms. *AgBioForum, 16*(1), 53-65.

Leach, T. (2018, October 1). *Labor, Dairy's Next Frontier*. Retrieved from Dairy Herd Management: https://www.dairyherd.com/news-news/business/labor-dairys-next-frontier

Leedstone. (2023). Average AMS Cost. (Z. Uter, Interviewer)

Mathijs, E. (2004). Socio-economic aspects of automatic milking. In A. Meijering, H. Hogeveen, & K. Koning , *Automatic Milking: a better understand* (pp. 46-55). Netherlands: Wageningen Academic Publishers.

Moyes, K., Ma, L., McCoy, T., & Peters, R. (2014). A survey regarding the interest and concern associated with transitioning from conventional to automated (robotic) milking systems for managers of small- to medium-sized dairy farms. *The Professional Animal Scientist, 30*(4), 418-422.

Olson, K. (2011). *Economics of Farm Management in a Global Setting*. Hoboken, New Jersey: John Wiley & Sons, Inc.

Quddus, A. (2013). Adoption of dairy farming technologies by small farm holders: Practices and constraints. *Bangladesh Journal of Animal Science, 41*(2), 124-135.

Rotz, C., Coiner, C., & Soder, K. (2003). Automatic Milking Systems, Farm Size, and Milk Production. *Journal of Dairy Science, 86*(12), 4167-4177.

Salfer, I. (2022, April 13). *Milk fat above 4% is the new normal*. Retrieved from University of Minnesota Extension: https://extension.umn.edu/dairy-news/milk-fat-above-4-new-normal

Salfer, J., & Endres, M. (2014). How are Robotic Milking Dairies Feeding their Cows? *Four-State Dairy Nutrition and Management Conference,* (pp. 77-79). Dubuque.

Salfer, J., Minegishi, K., Lazarus, W., Berning, E., & Endres, M. (2017). Finances and returns for robotic dairies. *Journal of Dairy Science, 100*(9), 7739-7749.

Shortall, J., Shalloo, L., Foley, C., Sleator, R., & O'Brien, B. (2016). Investment appraisal of automatic milking and conventional milking technologies in pasture-based dairy system. *Journal of Dairy Science, 99*(9), 7700-7713.

Systems, F. (2023). Average AMS Cost. (Z. Uter, Interviewer)

Tse, C., Barkema, H., DeVries, T., Rushen, J., Vasseur, E., & Pajor, E. (2018). Producer experience with transitioning to automatic milking:. *Journal of Dairy Science, 101*(10), 9599-9607.

United States Department of Agriculture. (2023a). *History of Class III Price.* Retrieved from Federal Milk Marketing Order 30: https://www.fmma30.com/ClassIII_History.html

United States Department of Agriculture. (2023b). *Dairy Data*. Retrieved from Economic Research Service: https://www.ers.usda.gov/data-products/dairy-data/

United States Department of Agriculture. (2023c). *Quick Stats*. Retrieved from National Agricultural Statistics Service: https://quickstats.nass.usda.gov/results/2130CAD5-92C2-39CC-BDEB-C82BB348F272

United States Department of Agriculture. (2023d). *2023 Federal Milk Order Mailbox Prices*. Retrieved from Federal Milk Marketing Order: https://www.fmma30.com/MailboxPrices/2023MailboxPrices.pdf

APPENDIX A: Data Sources

Table A1. Data Sources Used in Survey Summary Statistics

Data	Source
Investment Costs	Study Survey
Decision Making	Study Survey
Operational Characteristics	Study Survey
Labor Management	Study Survey
Feeding Management	Study Survey
Reproduction Management	Study Survey
Full Time Employees	Study Survey

Table A2. Data and Sources Used in NPV Analysis

Data	Source
Initial Milking System	Study Survey
Number of Cows per AMS Unit	Study Survey
Investment Costs	Study Survey
Milk Production	FINBIN/Financial Records
Number of Cows	FINBIN/Financial Records
Accrual Revenues	FINBIN/Financial Records
Accrual Expenses	FINBIN/Financial Records
Net Farm Income (NFI)	FINBIN/Financial Records
Total Asset Value	FINBIN/Financial Records
Total Liability Value	FINBIN/Financial Records
Cost of Debt	Federal Bank of Chicago, 2023
Cost of Equity	Author's Assumption
Marginal Tax Rate	Internal Revenue Service, 2023

APPENDIX B: Study Survey Questions

Investment Costs

What was the total cost of the AMS facility and equipment, not including expenses outside the facility's structure (e.g., manure lagoon, additional buildings)?

- ☐ _______________

What was the total cost per AMS unit?

- ☐ _______________

Decision to Upgrade to AMS

What year was the AMS installed?

- ☐ _______________

If the AMS was not installed, which of the following management decisions would you have made for the farm?

- ☐ Update the current milking system
- ☐ Update facility/barn
- ☐ Change to different milking system other than AMS
- ☐ Sold cows
- ☐ Decrease herd size
- ☐ Only raise heifers
- ☐ Transfer farm to next generation
- ☐ Change nothing
- ☐ Other: ____

What was the main reason for switching to AMS? Choose one.

- ☐ Difficulty finding hired labor
- ☐ Difficulty paying current labor costs
- ☐ Lifestyle change
- ☐ Previous milking system was obsolete/end of useful life
- ☐ Increase milk production
- ☐ Increase herd size
- ☐ Decrease herd size
- ☐ Other: ____

Is there a succession plan for the farm in place?

- ☐ Yes
- ☐ No

Operation Characteristics

Was the AMS facility new or retrofitted?

- ☐ New (built new barn with)
- ☐ Retrofit (used most of the existing barn and installed AMS)

How many AMS units were installed?

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ Other: _______________

What brand of AMS was installed?

- ☐ BouMatic
- ☐ DeLaval
- ☐ Galaxy
- ☐ GEA
- ☐ Lely
- ☐ Other:

____

How many cows are milked per robot?

- ☐ <50
- ☐ 50-59
- ☐ 60-69
- ☐ 70+

Where are the robots located in reference to the facility?
(ex. Side of the facility parallel to feed alley, End of facility perpendicular to feed alley, etc.)

- ☐ ____

What cow traffic type does the AMS barn utilize?

- ☐ Guided (or directed) flow
- ☐ Semi-guided or modified flow
  - (commonly seen when freestalls and feeding area share the same ally)
- ☐ Free flow

What was the cow herd size prior to installation of AMS? After?

Before	After
☐ _______________	☐ _______________

What type of milking system was used prior to AMS?

- ☐ Parlor
- ☐ Tie Stall
- ☐ Other: ____

Is the old milking system still utilized?

- ☐ Yes
- ☐ No

If the old milking system is still utilized, describe how it is used. (For example, used to milk treated cows")

☐ ____

Labor Management Characteristics

Number of Full-Time Employees (or Equivalent, 1 FTE equals 40 hours/wk) before and after installation.

Before		After	
☐ 0	☐ 5	☐ 0	☐ 5
☐ 1	☐ 6	☐ 1	☐ 6
☐ 2	☐ 7	☐ 2	☐ 7
☐ 3	☐ 8	☐ 3	☐ 8
☐ 4	☐ Other: _______	☐ 4	☐ Other: _______

How much total time is spent fetching cows each day?

- ☐ 1-2 Hours
- ☐ 3-4 Hours
- ☐ 5-6 Hours
- ☐ 7+ Hours

Is a foot bath utilized in the AMS barn?

- ☐ Yes
- ☐ No

Does the farm hoof trim?

- ☐ Yes
- ☐ No

If yes, how often does hoof trimming occur?

- ☐ Every _____________ weeks

What type of bedding is used for the AMS facility? Select all that apply.

- ☐ Straw

☐ Sand
☐ Manure Solids
☐ Wood shavings
☐ Other: ____

How often is the AMS barn bedded?

☐ Every ____________ days

How is the barn cleaned (manure scraped)?

☐ Using automatic manure scrapers
☐ Manually scraped
☐ Other: ____

Does the farm use DHIA Testing?

☐ Yes
☐ No

Feeding Characteristics

Was a total mixed ration fed before AMS?

☐ Yes
☐ No

Has your feeding program changed with AMS?

☐ Yes
☐ No

If yes, how has it changed?

☐ ____

How many times a day was feed pushed up before AMS? After?

Before		After	
☐ 0	☐ 4	☐ 0	☐ 4
☐ 1	☐ 5	☐ 1	☐ 5
☐ 2	☐ 6	☐ 2	☐ 6
☐ 3	☐ Other: _______	☐ 3	☐ Other: _______

What type of feed is used in the AMS?

☐ Pellets
  ☐ What kind: ______________________________________
☐ Other:

____

Average Feed per Visit per Cow?

☐ ____________ lbs

Milk Production Characteristics

How many milkings per day before AMS?

☐ 2

☐ 3

Average somatic cell count before installation? After?

Before	After
☐ <100,000	☐ <100,000
☐ 100,000 to 199,999	☐ 100,000 to 199,999
☐ 200,000 to 299,999	☐ 200,000 to 299,999
☐ 300,000+	☐ 300,000+

What has happened to the proportion of treated cows (cows whose milk cannot be shipped) since installing AMS?

☐ Increased

☐ Decreased

☐ Stayed the same

Are treated cows milked by the AMS?

☐ Yes

☐ No

Please check the boxes for the milk premiums you receive from your processor.

☐ SCC

☐ Quantity

Average Box Time per Cow?

☐ ________________ minutes

Average Number of Milkings per Cow?

☐ ________________ minutes

Reproduction Characteristics

Were activity trackers/collars used before AMS?

☐ Yes

☐ No

Are activity trackers/collars used after AMS installation?

☐ Yes

☐ No

Were changes made to the breeding program to target favorable AMS features?

☐ Yes

☐ No

If yes, what features were targeted?

☐ ____

Other

What other technology was invested in for the AMS barn? Check all that apply.

- ☐ Feed pusher
- ☐ Automatic manure removal system
- ☐ Automated feeding kitchen
- ☐ Cow brushes
- ☐ Ventilation system
  - ☐ Tunnel
  - ☐ Cross Vent
  - ☐ Other:
- ☐ LED Lighting
- ☐ Radiant heating
- ☐ Forced air heating
- ☐ Air Conditioning
- ☐ Wash down pump and hose
- ☐ Built-in footbath
- ☐ Other notable investments: ___________________________

Were any grants/special funding received for renovation/construction of the AMS barn?

- ☐ Yes
- ☐ No

If yes, what type of grant(s)/special funding?

- ☐ MDA AGRI Livestock Investment Grant
- ☐ FSA Guaranteed Loan
- ☐ Other: ___________________________

What other investments would you have made if you were to install AMS again?

- ☐ Feed pusher
- ☐ Automatic manure removal system
- ☐ Automated feeding kitchen
- ☐ Cow brushes
- ☐ Ventilation system
  - ☐ Tunnel
  - ☐ Cross Vent
  - ☐ Natural
  - ☐ Other: ___________________________
- ☐ LED Lighting
- ☐ Radiant heating
- ☐ Forced air heating
- ☐ Air Conditioning
- ☐ Wash down pump and hose
- ☐ Built-in footbath
- ☐ Other: ___________________________

What investments would you have not made if you were to install AMS again?

- ☐ Feed pusher
- ☐ Automatic manure removal system
- ☐ Automated feeding kitchen
- ☐ Cow brushes
- ☐ Ventilation system
    - ☐ Tunnel
    - ☐ Cross Vent
    - ☐ Natural
    - ☐ Other: ____
- ☐ LED Lighting
- ☐ Radiant heating
- ☐ Forced air heating
- ☐ Air Conditioning
- ☐ Wash down pump and hose
- ☐ Built-in footbath
- ☐ Other: ____